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Recommendations for

Treatment of water for steam boilers and water heaters

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Committees responsible for this British Standard

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British Association for Chemical Specialities
British Water
Chemical Industries Association
Chemical Industries Association (GOSIP)
Electricity Association
Health and Safety Executive
Institute of Domestic Heating and Environmental Engineers
Institute of Marine Engineers
Institute of Plumbing
Manufacturers Association of Radiators and Convectors Limited
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Summary of pages

The following table identifies the current issue of each page. Issue 1 indicates that a page has been introduced for the first time by amendment. Subsequent issue numbers indicate an updated page. Vertical sidelining on replacement pages indicates the most recent changes (amendment, addition, deletion).

Page	**Issue**	**Page**	**Issue**
Front cover	2	1	2
Inside front cover	2	2	2
a	1	3	2
b	blank	4-18	original
i	original	19	2
ii	original	20-40	original
iii	2	Inside back cover	original
iv	original	Back cover	2

blank

Contents

Page

Foreword iii

Specification

Section 1. General

1.1 Scope 1

1.2 Objectives 1

1.3 References 1

1.4 Definitions 2

Section 2. Water quality requirements for boilers

2.1 General 3

2.2 Quality of water supply 3

2.3 Hot water systems 3

2.4 Steam generating plant 5

2.5 Sampling and testing 16

Section 3. External water treatment

3.1 Introduction 18

3.2 Boiler feed water treatment options 18

Section 4. Removal of gaseous impurities

4.1 General 20

4.2 Physical de-aeration 20

4.3 Chemical de-aeration 20

Section 5. Boiler water conditioning

5.1 General 22

5.2 Control of concentration of solids in boiler water 22

5.3 Prevention of corrosion 23

5.4 Prevention and control of deposition in boilers 27

5.5 Hideout 28

5.6 Once-through boilers 28

5.7 Method of dosing boiler water conditioning chemicals 28

Section 6. Condensate treatment and purification

6.1 Condensate treatment 30

6.2 Condensate contamination by oil 30

6.3 Condensate polishing 31

Section 7. Corrosion and deposit control

7.1 Feed water tanks 32

7.2 Protection of feed systems 32

7.3 Protection of condensate lines 34

7.4 Corrosion in boilers 35

Section 8. Water-side protection of idle boilers

8.1 General 36

8.2 Storage overnight or for a few days but not exporting steam 36

8.3 Standby and load topping boilers 36

8.4 Storage for extended periods 36

Annexes

A	(informative) Methods of expressing concentrations of impurities in water	38
B	(informative) Typical analyses of treated water	38
C	(informative) Steam purity, carryover, foaming and priming	39
D	(informative) The principal sources of contamination requiring condensate purification	40

Tables

1	Water treatment for hot water systems	5
2	Recommended water characteristics for shell boilers up to 30 bar	6
3	Recommended water characteristics for fired water tube boilers	8
4	Recommended water characteristics for non-fired water tube boilers	12
5	Recommended water characteristics of feed water at economizer inlet for once-through boilers	13
6	Recommended water characteristics for coil boilers	14
7	Recommended water characteristics for electrode boilers	15
8	Some neutralizing amines with their distribution ratios	30
B.1	Analyses of water treated by systems A to F	39

Figures

1	Steam boiler feed water pre-treatment options	4
2	Maximum concentrations of silica in boiler water	11
3	Conductivity of sodium nitrate solution	17
4	Variation in the concentration of dissolved oxygen in water with temperature	21
5	Coordinated and congruent phosphate treatments	26
6	A well-designed feed water tank	33

List of references Inside back cover

Foreword

This British Standard was prepared by Subcommittee EPC/37/8. It revises and supersedes BS 2486 : 1978, which is withdrawn. The responsibility for this standard has now been allocated to CII/62.

BS 2486 was first published in 1954 and last revised in 1978. This revision of the standard brings the technical content up to date, reflecting developments and experience gained in industrial boiler design and operation since 1978. The scope has been broadened to include water treatment for electrode boilers or evaporators, combined heat and power plant (CHP), combined cycle plant (CCP) and plant that produces hot water for heating or process purposes only.

Further information on the design and manufacture of water-tube steam generators and plant can be found in BS 1113 : 1992 and that of shell boilers in BS 2790 : 1992.

Further information on the maintenance of hot water systems of output >45 kW can be found in BS 6880 : Part 3 : 1988.

Given the range of knowledge and experience of the users of this standard, descriptive and introductory text cannot be entirely eliminated. It is also necessary to provide explanations for those applications which do not fall conveniently within the tables provided, or where there are risks if the treatment concerned is not adequately understood.

Values for levels of water treatment chemicals given in this standard are typical values given for information only. It is strongly recommended that, for specific applications, the advice of specialists in boiler water treatment be sought and followed.

Wherever a pressure is quoted in terms of bar, it refers to bar (gauge).

WARNING. Many of the chemicals referred to in this standard are hazardous to human health and or environment and should be handled with care. Attention is drawn to the provisions of the Control of Substances Hazardous to Health Regulations 1994 [1] and applicable environmental legislation. (See note 2 to **1.1**.)

Attention is drawn to the fact that it is claimed that the use of methyl ethyl ketoxime is the subject of British patent No. 2 145 707, copies of which can be obtained from the Sale Branch, The Patent Office, Cwmfelinfach, Cross Keys, Newport NP1 7HZ. BSI takes no position as to the validity of the patent or whether it is still in force. The patent is endorsed 'licences of right' under Section 46 of the Patents Act 1977[1], which states:

'(3) Where such an entry is made in respect of a patent —

> a) any person shall, at any time after the entry is made, be entitled as of right to a licence under the patent on such terms as may be settled by agreement or, in default of agreement, by the Comptroller on the application of the proprietor of the patent or the person requiring the licence.'

