भारतीय मानक

Indian Standard

IS 1680 : 2022

निम्न और मध्यम दबाव वाले भूमि बॉयलरों के लिए जल के उपचार की रीति संहिता

(चौथा पुनरीक्षण)

Code of Practice for Treatment of Water for Low and Medium Pressure Land Boilers

(Fourth Revision)

ICS 27.060.01

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December 2022 **Price Group 8**

Water Quality for Industrial Purposes, CHD 13

FOREWORD

'This Indian Standard was adopted by the Bureau of Indian Standards on recommendation of the Water Quality for Industrial Purposes Sectional Committee and approval of the Chemical Division Council '

There are two sides to a boiler; the fire side and the water side. Usually much care is devoted on keeping the fire side free from accumulations of deposits that would tend to interfere with adequate heat transfer. However, in spite of availability of many simple forms of modern water treatment in many of the low pressure boilers, little attempt is made to keep the water side free from deposits. Scale on the water side can be far more dangerous than deposits on the fire side. This may result in overheating of the metal and consequent failure and risk of explosion.

This standard lays down conditions to be aimed at in boiler feed water and boiler water to overcome the troubles experienced on the water side of the boilers. Whist boilers operating at higher pressures are usually attended by qualified works chemists, low pressure boilers usually receive little attention. Particular attention has, therefore, been given in this standard to the needs of operators of low pressure boilers, that is, those operating below 2.0 MN/m^2 pressure. Quality requirement for boiler feeds and methods for treatment suitable for boilers working under higher pressure up to 5.9 MN/m^2 (60 kgf/cm^2) have also been given but it is recommended that advice of technical specialists in the treatment of water as also of boiler makers should be obtained to determine the special form of treatment suitable to meet the particular requirements. Whenever available, advice of these specialists may also be sought in operating low pressure boilers.

This standard was first published in 1960. In the first revision, it included methods for elimination of oil in boiler water and to change the limits of dissolved oxygen and *p*H. In the second revision, specific objects and methods for water treatment was included and in the third revision, boilers operating pressure was changed to 5.9 MN/m^2 instead of 4.1 MN/m^2.

In this fourth revision the following changes have been incorporated:

a) All the amendments issued till date have incorporated;
b) Method of removal of oil and grease has been updated;
c) In pretreatment the method of dealkalization and reverse osmosis has been added;
d) Use of sludge conditioners, oxygen scavengers and neutralizing amines have been added; and
e) Boiling out procedure has been updated.

In preparing this standard, the considerable assistance has been derived from BS 02486 : 1997 (2008) 'Recommendations for treatment of water for steam boilers and water heaters' issued by the British Standards Institution and American Society of Mechanical Engineers (ASME) guidelines.

The composition of the committee responsible for the formulation of this standard is given at Annex B.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for Rounding off Numerical Values (*second revision*)'.

Indian Standard

CODE OF PRACTICE FOR TREATMENT OF WATER FOR LOW AND MEDIUM PRESSURE LAND BOILERS

(Fourth Revision)

1 SCOPE

1.1 This standard deals with the chemical methods of attaining the conditions to be aimed at for water for land/ Industrial boilers in order to overcome the troubles on the water side of boilers operating up to 2.0 MN/m^2 (20 bar) Low Pressure and between 2.0 and 5.9 MN/m^2 (20 bar and 60 bar) for Medium Pressures.

1.2 Land boilers operating at pressure higher than 5.9 MN/m^2 (60 bar) marine boilers and locomotive boilers are not covered in this standard.

2 REFERENCES

The following standards contain provisions which through reference in this text constitute provisions of this standard. At the time of publications, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
IS 3025 (Part 21) : 2009	Methods of sampling and test (Physical And Chemical) for water and wastewater: Part 21 Hardness (*second revision*)
IS 3025 (Part 46) : 1994	Methods of sampling and test (Physical and Chemical) for water and wastewater: Part 46 Magnesium (*first revision*)
IS 3025 (Part 61) : 2008	Methods of sampling and test (Physical and Chemical) for water and wastewater: Part 61 Total and free carbon dioxide (*first revision*)
IS 10392 : 1982	Specification for feed water and boiler water for low and medium pressure boilers
IS 11671 : 1985	Glossary of terms relating to boiler water

3 TERMINOLOGY

For the purposes of this standard, the definitions given in IS 11671 shall apply, in addition to the following:

3.1 Distribution ratio

It is the ratio of product concentration in vapor phase to product concentration in liquid phase.

4 IMPURITIES IN WATER

4.1 A really satisfactory boiler feed water supply is never obtained free in nature. Rain water dissolves soluble gases from the air and as it begins to flow over the earth's surface or through its strata, it takes up more impurities, such as mineral salts, organic matter and clay. The water thus obtained in nature may contain the following:

a) Dissolved gases;
b) Dissolved solids;
c) Suspended solids; and
d) Living organisms.

4.1.1 *Dissolved Gases*

Rain water as it descends to the earth takes up oxygen, nitrogen and carbon dioxide from the air. The water also picks up carbon dioxide from decaying organic matter on the surface of the ground. Oxygen and carbon dioxide can cause corrosion and have, therefore, to be removed from feed water. Nitrogen is an inert gas and does not affect boilers. Carbon dioxide dissolves chalk or limestone; magnesium carbonate is also similarly dissolved. Calcium and magnesium bicarbonates are thus obtained in varying amounts in almost every natural water.

4.1.1.1 The dissolved oxygen which is corrosive for feed lines, boiler and condensate return line system needs to be removed by using a deaerator and subsequently treated by oxygen scavengers or by using oxygen scavengers alone for low pressure boilers. The use of deaerator and oxygen scavengers make the treatment economical, reduce TDS in boiler water thereby reducing blow down and save energy.

4.1.2 *Dissolved Solids*

The dissolved solids are the ones which are present in dissolved state in water. The salts in soluble form (dissolved solids) dissociate to cations (positively charged) and anions (negatively charged) in water. All in water chemistry are expressed as mg/l as calcium carbonate ($CaCO_3$) to balance the water analysis and to derive various interpretations used in water chemistry. Salts usually present in the dissolved state in natural water are those of sodium, calcium and magnesium. Salts of sodium are harmless unless present in very large quantity. Natural waters also contain varying amounts of silica. Iron is often present in the form of ferrous iron (Fe^{2+}) which is converted to the thermodynamically stable ferric iron (Fe^{3+}) in the presence of dissolved oxygen in the *p*H range of natural waters. The oxidized ferric iron is brown in colour.