Licence details can be obtained from the registered proprietor of the patent.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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[1] Or Section 35(2)(a) of the Patents Act 1949 if applicable.

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Section 1. General

1.1 Scope

This British Standard gives recommendations for the control of water-side conditions of steam boilers and water heaters and also for the preparation of feed water for such plant. The following categories of water heating or steam-raising plant are covered:

a) hot water systems as defined in **1.4**;

b) electrode boilers;

c) shell (fire-tube) boilers operating at pressures up to 30 bar;[2]

d) water-tube boilers operating up to critical pressure;

e) once-through boilers, including 'coil' and 'hairpin' types, operating up to, or above, the critical pressure.

NOTE 1. Regulation 11 of the Pressure Systems and Transportable Gas Containers Regulations, 1989 [2] came into effect on 1 July 1994 and requires boiler users to provide operators with adequate and suitable instructions for the safe operation of the boiler, and to ensure that the boiler is not operated, except in accordance with these instructions. Guidance given in the Health and Safety Executive's Approved Code of Practice *Safety of Pressure Systems* [3] requires that instructions should cover, if appropriate, the feed water treatment.

NOTE 2. The Control of Substances Hazardous to Health (COSHH) Regulations 1994 [1] require an assessment of the risk of exposure to substances hazardous to health and implication of the control measures needed to prevent, or if that is not reasonably practicable, adequately control such exposure. All sources of exposure in the workplace are covered including releases resulting from explosion or venting. For further information users are advised to consult the Approved Codes of Practice covering the control of substances hazardous to health and control of carcinogenic substances [4].

The recommendations are not applicable to:

a) the treatment of water for most domestic heaters, which is covered by BS 7593 *Code of practice for treatment of water in domestic hot water central heating systems*;

b) the treatment of water for marine boilers, which is covered by BS 1170 *Recommendations for treatment of water for marine boilers*;

c) the treatment of water for nuclear-powered steam-generation plant.

The use of electronic, electrostatic or magnetic products is outside the scope of this standard. The preparation of a future British Standard covering such physical treatments of water for steam boilers and water heaters is being considered.

Methods for the analysis of water are not described in this standard.

Additional information on water and water treament is given in annexes A to D.

1.2 Objectives

1.2.1 Objectives of water treatment

The objectives of water treatment are:

a) to contribute to the overall safety of operation of the boiler or water heater;

b) to assist in the maintenance of high heat-transfer efficiency in the boiler or water heater by:

  1) preventing deposition of precipitated scale or other debris;

  2) preventing corrosion or deterioration of surfaces in contact with water;

c) to maintain the quality of any generated steam or hot water, appropriate to the particular application.

Failure to maintain suitable water conditions could compromise the in-service integrity of pressure parts and lead to danger from the unintentional release of stored energy or the scalding effect of hot water or steam.

1.2.2 Factors influencing the quality of feed water required for steam boilers and water heaters

These are:

a) the type and design of boiler or water heater, materials of construction and the operating conditions, particularly heat transfer rates and pressure;

b) the desired steam or hot water quality and the requirements for any spray attemperators, desuperheaters or post-boiler plant, e.g. steam turbines.

Tables 1 to 7 fully reflect these criteria.

1.2.3 Factors influencing the type of water treatment necessary to meet the feed water quality requirements

These are:

a) the characteristics, relative proportions and cost of make-up water, condensate and other process water that can comprise the feed water;

b) the capacity and characteristics of any existing water treatment facilities and procedures;

c) the balance between capital and operating costs of any proposed water treatment plant or procedure, including the effect of energy costs.

1.2.4 The water treatment process

The water treatment process, except for closed circuit water systems, usually involves two distinct elements:

a) external treatment, which is concerned primarily with the removal of undesirable constituents;

b) internal treatment, where chemical additions are made to the feed water, boiler water and steam in order to confer desirable attributes, or to react with traces of undesirable constituents which can remain after external treatment.

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[2] 1 bar = 100 kPA.

1.3 References

1.3.1 Normative references

This British Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate points in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this standard only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

1.3.2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of the standard are listed on the inside back cover, but reference should be made to the latest editions.

1.4 Definitions

For the purposes of this standard the following definitions apply:

1.4.1 boilers

Items of plant which heat water to its boiling point to produce saturated steam. This steam can subsequently be superheated.

1.4.2 hot water heaters

Items of plant which heat water to a temperature below its boiling point at the pressure of the system.

NOTE 1. The water so heated feeds a closed primary circuit utilizing some form of heat exchanger which allows the primary water to heat air, water or other process fluids. The primary circuit water is never used for potable or domestic purposes.

NOTE 2. Hot water heaters and their associated primary circuits are usually classified according to their operating temperature, as defined in **1.4.3**, **1.4.4**, and **1.4.5**.

1.4.3 high temperature hot water (HTHW)

Water above 120 °C.

1.4.4 low temperature hot water (LTHW)

Water below 100 °C.

1.4.5 medium temperature hot water (MTHW)

Water at 100 °C to 120 °C inclusive.

Section 2. Water quality requirements for boilers

2.1 General

The recommendations and data presented in this section should be used as guidelines and reflect good operating and design experience from industry and from boiler manufacturers. It is important, however, that each application should be considered on its own merits. Boiler manufacturers' recommendations should be followed, especially when performance guarantees are given.

Good water treatment practice is dependent on a suitable treatment regime for the whole system. Planned, preventative maintenance of the steam boiler or water heater and all ancillary equipment will ensure the most efficient and safe operation.

2.2 Quality of water supply

Source water can vary considerably in quality and the effect of impurities can be detrimental to boiler operation (see annex D), so before a realistic attempt can be made to assess the treatment needed for any application it should be confirmed that reliable quality data, including variations, are available for the source water.