4.1.2.1 The most important dissolved salts from the point of view of boiler feed are those of calcium and magnesium. Their presence makes water hard and a deposit or scale is obtained by the use of such water in boilers as most salts of calcium and magnesium precipitate due to their reduced solubility at high temperature. Silica also is important, particularly in the case of medium pressure boilers, as it forms a hard scale. Further, silica may be steam volatile, creating problems with turbine blades.

4.1.2.2 The hardness of water is mostly present as calcium and magnesium salts of bicarbonates but may also present as salts of chlorides and sulphates.

4.1.2.3 The alkalinity is mostly present as bicarbonate in raw water but decompose to carbonates completely and carbonates decompose to hydroxides partly at high temperatures in boilers. The bicarbonates, carbonates and hydroxides of calcium and magnesium give rise to 'alkaline' or 'carbonate' hardness and the chlorides, sulphates and nitrates to 'non-alkaline' or 'non-carbonate' hardness. The terms temporary and permanent hardness are now discarded and have been replaced by carbonate and non-carbonate hardness respectively.

4.1.2.4 The hardness is removed by external treatment. The internal treatment is done to remove residual hardness by using chemical treatment by precipitating hardness with chemicals such as phosphate to a fluffy precipitates which do not settle on metal surfaces and are removed while giving boiler blow down.

4.1.3 *Suspended Solids*

Impurities which are held in suspension and can be removed by sedimentation and filtration, are mostlyin the form of clay, silt, insoluble inorganicsalts, organic matter or precipitated iron salts. They may get deposited in feed lines, economizers and boilers unless removed.

4.1.4 *Living Organisms*

Living organisms are present in varying numbers in all natural waters and are treated in pretreatment prior to the boiler by using oxidizing agents such as chlorine.

4.2 Oils and Grease

Sometimes oils and grease find their way into water used for boiler feed. Oils and greases are bad conductors of heat and when they form a film on the boiler plate or tube, they interfere with free transfer of heat to the water with the result that overheating takes place at some portions which may produce bulging or even bursting. Besides they also cause foaming in boilers.

5 SOURCES OF WATER

5.1 Water is obtained from different sources in nature and its composition is also found to differ widely with its source. It is therefore, necessary to study the characteristics of these supplies to treat them properly to obtain a supply of desired quality. The usual sources of water are as follows:

a) Surface Water — from rivers, streams or lakes; and
b) Underground Water — from wells and springs.

5.1.1 *Surface Water*

As water flows over the earth, it dissolves salts of sodium, potassium, calcium, magnesium, iron and aluminium, besides silica and traces of manganese and other heavy metals. In addition to these dissolved impurities, surface water particularly river water, contains significant concentrations of various colloidal clays of siliceous origin, referred to as turbidity. Turbidity is very high in rainy season. It also contains to a lesser degree hydrophilic and hydrophobic colloids of sewage and vegetative origin, depending on the degree of pollution from domestic and industrial waste waters. It contains carbonate and non-carbonate hardness in varying proportions. Iron, if present, may be in soluble or in insoluble state.

5.1.2 *Underground Water*

The character of underground water depends upon the strata through which it has passed. Usually, it may contains both carbonate as well as non-carbonate hardness. Underground waters in general are rich in free carbon dioxide and in bicarbonates. Silica content is sometimes high. In many cases iron and manganese are present along with bicarbonates.

6 OBJECTIVES OF TREATMENT

The objectives of treatment are:

a) Depositcontrol to maintain boiler efficiency;

b) Pitting corrosion control;
c) Prevent caustic gauging/caustic embrittlement;
d) Prevent corrosion of condensate return line system;
e) Managing steam purity;
f) Increasing equipment life;
g) Prevent shutdown; and
h) Safety of operations.

6.1 When water is evaporated in a boiler, dissolved salts are concentrated and insoluble salts are precipitated. They may either separate out in the form of a non-adhering soft sludge which can be removed without difficulty or they may deposit on the sides of the boiler and the tubes as a firmly adhering scale. Accumulation of scale and deposit formation on heating surfaces considerably reduces the rate of heat transfer and introduces the risk of overheating and failure of effected surfaces. The effect of scale becomes more serious as the boiler pressure and heat transfer rates increase to a point when temperatures approach more closely the upper safe value for the materials used.

6.2 Corrosion destroys the metal causing serious damage to the boiler. The corrosiveness of water is determined by the nature of salts present in it, *p*H and dissolved oxygen content. Under boiler conditions, concentrated alkalis and nitrates can also attack steel. The effect of neutral salts on corrosion is complex, but chlorides are known to increase it. It shall be remembered, however, that water of high purity may even be more corrosive than raw water, especially in presence of dissolved oxygen.

6.3 Condensate can become corrosive as a result of the presence of certain gaseous impurities such as carbon dioxide in the steam, since the gaseous impurities dissolve in the condensate as it is formed. The gaseous, impurities that may be formed in the boiler are carbon dioxide, oxygen, ammonia, hydrogen sulphide, sulphur dioxide and hydrogen. Of these carbon dioxide and oxygen are of greater significance in practice. Under certain conditions the water in the boiler produces foam, and a certain portion of it is carried forward by steam. This causes damage to fittings using steam.

6.4 Water before use may, therefore, require treatment for:

a) Removal of suspended matter;
b) Prevention of scale forming salts;
c) Prevention of corrosion and caustic embrittlement;
d) Elimination of certain gases;
e) Prevention of foaming; and
f) Removal of grease and oils.

7 TREATMENT OF FEED WATER

7.1 The treatment to be employed to obtain the desired results is generally effected in the following two stages:

a) External treatment; and

It is intended to use treatment for make up water and in some cases treat Return Condensate. The external treatment equipment should be designed based on correct sample analysis taking into account all seasonal variations and alternative supplies. It comprises of following two stages:

1) Pretreatment

Pretreatment for removal of suspended solids, organic matter and colloidal silica, wherever necessary; and

2) Softening/demineralization

Treatment of raw water to remove scale forming ions or / and to remove dissolved impurities reducing total dissolved solids (TDS) which also remove scale forming impurities.

b) Internal Chemical Treatment

Addition of small quantities of chemicals to the final feed water or into the boiler drum, if necessary, to adjust its composition to meet particular conditions of the boiler plant.

7.2 External Treatment

7.2.1 *Pretreatment*

The methods of pre-treatment commonly encountered are coagulation, sedimentation, clarification, floatation, filtration, chlorination and de chlorination.

7.2.1.1 *Sedimentation*

The water is passed through a tank of sufficient size to allow sediments to settle down with a defined retention time in the tank. The clear water is drawn from the top of the tank whereas sludge which gets settled at the bottom of tank is removed frequently. The suspended solids gets still carried over.

7.2.1.2 *Clarification and floatation*

The suspended solids which stay in a dispersed state due to electrostatically negatively charged particles consequently repelling each other due to presence of alkalinity are settled or floated by adding coagulants in the clarifier. The function of coagulants is to neutralize the charge of these negatively charged particles and agglomerate these particles to form flocs which settle down or float in the clarifier.

The typical coagulants used are alum or ferric chloride or aluminium chlorohydrate (ACH) as inorganic coagulants. The new generation organic coagulants such as polydadmac is also used as alternative to Inorganic Coagulants. The polyamine is also used selectively where there are high organics in water. The superannuated clear water is taken from top of the clarifier. The best way to decide a coagulant and its dosage is to do jar test which should be done prior to finalizing the one. The user should verify purity, quality, effectiveness and portability (if water is used for drinking water) of coagulants before use. The sludge is removed from the clarifier. The user should also be careful about carryover of these coagulants if added in even in little excess and the implications on demineralizing resins or reverse osmosis membranes.

7.2.1.3 *Filtration*

The suspended solids/carried over flocs up to about above 50 microns can be removed by using a filtration plant. This is usually carried out by passing the water through a granular material such as sand. The filter units which often gets blocked by deposits or / and microbes should be cleaned by carrying out the open backwash. If soluble iron and manganese are present the same can be removed by using an aeration unit before filter converting soluble iron and manganese to insoluble particles which gets removed by filter. If oil or organic impurities are present the same can be removed by using activated carbon filter after the normal filtration unit in the stream or else it can foul Ion exchange resin and create problems in the boiler.

7.2.1.4 *Removal of oil and grease*

The oil and grease can be present in two forms as follows:

a) Emulsified; and

The deoiling polyectrolyte (DOPE) which is most commonly a polyamine, a cationic polyelectrolyte, is used to demulsify the emulsified oil and is added before dissolves air floatation unit (DAF) and the floating oil is removed. The jar test is conducted to find out the actual dosage which varies depending upon type of oil and its emulsification.

b) Demulsified

The demulsified oil and grease is removed through TPI or API or Trickling filter. A Cationic Polyacrylamide (Flocculant) can be used to improve the efficiency of oil removal.

7.2.2 *Softening and Demineralisation*

Three methods are available for softening water externally, namely, (a) precipitation method, (b) exchange method, and (c) distillation method.

7.2.2.1 *Softening by precipitation methods*

In the precipitation methods, hardness and carbon dioxide are reduced; the precipitates are then separated by sedimentation and filtration.

a) Lime-soda process

The oldest and the most widespread method of precipitation softening is the lime-soda process, hot and cold. In this process, water is treated with hydrated lime (calcium hydroxide) and soda ash (sodium carbonate).

1) Hydrated lime treatment

In theory, treatment with hydrated lime removes calcium carbonate hardness and uncombined carbon dioxide by precipitation in the form of calcium carbonate. At the same time magnesium carbonate hardness is removed by precipitation in the form of magnesium hydroxide. Another reaction of a slightly different type takes place between hydrated lime and magnesium non-carbonate hardness. In this reaction, magnesium non-carbonate hardness is removed by precipitation in the form of magnesium hydroxide and replaced by an equivalent amount of calcium non-carbonate hardness. The calcium non-carbonate hardness produced in this way together with that originally present in raw water is removed by treatment with sodium carbonate. In practice the chemical reaction between lime and magnesium hardness may not go to completion. When waters containing sodium bicarbonate are treated with hydrated lime, sodium bicarbonate is converted into sodium carbonate.

2) Sodium carbonate treatment

Treatment with sodium carbonate causes non-carbonate hardness to precipitate from solution in the form of calcium and magnesium carbonate. The calcium and magnesium salts are replaced by an equivalent amount of sodium salts. Thus, by means of treatment with hydrated lime and sodium carbonate in appropriate quantities, most of the carbonate and non-carbonate hardness can be removed and soft water produced with hardness of approximately 20 mg/1 to 40 mg/1 in terms of calcium carbonate.

3) Coagulants

The coagulants generally used are sodium aluminate, magnesium oxide, alum, etc. The amount of coagulant used is normally very small and is always less than 30 mg/1 of the water being treated. It is added to the lime-soda mixture. The improvements obtained are as follows:

i) Magnesium is precipitated more efficiently, thus preventing, a difficulty associated with precipitation;

ii) Less lime is required to complete the softening reactions;

iii) Hardness of the softened water is reduced to 20 40 mg/1 to 40 mg/1 as calcium carbonate;

iv) Sedimentation is accelerated, and softened water of low suspended solids is passed to the filters; and

v) Reactive Silica content of the softened water is generally reduced by precipitating silica with magnesium hydroxide.

Rapid flocculation and sedimentation may be used to reduce the retention time, and this is valuable where a plant has to be overloaded. Another refinement which improves the characteristics of softened water is the establishment, in the softener, of a blanket of sludge through which the chemicals and the water are made to pass after leaving the mixing zone. Provided no short-circuiting takes place, a water of lower hardness and with less suspended solids may be produced. Another improvement with regard to precipitation softening is 'sludge return' or 'sludge recirculation'. A small quantity of sludge is continuously withdrawn from the sludge zone of the clarifier and added to the incoming mixture of water and reagents. The return sludge gives a seeding effect to both flocculation and precipitation and results in better sedimentation and better softening.

4) Partial softening

When a fully softened water is not required, it may be partially softened by treatment with hydrated lime alone to precipitate a major part of the carbonate hardness, according to the degree of softening required.

5) Hot softening

The efficiency of any precipitation process of water softening increases considerably with rise in temperature but the degree of improvement is most marked in the lower temperature range (up to about 50 °C). The heat may be derived from waste steam, or live steam or water drawn from the boiler. If boiler water is returned to the softener, some modification of chemical charges will be required. Boiler water containing sodium orthophosphate sometimes retards the softening reactions when the temperature at the softener is below 70 °C and *p*H is less than 9.