2.3 Hot water systems

2.3.1 General

Because more than one approach to water treatment exists for hot water systems, each of which gives varying degrees of protection to the system, the approach most suited to the system should be selected after consideration of its type, age and condition in order to provide the most cost-effective regime.

Consideration of existing systems should include an assessment of the quality of the water found in the system and it is particularly important to gauge the extent of any corrosion or scaling. This data should be augmented by determination of the concentrations of dissolved metals and the presence or absence of debris, e.g. iron oxides and/or lime scale. Comparison of the system performance with its design parameters in respect of flow rates, heat distribution, efficiency and response time should also indicate any problems. In addition, the operating history of the system should be ascertained, especially regarding occurrence of blockages and burst pipes, and the level of maintenance required, as this will help to determine the tolerance of the system to corrosion and scaling.

The flow diagram, figure 1, should be referred to for recommendations on water treatment plant selection.

Where the temperature in the system exceeds 100 °C pressurization is necessary to prevent the recirculating water from boiling. Medium temperature hot water systems (MTHW) operating below 3.5 bar generally are pressurized by the height of the expansion tanks above the system, but above 120 °C nitrogen-pressurizing should be used, when system pressures can go as high as 17 bar (177 °C).

2.3.2 Water treatment

Water treatment for hot water systems should be selected after consideration of the following parameters:

- materials of construction
- operating temperature and pressure
- water pre-treatment
- plant and system make-up water quality and quantity.

Two different approaches to chemical treatment for corrosion should be considered:

a) the use of oxygen scavengers, such as sodium sulfite or tannins, buffered to provide the recommended pH range;

b) the use of proprietary blends of corrosion inhibitors which can include nitrite and film-forming additives under appropriate pH conditions.

Where copper or its alloys are present a specific inhibitor against copper corrosion should be used; tannin and organic azoles are the most commonly used. Where aluminium is present specialist water treatment advice should be sought.

Standards of performance should be agreed with the chemical service company with the aim of maintaining plant performance and integrity. Corrosion monitoring can be carried out using direct measurement with corrosion coupons of suitable metallurgy or by routine monitoring of corrodible metal levels in the water. There are no generally acceptable levels and these should be agreed with the chemical service supplier.

Recommendations for suitable water treatment approaches are given in table 1.