7.2.2.2 *Exchange methods of softening*

If water containing calcium and magnesium salts in solution is passed through a bed of ion exchange materials, synthetic or natural, calcium and magnesium are retained by the material and are replaced by sodium so that the water leaving the mineral bed contains sodium salts instead of calcium and magnesium salts. Some of these synthetic ion exchange materials can operate at elevated temperatures up to 100 °C and under high pH conditions. In another method partial deionisation to reduce dissolved solids is carried out by passing the water through a bed of ion exchange resins in hydrogen ion form which converts carbonates and bicarbonates into carbonic acid; sulphates, nitrates and chlorides into their respective acids, and the cations are retained by the resin itself. The water is subsequently aerated to remove carbon dioxide and is either neutralized with sodium hydroxide to produce zero hardness water of low dissolved solid content or can be further treated by passing through a bed of anion exchange resin to remove all free acids. The water resulting from the latter treatment is demineralized water containing less than 5 mg/1 of total dissolved solids.

a) Base exchange process

This is the name given to the original method of softening water by zeolites. The name is still applied to the general process whereby sodium is substituted for another metal by means of exchange materials not necessarily of the zeolite class. Calcium and magnesium are retained by the exchange material and an equivalent amount of sodium salts passes out with water leaving the exchange unit. Once the exchange capacity is exhausted, regeneration is carried out with a strong solution of sodium chloride. By this process, sodium is replaced in the exchange material, calcium and magnesium chloride pass out to drain, and the cycle can be restarted. The advantages of the base exchange method of softening are that there is no sludge to be disposed of; that it can be operated under pressure; and that it is simple in operation. However, in general the quantity of water wasted in regeneration is considerable and there are certain other disadvantages also. With precipitation softening, the dissolved solids of the water are reduced but, with base exchange method, they are slightly increased and all carbonate hardness salts appear as sodium bicarbonate. Thus the alkalinity of the raw water is unaltered. Generally a base exchange softened water is more corrosive to iron and steel than water in the un-softened state and a softened water containing a high sodium bicarbonate content may be unsuitable for some purposes, for example, laundry or boiler feed. These disadvantages can be overcome by the use of a split stream process which consists of dividing the water into two streams. One passes through a cation exchange resin in sodium form as in a base exchange process and the other through another cation exchange resin in the hydrogen form. The two treated streams are mixed and aerated to remove carbon dioxide. This process produces water of low dissolved solids and of any desired alkalinity. Many modifications of this process are available for various characteristics of the raw water.

b) Cation exchange and anion exchange

1) Cation exchange

It is the exchange of one cation for another. The types of exchange most frequently used in water treatment are the exchange of calcium and magnesium for sodium by a softening and the exchange of calcium, magnesium and sodium for hydrogen by means of hydrogen exchange materials in a demineralization plant. The exhausted exchange material is regenerated by passing a solution salt or mineral acid, depending upon the unit.

2) Anion exchange

In the anion exchange process, the sulphate, chloride, nitrate ions, etc, are exchanged by hydroxyl ion. This exchange is effected by passing the water through a bed of a synthetic anion exchange resin. In practice, anion exchange is usually applied only to waters that have previously been treated by hydrogen exchange process and hence anion exchange process may be regarded as the conversion of dilute solutions of mineral acids into water. The exhausted anion exchange resin is regenerated with caustic soda or soda ash and the waste sodium salts washed to drain.

c) Demineralization

Demineralization (sometimes referred to as deionization) is the process of cation exchange followed by anion exchange and mixed bed. The outlet of demineralization plant (DM) plant should give conductivity less than 1 µS/cm at 25 °C and Silica less than 0.02 ppm as SiO_2.

d) Dealkalization

The dealkalization is a process by which temporary hardness is removed by using a weak acid cation exchanger in the hydrogen form. In other words hardness equal to alkalinity, both expressed as calcium carbonate ($CaCO_3$), is exchanged by hydrogen ions converting it to carbonic acid and stream is further passed through a degasser which removes most of carbonic acid (dissolved carbon dioxide). At the outlet of cation exchanger the alkalinity can be 0 mg/l to 20 mg/l as calcium carbonate ($CaCO_3$) giving *p*H in the range of 4.2 to 5.5 which rises after degasser. The total dissolved solids (TDS) gets reduced equal to the extent of alkalinity removed, the *p*H after degasser is further increased by adding sodium hydroxide (increases TDS) or neutralizing amine (does not increase TDS but conductivity increases by few units) to raise *p*H to 8.5 to 9.2. The permanent hardness does not get removed by dealkalizer and remains as it is. The advantages of dealkalizing with a weak acid cation exchange resin are as follows:

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

2) The TDS value of the water is reduced (by the removal of bicarbonate salts) by either the amount of hardness oralkalinity, whichever is lower. Accordingly, the treated TDS value is also lower.

3) The Dealkalizer is a low cost preferred option as compared to Base Exchanger (Softener), where temporary hardness is present in raw water and reduction of TDS in treated water can increase cycles of concentration in the boiler.

e) Reverse Osmosis (RO)

Reverse Osmosis works by using a high pressure pump to increase the pressure on the salt side of the RO and force the water across the semi-permeable RO membrane, leaving almost all (around 95 per cent to 99 percent) of dissolved salts behind in the reject stream. The amount of pressure required depends on the salt concentration of the feed water. The more pressure is required to overcome the osmotic pressure if the concentration of salts is more in RO feedwater.

The water which gets demineralized, is called permeate (or product) water. The water stream that carries the concentrated contaminants that did not pass through the RO membrane is called the reject (or concentrate) stream.

The reverse osmosis is capable of removing about (95 to 99) per cent of the dissolved salts (ions) from the feed water. An RO system does not remove gases such as carbon dioxides (CO_2) very well because they are not highly ionized (charged) while in solution and have a very low molecular weight. As an RO system does not remove gases, the permeate water can have a slightly lower than normal *p*H level depending on CO_2 levels in the feed water as the CO_2 is converted to carbonic acid.

Reverse osmosis is the finest level of filtration available. The RO membrane acts as a barrier to all dissolved salts and inorganic molecules, as well as organic molecules with a molecular weight greater than approximately 100 gm/mol. Water molecules, on the other hand, pass freely through the membrane creating a purified product stream. Rejection of dissolved salts is typically of range 95 percent to greater than 99 percent.

The applications for RO are numerous and varied, and include desalination of seawater or brackish water for drinking purposes, wastewater recovery, food and beverage processing, biomedical separations, purification of home drinking water and industrial process water.

Also, RO is often used in the production of ultrapure water for use in the semiconductor industry, power industry (boiler feed water), and medical/laboratory applications. Utilizing RO prior to ion exchange (IX) dramatically reduces operating costs and regeneration frequency of the IX system. Trans-membrane pressures for RO typically range from 75 psig (5 bar) for brackish water to greater than 1 200 psig (84 bar) for seawater.

7.2.2.3 *Distillation process*

Raw water is distilled in an evaporator and the distillate which is almost completely free from dissolved solids is used. As the evaporator itself may be considered as a very low pressure boiler, the feed may, under certain conditions, require softening. Distillation process is not generally required for low pressure boilers.

NOTE — Ion exchange methods as mentioned above at point nos. a), b) and c) and Reverse Osmosis above point no e) are preferable compared to other methods since they give better quality water, ease of operation with less waste generation, and are economical.

7.3 Internal Treatment

7.3.1 The residual hardness which is left out after an external water treatment need to be treated by an internal chemical treatment to keep the boilers completely free from deposits. The two type of chemical treatment used for boilers are as follows:

a) Carbonate Cycle Treatment;

The carbonate cycle treatment is used only up to a pressure of 20 bar. The calcium hardness is reacted with carbonates to precipitate it as a desired complex of $CaCO_3.Ca(OH)_2$ which is fluffy in nature and is easily dispersed by using any sludge conditioner and does not settle on metal surface and is easily removed while giving blowdown. The carbonate and hydroxide alkalinity are needed in the boiler to precipitate calcium to $CaCO_3.Ca(OH)_2$ complex. The magnesium is precipitated with hydroxide in the boiler as $Mg(OH)_2$ which is again a fluffy precipitate and can be easily dispersed and removed through blowdown.

$2CaCl_2+Na_2CO_3+2NaOH \rightarrow CaCO_3.Ca(OH)_2+$
$4\ NaCl$…(1)

The sludge conditioners are low molecular weight synthetic polymers which disperse these precipitates by imparting (-) ve charge to these particles and as a result these particles repel from each other and stay dispersed. Typically low pressure boilers do not have dearators but the feedwater should be heated to remove dissolved oxygen to the maximum. The corrosion by dissolved oxygen is generically prevented by using tannin which form a protective film on the metal which acts as a barrier between metal and dissoved oxygen. The corrosion by carbonic acid (formed from co_2 present in steam) in condensate return lines is prevented by neutralizing it with neutralizing amines, typically morpholine and cyclohexamine and raising the *p*H above 8.3, typically 8.5 to 9.5. (9.2 in case copper is present in the system)

An alkalinity reserve is kept in the boiler to neutralize permanent hardness. The alkalinity demand in feed water will be as follows to maintain desired alkalinity reserve in the boiler.

(H – M) + (Alkalinity Reserve in boiler /
C)…(2)

Whereas Alkalinity Reserve in boiler represent desired Alkalinity Reserve as $CaCO_3$ and C as operating cycles of concentration.

b) Phosphate Hydroxide Treatment

Phosphate hydroxide treatment is recommended for boilers upto 60 bars. The phosphate such as trisodium phosphate (Na_3PO_4) is used to precipitate calcium as $Ca_3(PO_4)_2.Ca(OH_{)2}$ which is termed as hydroxyapetite and forms in presence of both phosphate and OH alkalinity. Sodium Hexametaphosphate (SHMP) or Sodium Tripolyphosphate (STPP) may be used but these additions consume boiler water alkalinity and may reduce *p*H in the boiler.

$3\ Ca(HCO_3)_2 + 2\ Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6\ NaHCO_3$…(3)

The use of trisodium phosphate (tsp) is also used to maintain phosphate reserve to neutralize ingress of hardness more than calculated and also to maintain hydroxide (OH) alkalinity reserve desired in the boiler by following reaction:

$Na_3PO_4 + H_2O \rightarrow 3Na + HPO_4 + NaOH$…(4)

The OH Alkalinity in the boiler is also desired to maintain desired pH in the boiler, precipitate Magnesium Hardness as $Mg(OH)_2$ and control Silica Volatility.

7.3.2 Sludge Conditioners

The sludge conditioners are the ones which keep the suspended particles / precipitates such as calcium carbonate, calcium phosphate, iron oxide and silicates in dispersed state by providing negative charge to these particles which repel from each other and stay in dispersed state. These are synthetic low molecular weight polymers, typically using Acrylic Acid. These may be homopolymers of acrylic acid with different molecular weights or use another monomer to give a copolymer to handle more difficult deposits. These polymers replace polymer of natural origin such as starch and tannin. The user must ensure that the synthetic polymers must be stable at the operating pressure of the boiler.

7.3.3 Oxygen Scavengers

The corrosion control in this type of treatment is achieved by neutralizing the residual dissolved oxygen in the feedwater. The Dissolved Oxygen must get neutralized in the feed itself before entering the boiler. That's why now most often the catalyzed oxygen scavengers are used which increases the reaction rate substantially.

The Oxygen Scavengers are of following types:

a) Non Volatile Oxygen Scavengers

The non volatile oxygen scavengers are the scavengers which do not get volatilized and travel with steam. The commonly used non-volatile oxygen scavengers are as follows:

1) Sodium Sulphite

It is most commonly used upto 40 bar but carefully used upto 60 bar as at high temperature and pressure beyond 60 bar it decomposes to sulphur dioxide and sulphides. Sodium Sulphite reacts stoichometrically with oxygen requiring 8 mg/l of sodium sulphite to react with each 1 mg/l of dissolved oxygen. The by product of the reaction is sodium sulphates which adds total dissolved solid in the boiler.