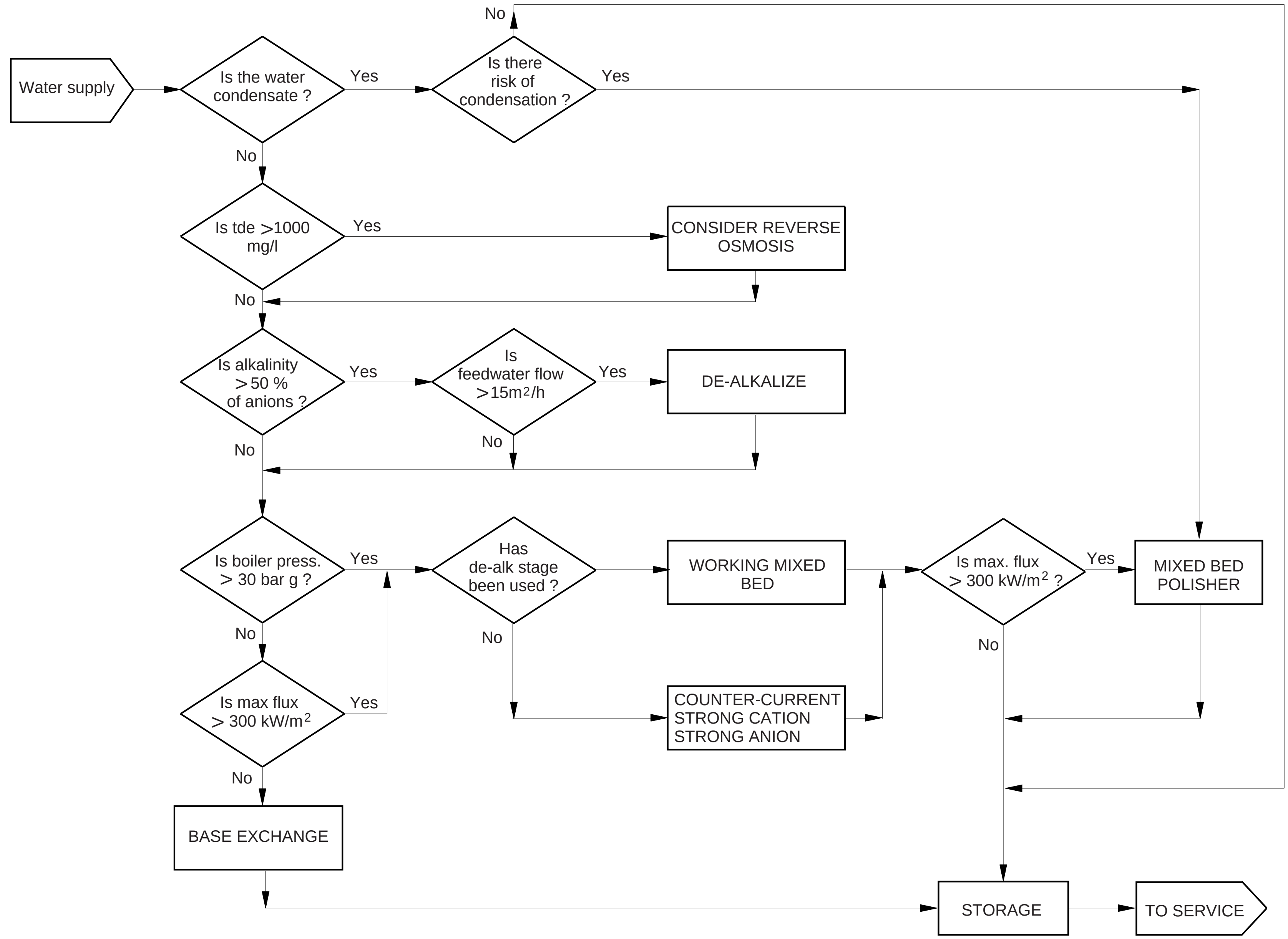


Figure 1. Steam boiler feed water pre-treatment options

Table 1. Water treatment for hot water systems

System type	**Low and medium temperature hot water systems up to 120°C**			**High temperature hot water systems above 120°C**		
Materials of construction (note 2)	Iron only	Iron with copper and copper alloys	Iron with copper, copper alloys and aluminium	Iron only	Iron with copper and copper alloys	Iron with copper, copper alloys and aluminium
Water quality (note 4)	Raw water	Raw water	Raw water (notes 5 and 6)	Raw water (note 7)	Raw water (note 7)	Raw water (notes 5, 6 and 7)
pH limits	8.0 to 10.5	7.5 to 9.2	7.0 to 8.0	8.0 to 10.5	7.5 to 9.2	7.0 to 8.0
Alkalinity control	Sodium hydroxide	Sodium hydroxide	Untreated or buffered	Sodium hydroxide or amines	Sodium hydroxide or amines	Amines
Copper corrosion inhibitor	None	Benzotriazole/ tolyltriazole	Benzotriazole/ tolyltriazole	None	Benzotriazole/ tolyltriazole	Benzotriazole/ tolyltriazole
Oxygen scavenger and/or	Sodium sulfite, tannin, hydrazine or DEHA	Sodium sulfite, tannin, hydrazine or DEHA	Sodium sulfite, tannin, hydrazine or DEHA	Volatile oxygen scavengers (see **5.3.2**)	Volatile oxygen scavengers (see **5.3.2**)	Volatile oxygen scavengers (see **5.3.2**)
Corrosion inhibitor (note 3)	Suitable inhibitor blend (note 1)	Suitable inhibitor blend (note 1)	Suitable inhibitor blend (note 1)			
Sludge conditioner	Suitable organic polymer or blend	Suitable organic polymer or blend	Suitable organic polymer or blend	Suitable organic polymer or blend	Suitable organic polymer or blend	Suitable organic polymer or blend

NOTE 1. Chromate inhibitors should not be used because of their undesirable impact on the environment. It should also be noted that some treatment chemicals are microbiologically degraded in storage.

NOTE 2. Galvanized steel is not considered suitable for hot water systems.

NOTE 3. Alkaline oxygen scavengers can be used as an alternative treatment where toxicity restrictions prohibit proprietary blends.

NOTE 4. Raw water can be used, although in areas where the hardness exceeds 200 mg/kg as $CaCO_3$ and make-up exceeds 1 % of system capacity per week, a supplementary dispersant should be employed.

NOTE 5. Some naturally soft mains waters can be unsuitable because they contain dissolved copper ions which could lead to aluminium failure. Poor buffer control can also cause attack.

NOTE 6. Hard waters which have been fully softened should be avoided when aluminium is present.

NOTE 7. Anions such as chloride and sulfate should not exceed 10 mg/kg. Where the available water contains more than 10 mg/kg of each anion, demineralized water should be used.

2.4 Steam generating plant

2.4.1 Shell boilers (horizontal or vertical)

Shell or fire tube boilers produce steam by heat transfer from the heat source into water confined within a cylindrical vessel or shell, by passage of hot gases through a sequence of tubes. Modern shell boilers are designed to BS 2790.

From a combination of the boiler design and operating parameters it should be noted that solids entering the boiler with the feed water can rapidly concentrate at the metal water interface, especially at areas of high heat transfer. Such deposits can restrict heat transfer and consequently raise mean metal temperature, which can cause corrosion and reduce safety margins.

NOTE. Most shell boilers operate without de-aeration equipment (except feed tanks) and as a consequence high levels of oxygen and free carbon dioxide enter the boiler, both of which, without adequate internal treatment, cause severe corrosion.

As a result of experience gained since the last revision of this standard it is recommended that the operational parameters should not exceed the values given.

The recommendations in table 2 apply to high efficiency shell (fire-tube) boilers operated under design conditions. In view of the great variety of boiler designs in this category it is not possible to stipulate the precise feed water characteristics required for all boilers.

Whilst these recommendations should be generally applicable, there are some boilers, particularly of older and more conservative designs, where deviations from the recommendations of tables 2, 3 and 4 might be justifiable. The advice of the boiler manufacturer should be obtained particularly with regard to the maximum limits recommended for suspended solids and feed water hardness.

The following factors should be taken into consideration:

a) boiler design;

b) blowdown facilities including those of the water level controls;

c) intermittent operation;

d) operation of the boiler at less than the design pressure.

The levels of water treatment chemicals shown in table 2 are typical values only. It is strongly recommended that for a specific installation, the recommendations of the chemical service supplier should be followed.

Table 2. Recommended water characteristics for shell boilers up to 30 bar

Feed water			
Parameter	**Units**	**Values**	
Appearance		Clear, produces no stable foam	
pH value at 25 °C		8.5 to 9.5 (note 1)	
Total hardness	mg/kg $CaCO_3$	2 max. (note 2)	
Dissolved oxygen	mg/kg O_2	(notes 3 and 4)	
Total alkalinity to pH 4.5 (M-alkalinity)	mg/kg $CaCO_3$	(note 5)	
Oil and grease	mg/kg	1 max. (note 6)	
Boiler water			
Heat flux	kW/m^2	≤ 300	> 300 (note 7)
pH value at 25 °C	—	10.5 to 12.0 (note 8)	9.5 to 10.5 (note 8)
Total alkalinity (M-alkalinity)	mg/kg $CaCO_3$	1000 max.	100 max.
Caustic alkalinity (O or P_2 alkalinity)	mg/kg $CaCO_3$	350 min. (note 9)	20 min (note 10)
Oxygen scavenger (note 18)			
Sodium sulfite	mg/kg	30 to 70	(note 12)
or			
Hydrazine	mg/kg	0.1 to 1.0	0.1 to 1.0
or			
Tannin	mg/kg	120 to 160	(note 12)
or			
Iso ascorbic acid	mg/kg	15 to 30	(note 12)
or			
Diethyl hydroxylamine (DEHA)	mg/kg	0.1 to 1.0 in feed water	0.1 to 1.0 in feed water
Phosphate	mg/kg PO_4	30 to 60 (notes 11 and 13)	10 to 30 (notes 11 and 13)
Silica	mg/kg SiO_2	150 max. (note 14)	5 max. (note 14)
Suspended solids	mg/kg	200 max.	20 max.
Dissolved solids (note 15)	mg/kg	3500 max. (notes 16 and 17)	1000 max. (notes 16 and 17)
Electrical conductivity at 25° C. on un-neutralized sample (note 15)	µS/cm	7000 max. (notes 16 and 17)	2000 max. (notes 16 and 17)

Table 2. Recommended water characteristics for shell boilers up to 30 bar *(continued)*
NOTE 1. When copper alloys are present in the feed system this value should not exceed pH 9.2 if corrosion of these materials is to be avoided.
NOTE 2. This value can be achieved only by the use of suitable external pre-treatment plant. It is essential that such plant should be properly maintained. It is also recommended that a suitable polymer dispersant be used to ensure clean heat transfer surfaces.
NOTE 3. Dissolved oxygen should be reduced to the lowest practicable level which will be achieved by the use of a properly designed feed tank or a deaerator. (See **5.3** and figure 6.)
NOTE 4. An oxygen scavenger should be used (see **5.3.2**) and should be added at the outlet of the feed tank or the deaerator in sufficient quantity to reduce the dissolved oxygen level to zero before the feed water enters the boiler or the economizer (where fitted).
NOTE 5. It is recommended that feed water alkalinity be maintained below 25 mg/kg. Alkalinity of 25 mg/kg and above will result in 10 mg/kg carbon dioxide in the steam. This level of carbon dioxide can be economically controlled by the use of a neutralizing amine (see **6.1**). If this feed water alkalinity level cannot be achieved, it is recommended that dealkalization of the make-up water be carried out.
NOTE 6. As determined by the method given in BS 2690 : Part 11 : 1989. This standard has been withdrawn because it involves the use of chlorinated hydrocarbons and the replacement method is not yet available. Copies of the withdrawn standard are, however, obtainable from BSI on request.
NOTE 7. At these heat fluxes the use of demineralized water is essential.
NOTE 8. Corrosion of boiler internals can occur if the pH value is outside these limits.
NOTE 9. At these heat fluxes it is recommended that the caustic alkalinity be maintained at 10 % to 15 % of the total dissolved solids concentration if phosphate conditioning is practised. If carbonate conditioning is used, see note 11.
NOTE 10. This value will depend upon the silica concentration in the boiler water and also on the pH requirement.
NOTE 11. Maintenance of a phosphate reserve is not essential provided either that a minimum carbonate alkalinity of 250 mg/kg can be maintained, depending on the alkalinity of the feed water and the working pressure of the boiler, or that an appropriate programme of transporting polymers is employed. It is important to ensure that magnesium phosphate is not precipitated in the boiler water as it can cause sludges to adhere and form hard scales on heat transfer surfaces. Experience has shown that this is unlikely if the phosphate does not exceed 10 % of the minimum caustic alkalinity specified in the tables. As an additional safeguard it is common practice to use an appropriate polymeric sludge conditioner which will maintain precipitates in suspension for removal with the blowdown.
NOTE 12. These substances can, in some high heat flux and high pressure applications decompose to yield corrosive components. Applications should be individually assessed with the supplier concerned.
NOTE 13. The use of solubilizing treatments using chelants (EDTA, NTA etc.) is permissible provided that a maximum of 10 mg/kg is not exceeded at any time. Complete removal of oxygen should have been achieved prior to injection of the chelant. In boilers having heat fluxes greater than 300 kW/m^3, the use of chelants should be avoided since they can decompose to produce acidic residues.
NOTE 14. Silicate scales can be formed readily in all boilers. Maintenance of a ratio of silica content to caustic alkalinity of less than 0.4 : 1 can prevent this.
NOTE 15. Of these two parameters, conductivity and TDS, only one needs to be measured. See **5.1.**
NOTE 16. These values are for guidance only. It might be found from experience that lower values are necessary to avoid priming or carryover. (See annex C.)
NOTE 17. These values are recommended for fully softened feed water in accordance with the table. If, for whatever reason, feed water with a significant hardness has to be used then TDS/conductivity level should be reduced to achieve the suspended solids limit. At 20 mg/kg feed water hardness the upper limit should be reduced to 6000 μS/cm[*] and at 40 mg/kg hardness it should be reduced to 4000 μS/cm[*]. [*] Conductivity measured on un-neutralized sample.
NOTE 18. Other oxygen scavengers are referred to in **5.3.2.** The control levels of these should be as recommended by the supplier of the treatment chemical.

2.4.2 Water tube boilers

2.4.2.1 *Fired boilers*

Water tube boilers produce steam by heat transfer from the heat source into water confined within a tube. Except at very high pressures, the thermal conductivity of steam is much lower than that of water and the lower cooling effect of a flow of a steam water mixture passing through a tube results in a higher metal temperature than that from water alone. The flow velocity of the steam water mixture through a tube will determine the phase distribution of the mixture. This mixture can take the form of a turbulent mousse which speeds up the fluid flow velocity or some form of phase separated flow which slows down the liquid phase velocity. These effects cause metal cooling problems and present corrosion risks.