2) Iso Ascorbic acid (Erythorbic Acid)

It is non-toxic and work upto 10.3135 MN/m^2 and also gets involved in passivation of metal. It requires 11 l of active ascorbic acid to neutralize 1 mg/l of dissolved oxygen but the actual dosage may be higher for good oxygen scavenging

b) Volatile Oxygen Scavengers
Which partially travel along with steam depending upon their distribution ratios. The commonly used volatile oxygen scavengers are as follows:

1) Hydrazine

It reacts with dissolved oxygen producing nitrogen and water consequently not adding any dissolved solid to the boiler. It reacts with ferrous iron oxide to form a magnetite film. It requires 1 mg/l of hydrazine as N_2H_4 to neutralize each 1 mg/l of dissolved oxygen stoichometrically but actual dose may be up to 2 ppm hydrazine as N_2H_4 per 1 mg/l of dissolved oxygen for good oxygen scavenging. Hydrazine is known carcinogenic and should be avoided. It has very low volatility and decompose to ammonia at higher temperatures. The higher ammonia levels can lead to corrosion of Copper and / or it's alloys.

2) N,N – diethylhydroxylamine (DEHA)

It is a good option to replace hydrazine. It has relatively low toxicity. It also form the magnetite layer and add no dissolved solids in the boiler. It's volatile and also travel with steam and protect the condensate return line corrosion (due to oxygen) as well. It's by products at low pressure is acetaldehyde and acetaldoxime at pressure over 70 bar. It requires 1.24 mg/l per 1 mg/l of dissoved oxygen stoichometrically but actually2.8 mg/l of DEHA (100 per cent Active) to neutralize each 1 mg/l of dissolved Oxygen may be needed.

3) Carbohydrazide

It is a low volatility source of hydrazine as when heated produce hydrazine and carbon dioxide. It becomes safer than hydrazine in handling the product, nonetheless, as for any chemicals Personal protection equipments (PPEs) should be used and safety guidelines should be followed. It requires 1.4 mg/l of Carbohydrazide for each 1 mg/l of Oxygen stoichometrically but actual dose may be upto 2.5 times higher.

7.3.4 *Neutralizing Amines*

Neutralizing amines are used to prevent carbonic acid attack in condensate return line system by neutralizing it. The presence of amines also increases *p*H of condensate above 8.3 typically between 8.5 to 9.5 depending on the dosage. Usually, blend of amines are used to give protection all across the system — high, medium and low pressure zone in condensing zones. Ammonia is also used but it provides desired *p*H at almost end of the condensate i.e low pressure. It can also attack copper if higher than 30 ppb to 50 ppb. The use of blend of amines reduces iron pick up as compared to using ammonia alone. The different amines has different distribution coefficients as specified in Table 1 and that's why the blends often works better.

Table 1 Neutralizing Amines with their Distribution Ratios
(*Clause* 7.3.4)

Sl No. (1)	Neutralizing Amines (2)	Distribution Ratios (3)
i)	Ammonia	10.0
ii)	Cyclohexamine	2.0
iii)	Diethylhyroxylamine (DEHA)	1.260
iv)	Diethylaminoethanol	1.0
v)	Morpholine	0.40

NOTE — It changes at different operating pressures. Amines with a distribution ratio more than 1.0 will have more amine present in the steam phase, while amines with a distribution ratio of less than 1.0 will have more amine present in condensate phase.

7.4 Critical Controls

7.4.1 *pH*

The *p*H is a critical parameter for make up water, feedwater, boiler water and steam condensate. The *p*H of makeup water after demineralization unit, dealkalizer and reverse osmosis with or without mixed bed is raised range of 8.5 to 9.5. By dosing an alkalinity builder such as sodium carbonate (increases TDS) or a volatile amine (increase conductivity but not TDS) to ensure that there is no free carbon dioxide in makeup water. The feed water *p*H is also maintained typically in range of 8.5 to 9.5. The boiler water *p*H is maintained on higher side to control corrosion at a higher temperature and to ensure that a good magnetite layer is formed. The magnetite layer formation and to make it more stable, a *p*H in range 10.5 to 11.2 is most suitable. The condensate water *p*H is also maintained between 8.5 to 9.5. The *p*H of makeup, boiler feed and condensate between 8.5 to 9.5 is to ensure a reduced iron pick. The more of iron in feed water may result in undesirable iron oxide deposits in the boiler. The max *p*H in makeup, feed water and return condensate only can be max 9.2 if copper and it's alloys are present in the system.

7.4.2 *Total Dissolved Solids or Conductivity*

The limits of total dissolved solids (TDS) reduce as the boiler pressure goes up as otherwise it increases the possibility of entrainment to boiler water with steam. At pressures greater than 40 bar some solids have a significant solubility in steam. The presence of these solids in steam can lead to deposits in post boiler system such as turbine blade and affect it's performance. There is a relationship between conductivity and TDS as conductivity is due presence of dissolved ions in water. The concentration of total dissolved solids in boiler water should be generally kept as specified in Table 2.

Table 2 Concentration of Total Dissolved Solids based on Boiler Pressure
(*Clause* 7.4.2)

Sl No. (1)	Boiler Pressure, MN/m^2 (2)	Total Dissolved Solids, mg/l, *Max* (3)
i)	Upto 2.0	3 000
ii)	2.1 to 3.9	2 500
iii)	4.0 to 6.0	1 000

NOTE — For utility boilers where turbines are used the total dissolved solid content shall be dependent on the steam purity requirements.

Blow down of boilers may be intermittent or continuous as necessary to maintain the concentration of total solids within the above limits. Suspended solids also give rise to considerable trouble in the boiler and cause priming. Care should be taken to prevent their undue concentration by means of suitable blow down.

7.4.3 *Dissolved Oxygen*

The dissolved oxygen (DO) should be as less as possible in feedwater before addition of oxygen scavengers as it may require more quantity of oxygen scavengers or else it may lead to pitting corrosion in the boiler. The conventional method is to heat up the feed water by injecting steam for low pressure boilers. The use of deaerator is an efficient method to remove dissolved oxygen for any boiler, as a well operated deaerator can reduce upto 7 ppb of dissolved oxygen at the outlet. The oxygen content changes with changes in the feed temperature as shown in Fig 1.

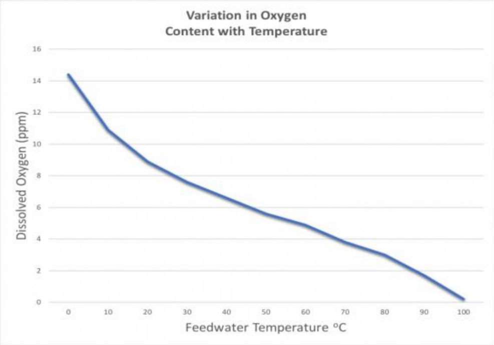

Fig 1. Variation in Oxygen Content with Temperature.