Modern water tube boilers are designed to produce large amounts of steam from a relatively small boiler size and utilize a relatively high heat input. The heat distribution in a natural flow boiler can have major effects on the velocity of fluid flow in any particular area of the boiler and this should be taken into consideration when boilers are operated at pressures and steaming rates different from their designed optima.

Boiler design and operating parameters mean that the solids entering the boiler with the feed water can rapidly concentrate at the metal–water interface at high heat flux regions. High solids concentration can form deposits or interfere with the protective magnetite layer, thus allowing either overheating or corrosion to take place.

In general, it should be ensured that the boiler feed water does not contain any scale-forming entities. Dissolved solids concentrations should be kept at levels commensurate with the boiler heat flux and steam purity requirements.

A water tube boiler is an energy efficient package with the boiler feed water passing through an economizer to the boiler. Evaporation does not occur throughout most, if not all, of its forced circulation tubes. The corrosion protection afforded by the water cannot rely therefore on any concentration mechanism or steam scrubbing effect, so the pH value and oxygen scavenging treatments are of paramount importance for the feed system protection and should be maintained as closely as possible to their optimum levels.

Many prime mover (steam turbine) steam supplies originate from drum boilers, with further energy put into the steam downstream by superheating. Therefore, the purity of the steam should be considered of greatest importance, both in terms of dryness and of dissolved solids content, to ensure the protection of the downstream units from corrosion and physical damage in operation. Steam quality should be one of the governing factors in the determination of the operating parameters chosen from the tables in this standard.

One type of boiler in this group evaporates all the feed water entering the circuit and is referred to as a once-through boiler. The fact that there is no residual body of water to contain and concentrate the solids entering the circuit produces particular treatment problems.

Tables 3 and 4 give the recommended operating parameters for drum boilers of typical current design. The boilermaker and the prime mover supplier should take the responsibility to justify deviation from these specified conditions, which are normally required for the safe and economic operation of the units.

Table 3. Recommended water characteristics for fired water tube boilers

Pressure at boiler outlet bar [1)]	**0 to 20**	**21 to 40**	**41 to 60**	**61 to 80**	**81 to 100**	**101 to 120**	**Above 121** (note 11)
Feed water at economizer inlet							
Total hardness, mg/kg as $CaCO_3$ max.	2	1	ND	ND	ND	ND	ND
pH value at 25 °C (note 2)	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5
Oxygen, mg/kg as O_2 max. (note 3)	0.02	0.02	0.01	0.005	0.005	0.005	0.005
Iron and copper and nickel, mg/kg max. (note 4)	0.05	0.05	0.03	0.02	0.02	0.02	0.02
Total solids, alkalinity, silica	note 5	note 5	note 5	note 5	note 5	note 5	note 5
Organic carbon	note 6	note 6	note 6	note 6	note 6	note 6	note 6
Boiler water							
Phosphate mg/kg PO_4 (note 7)	30 to 70	20 to 50	20 to 40	15 to 30	10 to 20	3 to 10	3 to 5
Caustic alkalinity mg/kg $CaCO_3$	50 to 300	50 to 150	25 to 50	10 to 20	5 to 10	2 to 5	1 to 5

Table 3. Recommended water characteristics for fired water tube boilers *(continued)*

Pressure at boiler outlet bar [1)]	**0 to 20**	**21 to 40**	**41 to 60**	**61 to 80**	**81 to 100**	**101 to 120**	**Above 121** (note 11)
Silica as mg/kg SiO_2 (note 8)	<0.4 times caustic alkalinity	<0.4 times caustic alkalinity	20 max.	5 max.	2 max.	1.5 max.	0.5 max.
Sulfite as mg/kg Na_2SO_3 or	30 to 50	20 to 40	15 to 20	NR	NR	NR	NR
Hydrazine as mg/kg N_2H_4 or	0.1 to 1.0	0.1 to 0.5	0.1 to 0.2	0.05 to 0.1	0.05 to 0.1	0.05 to 0.1	0.05 to 0.1
DEHA as mg/kg	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water
Tannin mg/kg or	120 to 160	NR	NR	NR	NR	NR	NR
Iso ascorbic acid mg/kg	15 to 30	15 to 30	15 to 30	NR	NR	NR	NR
Chloride mg/kg Cl (note 9)	—	—	—				
NVAT (Coal-fired)				<8	<4	<2	<2
NVAT (Oil-fired)				<8	<4	<0.5	<0.5
AVT (Coal-fired)				<0.02	<0.2	<0.2	<0.2
AVT (Oil-fired)				<0.02	<0.2	NR	NR
Dissolved solids mg/kg max.	3000	2500	1000	200	50	20	10
Conductivity at 25 °C μS/cm (note 10)	6000	5000	2000	450	150	60	35

Notes to table 3
ND = not detectable
NR = not recommended

NOTE 1. The values given in the table apply to boilers of modern design and heat flux rating. Boilers of low heat flux can tolerate higher concentrations of solids. Boilers operating at up to 40 bar, but which have a local heat flux density of greater than 300 kW/m^2, should be treated as for the column '41-60 bar'. Boilers which operate at up to 120 bar, but which have a heat flux density of greater than 750 kW/m^2, should be treated as for the column 'above 121 bar'.

NOTE 2. Plant containing copper alloys in either the feed or condensate system should have the pH of the feed water limited to 8.5 to 9.2. If the feed system is completely ferrous, the pH should be limited to 9.2 to 9.5. For plant utilizing the feed water for spray attemperation or desuperheating, the pH should be controlled with volatile alkalis only.

NOTE 3. The oxygen limits are those that should be targeted for after mechanical de-aeration. In addition, it is recommended that a catalyzed chemical oxygen scavenger should be used. It is feasible to use oxygen control to produce a stable protective film in the boiler, but this is a highly specialized approach requiring feed water of extreme purity and a very high level of specialist supervision and as such is outside the consideration of this standard. The table gives values for five common chemical oxygen scavengers. Where feed water is used for spray attemperation or desuperheating, sodium sulfite should not be used.

NOTE 4. The proportions of iron, copper and nickel in the feed water will depend on the materials of construction, the operating age of the plant and the water treatment employed. The maxima given relate to normal steady state operation and they will be exceeded during start-up and also possibly during significant load changes. The weighted mean metal content should not exceed the figures in the table during the 24 h following start up and 1 h following greater than a 20 % load change.

Table 3. Recommended water characteristics for fired water tube boilers *(continued)*

NOTE 5. The level of solids in feed water depends on the level of blowdown required to maintain the specified boiler water conditions. For feed water used in spray attemperation or desuperheating, the solids content should not exceed 1 mg/kg. Modern steam turbines often have strict limits on sodium (and other alkali metals) e.g. less than 0.005 mg/kg Na.

NOTE 6. In general, oil and organic matter that can degrade or deposit will produce undesirable effects in boilers. The levels of these contaminants in the feed water should be minimized. Oils that do not volatilize at the operating pressure should be eliminated from the feed water, e.g. steam condensate that could be contaminated with these low volatility materials, should not be used in feed water (see **6.2**).

NOTE 7. Phosphate need not be used in boilers where hardness can be eliminated from the feed water at all times. Its use is not recommended for boilers which can exhibit severe hideout. (See **5.3.5** for an explanation of coordinated phosphate treatment.) In these circumstances sodium hydroxide is the preferred alkalizing agent and should be dosed to a maximum of 1.5 times the sodium chloride content.

NOTE 8. Silica limits are based on the avoidance of silicate scale deposition and the limitation of silica solubility in steam. Figure 2 is based on a steam silica content of 0.02 mg/kg which is the usual level specified for modern steam turbines.

NOTE 9. Chloride attack. In high pressure, highly rated water tube boilers, the ingress of chloride ions can constitute a hazard. The chloride ions can penetrate deposits and hydrolyze to form hydrochloric acid, which will then attack the tube metal. In severe cases the hydrogen formed in this corrosion process diffuses into the metal. The hydrogen reacts with carbon in the metal and methane is produced under extreme pressure destroying the metal structure. Failures by this mechanism, known as hydrogen embrittlement, are often violent with sections of the tube blowing out.

It is important that the tube surfaces be kept clean to avoid the initiation of corrosion and therefore regular water-side inspection and, if necessary, chemical cleaning of high pressure plant is recommended. The level of chloride which can be tolerated in such boilers during steady operation will depend upon the type of treatment employed. Where all-volatile alkaline treatments are used (AVT) then the chloride levels should be lower than where non-volatile alkalis (NVAT) such as sodium hydroxide and sodium phosphate are used. The values can also vary according to whether the boiler is coal- or oil-fired.

NOTE 10. Conductivities are determined on un-neutralized samples without cation exchange at 25 °C. See **5.1**.

NOTE 11. At these pressures, control values should be agreed between the boiler manufacturer and the operator. Values given in the table are for guidance only.