7.4.4 *Steam Purity*

A stringent steam purity may be often required for turbine operation or a process requirement. It is always challenging to control entrainment of solids in steam which depends upon boiler design, boiler operation, and presence of higher dissolved solids, suspended solids and alkalinity. The another reason is silica volatility which depends upon boiler pressure, *p*H, silica concentration in boiler and caustic alkalinity as shown in Fig 2. Generally 2.4 ppm of hydroxide alkalinity is required for each 1 ppm of silica as SiO_2 to keep silica in nonvolatile condition. The foaming may also happen due to any contamination or high TDS coupled high alkalinity or any contamination like oil etc. In such cases the use of antifoams may be helpful though prevention is better than cure.

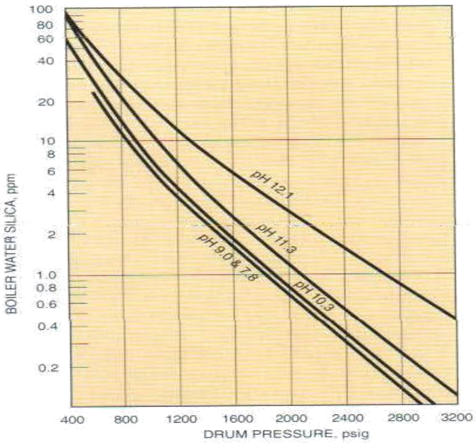

Fig 2. Silica Limits in Boiler Water

7.4.5 *Prevention of Caustic Embrittlement*

7.4.5.1 Caustic embrittlement or intergranular cracking takes place only when the metal is under stress and a high concentration of caustic alkali is present. This can thus take place only on riveted and welded drums which have not been stress relieved. In modern practice, riveting is dying out and this difficulty will be avoided to a great extent.

7.4.5.2 Caustic embrittlement can be prevented to a great extent by maintaining a ratio of sodium sulphate to caustic alkalinity to 2.5:1 or a ratio of sodium nitrate to caustic alkalinity to 0.4:1 in the boiler. As sodium sulphate is normally present in feed waters and also as sodium sulphite is injected into the boiler feed for the removal of dissolved oxygen which later converts itself into sodium sulphate, in many cases the ratio is maintained without further addition of sodium sulphate. If, required sodium sulphate can be added if ratio is not being maintained. Whereas, if it is desired to use sodium nitrate the same may have to be added in defined ratio with caustic alkalinity.

8 CARE OF BOILERS

8.1 Although boiling out, initial boiler filling and protection of standing boilers have been described briefly, chemical cleaning of boilers is given in IS 10391.

8.2 Boiling Out

Before putting a boiler into service, it is necessary to remove all traces of oil and grease from the internal surface as it might lead to overheating and failure. For this purpose, it should be filled with clean water just below the working water level. The chemicals as specified in Table 3 should beadded.

Table 3 Boilout Treatment Additives
(*Clause* 8.2)

Sl No. (1)	**Boilout Treatment Additives** (2)	**Concentration in boiler, in mg/l** (3)
i)	Trisodium Phosphate ($Na_3PO_4.12H_2O$)	1 000
ii)	Disodium Phosphate (Anhydrous)	500
iii)	Surfactant	225

The boiler shall be warmed through by a slow fire, keeping the manhole closed, immediately after adding the chemical and pressure is allowed to rise slowly. It should be raised sufficiently to give a strong blow of steam at the air cocks. It should be allowed to cool and later blown down for about 15 sec on each blow down valve and refilled to about 5 cm level in the gauge glass. On the following day, carry out the same process except that the pressure is raised to approximately 25 percent of the normal working pressure. On the third day carry out the same process and then drain the water as detailed below. When the pressure falls to 0.04 MN/m^2 (0.4 kgf/cm^2), the unit is blown down completely until it is empty, refilled to flood the drum and superheater and blown down again. It should then be carefully inspected. If any trace of oil or grease is observed, the process of boiling out should be repeated. If the boiler is found free from grease or oil or sediment, it should be closed and filled with feed water as specified in IS 10392.

NOTE — If the superheater is non-drainable, it should be filled with only treated demineralised or condensate water.

8.2 Initial Boiler Filling

When a boiler is to be filled with water for service, it is desirable that normal feed water is used after proper softening or demineralization and treatment chemicals are added. The sodium sulphate or sodium nitrate should also be added to ensure the safe ratio for prevention of caustic embrittlement.

8.2.1 If normal feed would consist of a large portion of condensate and if the boiler is to be put into operation for the first time and no condensate is available, the best available water should be used after proper treatment, either external or internal. Sodium phosphate should be added to water as required to remove the residual hardness. The boiler should be blown down frequently to remove the sludge. Condensate should be collected and changeover to it should be made as soon as possible.

8.3 Protection of Standby Boilers

When boilers are temporarily at idle state, they are liable to be impacted by corrosion. If they are to be kept idle for more than a few hours, special measures, such as those given below, have to be taken to protect against corrosion during that period.

8.3.1 *Hot Standby or Banked Condition*

Such a condition lasts for few hours or an overnight. It is generally sufficient to keep the boiler on banked fire for short periods with water conditions that existed when it was steaming out in operation. If any water is added due to expansion or contraction, the water should be sufficiently treated with suitable external treatment and deaerated. The oxygen scavenger residuals should be leveled up. It is important to frequently check alkalinity and oxygen scavenger residuals to identify any short fall which is made up to desired levels. Special precautions should be taken to protect superheaters and expert advice should be sought

8.3.2 *Standby and Load Topping Boilers*

Boilers that are lightly steamed or kept up to pressure to act as standby or load topping boilers can lose boiler water, through level sensor checking, blowdown and sampling. The water lost will be replaced by feedwater with a lower dissolved solids content and normal water-conditioning chemicals are added. There will always be a chance for oxygen scavenger residuals to fall down. To avoid this, residuals of oxygen scavenger should be maintained 3 times of the maximum specified value. It is important to test specified parameters more frequently than normal.

8.3.3 *Extended Periods (Wet Storage)*

The wet storage is done usually for 2 to 3 months or when the boiler may be needed in operation at short notice. The following treatment as specified in Table 4 should be applied based on various conditions.

Table 4 Treatment of Boilers During Wet Storage Under Idle Conditions

(*Clause* 8.3.3)

Sl No. (1)	Boiler Operating Pressure (2)	Treatment (3)
i)	Low Pressure boiler operating at < 250 psig	Add sufficient alkali to maintain a *p*H of 10.0 to 11.5. The minimum hydroxide alkalinity to 400 ppm as $CaCO_3$ and sodium sulfite residual to be 100 ppm to 200 ppm as Na_2SO_3.
ii)	Boiler operating at > 250 psig, having a drainable superheater	Add 300 ppm to 500 ppm cyclohexamine to maintain *p*H of 10 to 11.5 and sodium sulfite residual to be 100 ppm to 200 ppm as Na_2SO_3 or 100 ppm to 200 ppm hydrazine as N_2H_4.
iii)	Boiler operating at > 250 psig having non drainable superheater	Add 300 ppm to 500 ppm cyclohexamine to maintain *p*H of 10 to 11.5 and add 100 ppm to 200 ppm hydrazine as N_2H_4 or 100 ppm-200 ppm Diethylhydroxylamine (DEHA) as DEHA.

NOTE — In case of copper or its alloys pH should not exceed 9.2

All parts, including the economizer and superheater, should be completely filled with correctly conditioned water. Non-drainable super heaters should be filled only with condensate quality water treated. It is most important that pockets of air should not be allowed to remain in the boiler and that there should be no leakage.

Distribution of these chemicals throughout the bulk of the boiler water should be ensured by filling with a premixed solution, by use of a circulating pump or by heating the boiler when partially filled and then topping up with conditioned water. The oxygen scavenger reserve, *p*H value and alkalinity should be checked regularly. Additional treatment chemicals should be added as necessary and distributed to maintain the treatment levels within the recommended range.

8.3.4 *Extended Periods (Dry Storage)*

It is advisable to completely empty the boiler and dry thoroughly and remove all deposits to ensure that no moisture remains below them. Trays of quick lime or silica gel should be placed in the boiler drums before sealing them up. The amount of quick lime or silica gel required will be 1.5 kg/m^2 of boiler drum and tube volumes. Lime or silica gel should be changed from time to time.

9 CONTROL OF TREATMENT

9.1 Testing

It is absolutely necessary that raw water treated with softener, feed water and boiler water are tested at regular intervals and records are maintained. Routine tests on raw and treated water are few and simple. It should be the duty of some responsible person to examine these results interpret them and make necessary regulation in the chemical charges.

9.1.1 The water softening plant should be kept clean and chemical proportioning gear and other mechanisms in good mechanical order. The softener-reaction tanks should be regularly desludged. The softer should, on no account, be operated above maximum rating advised by a manufacturer.

9.2 Blow Down

The boiler should be blown down periodically to maintain the concentration of dissolved solids within recommended limits. Blow down is also based on silica content in boiler water. The quantity of water to be blown clown is calculated as follows:

$$\text{Quantity of water to be blow down} = \frac{100\,Y}{X - Y}$$

where

Y = total dissolved solids in mg/l in feed water; and

X = maximum permissible concentration in mg/l of total dissolved solids in boiler water.

NOTE — Under all conditions, a small amount of continuous blow down may be desirable in addition to the periodical blow down to remove the precipitated sludge.

10 CHEMICAL COMPOSITION OF WATER

Chemical composition of feed water and boiler water is given in IS 10392.

11 COMPUTATION OF INITIAL DOSAGE OF CHEMICALS FOR TREATMENT OF WATER

In order to guide the user, simple directions for computing the correct initial dosage of chemicals for treatment of water are given in Annex A. This computation is based on regular chemical analysis of water. For detailed methods of test mentioned in Annex A, reference may be made as specified in Table 5.

Table 5 Method of Test for Chemicals for Treatment of Water
(*Clause* 11.1)

Sl No. (1)	Characteristic (2)	Method of Test (3)
i)	Carbonate hardness	IS 3025 (Part 21)
ii)	Magnesium hardness	IS 3025 (Part 46)
iii)	Free carbon dioxide	IS 3025 (Part 61)
iv)	Non-carbonate hardness	IS 3025 (Part 21)

ANNEX A

(*Clause* 11.1)

DIRECTIONS FOR COMPUTING DOSES OF CHEMICALS FOR TREATMENT OF WATER FOR LAND BOILERS

A-1 CHEMICALS FOR PRECIPITATION SOFTENING

A-1.1 The quantities given below are based on stoichiometric ratios of chemical reactions involved. In actual practice, a small excess over the theoretically required amount is found necessary to obtain best results and to maintain recommended alkalinity in feed water. In general a 5 percent excess is recommended. Where necessary, the charge may be further adjusted, as required, to obtain desired results.

A-1.1.1 The quantities recommended are for pure chemicals. Commercials samples of lime vary considerably in their available lime content and this should be taken into consideration when calculating the dose. Same observations also apply to soda ash and sodium aluminate.

a) Lime

1) *As Quick Lime* (CaO)

Quick lime (CaO) to be added, kg/1 000 l = 0.000 56 [total alkalinity (as $CaCO_3$) mg/1 + magnesium hardness (as $CaCO_3$) mg/l + free carbon dioxide (as $CaCO_3$) mg/l]

2) *As Hydrated Lime*

Hydrated lime to be added, kg/1 000 l = 0.000 74 [total alkalinity (as $CaCO_3$) mg/l + magnesium hardness (as $CaCO_4$) mg/l + free carbon dioxide (as $CaCO_3$) mg/l]

b) *Soda Ash*

Soda ash to be added, kg/1 000 l= 0.001 06 [non-carbonate hardness (as $CaCO_3$) mg/l]

c) *Sodium Aluminate*

1) Up to total hardness (as $CaCO_3$) of 200 mg/l sodium aluminate to be added, kg/1 000 l = 0.02

2) Total hardness (as $CaCO_3$) above 200 mg/1 sodium aluminate to be added, kg/1 000 l = 0.03

A-2 OTHER CHEMICALS

When sodium phosphate, sodium sulphate or sodium sulphite are to be used, sufficient quantities are to be added to maintain their desired concentration in water.

ANNEX B

(*Foreword)*

COMMITTEE COMPOSITION

Water Quality for industrial purpose Sectional Committee, CHD 13

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This Indian Standard has been developed from Doc No.: CHD 13 (18654).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Published by BIS, New Delhi