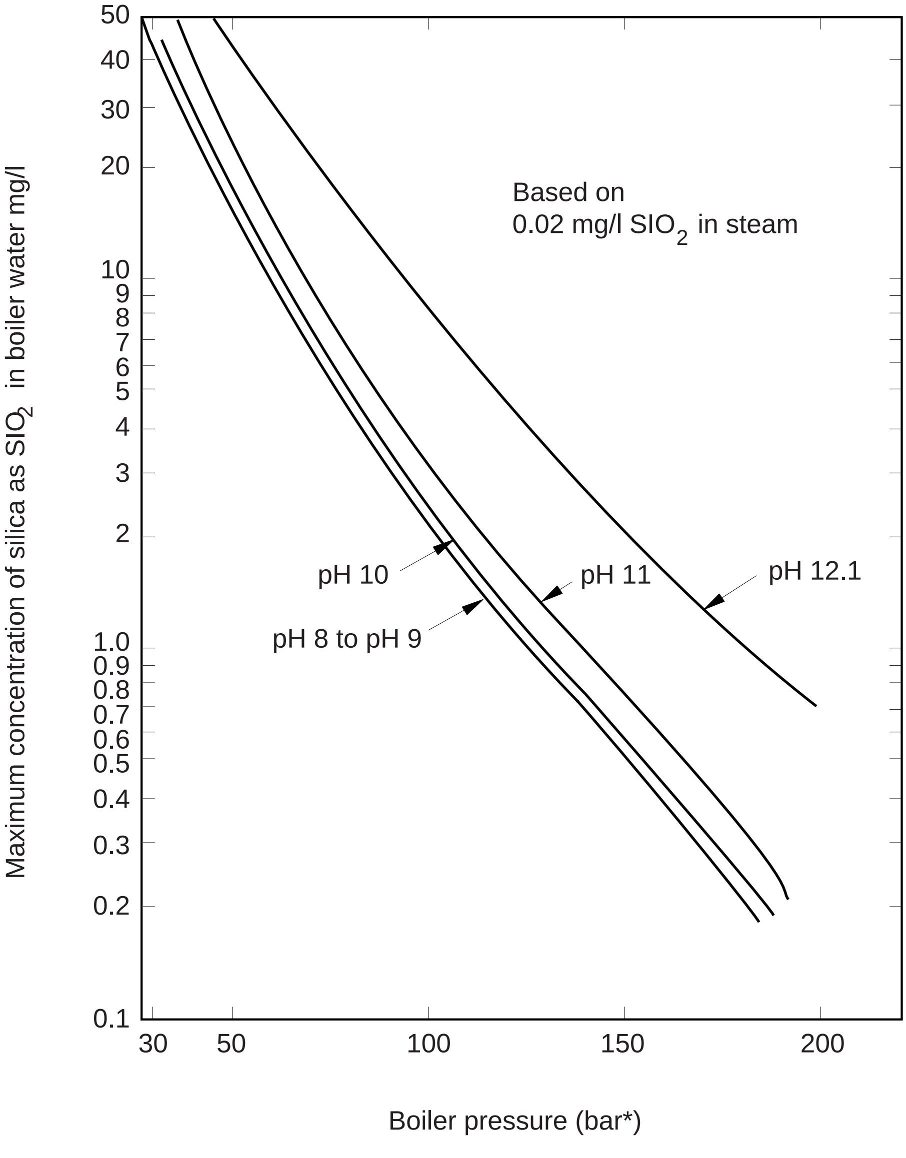


Figure 2. Maximum concentrations of silica in boiler water

2.4.2.2 *Non-fired water tube boilers*

This group of non-fired water tube boilers covers a wide range of operating pressures, designs and applications, e.g. combined cycle plant (CCP) and combined heat and power plant (CHP), so it is difficult to generalize on water chemistry and the advice of the boiler supplier or specialist water treatment chemical supplier should be sought. The figures in the table are indicative of good current practice.

With the widespread use of close-pitched finned tubes, heat fluxes in these boilers can be high in relation to the gas temperature.

Table 4. Recommended water characteristics for non-fired water tube boilers

Pressure range at boiler outlet bar (note 14)	**0 to 40**	**41 to 80**	**Above 80**
Feed water at economizer inlet (see also notes 10 and 11)			
Total hardness mg/kg $CaCO_3$	ND	ND	ND
pH value at 25 °C (note 1)	9.3 to 9.8	9.3 to 9.8	9.3 to 9.8
Oxygen mg/kg O_2 max (note 2)	0.02	0.01	0.005
Iron and copper and nickel mg/kg max. (notes 3 and 8)	0.05	0.03	0.02
Boiler water			
Phosphate mg/kg PO_4 (note 4)	20 to 40	15 to 30	3 to 10
Caustic alkalinity mg/kg $CaCO_3$	25 to 50	10 to 50	2 to 5
Silica mg/kg SiO_2 (note 5)	20	5	1 to 5
Oxygen scavenger (see notes 6 and 7)			
Sodium sulfite mg/kg Na_2SO_3 or	15 to 20	—	—
Hydrazine mg/kg N_2H_4 or	0.1 to 0.5	0.05 to 0.1	0.05 to 0.1
DEHA mg/kg or	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water	0.1 to 0.25 in feed water
Tannin or	120 to 160 (note 12)	NR	NR
Iso ascorbic acid	15 to 30 (note 12)	15 to 30 (note 12)	NR
Dissolved solids mg/kg max. (notes 8, 9 and 13)	1000	200	50
Conductivity µS/cm (note 13)	2000	400	100

ND = not detectable NR = not recommended

Notes to table 4

NOTE 1. Plant containing copper alloys material in either the feed or condensate system should have the pH of the feed water limited to 8.5 to 9.2. If the feed system is completely ferrous, the pH should be limited to 9.2 to 9.5. For plant utilizing the feed water for spray attemperation or desuperheating, the pH should be controlled with volatile alkalis only.

NOTE 2. These values are as measured before the addition of a chemical oxygen scavenger.

NOTE 3. The proportions of iron, copper and nickel in the feed water will depend on the materials of construction, the operating age of the plant and the water treatment employed. The maxima given relate to normal steady state operation and they will be exceeded during start-up and also possibly during load change. The weighted mean metal content should not exceed the values in the table.

NOTE 4. Phosphate need not be used in boilers where hardness can be eliminated from the feed water at all times. Its use is not recommended in boilers exhibiting severe hideout.

Table 4. Recommended water characteristics for non-fired water tube boilers *(continued)*

NOTE 5. The silica limits are based on the avoidance of silicate scale deposition and the limitation of silica solubility in steam. The boiler water silica levels in table 4 have been set to achieve a level of 0.02 mg/kg steam as this is the normal level specified for modern steam turbines. (See figure 2.)

NOTE 6. The oxygen limits are those that should be aimed at after mechanical de-aeration. In addition, it is recommended that a catalyzed chemical oxygen scavenger be used. It is feasible to use oxygen control to produce a stable protective film in the boiler but this is a highly specialized approach requiring feed water of extreme purity and a very high level of specialist supervision and as such is outside the consideration of this standard. The table gives typical values for some common chemical scavengers.

NOTE 7. Sodium sulfite can decompose at pressures higher than 50 bar and give rise to sulfur dioxide or hydrogen sulfide in the steam.

NOTE 8. In systems where the steam and condensate systems are extensive, it is important that any contamination of returned condensate be controlled either by monitoring and dumping or by condensate polishing. See **6.3**.

NOTE 9. Many of these boilers provide steam for turbines and it is important that good quality steam be produced. This requires the correct installation of drum internals and selection of the appropriate boiler water conditions. Boilers with only rudimentary drum internals will require lower concentrations to be maintained and/or further mechanical separation installed.

NOTE 10. The level of solids in feed water depends on the acceptable level of blowdown required to maintain the specified boiler water conditions. For feed water used in spray attemperation or desuperheating, the solids content should not exceed 1 mg/kg. Modern steam turbines often have strict limits on sodium (and other alkali metals) e.g. 0.005 mg/kg Na. In this case the recommendations of the boiler supplier should be followed.

NOTE 11. In general, oil and organic matter that can degrade or deposit and have undesirable effects in boilers and their feed water content should be minimized. Oils that do not volatalize at the operating pressure should be eliminated from the feed water. See **6.2**.

NOTE 12. Because of thermal decomposition the use of tannin above 20 bar or iso ascorbic acid above 60 bar are not recommended.

NOTE 13. Of these two parameters, conductivity and TDS, only one need be measured. See **5.1**.

NOTE 14. Non-fired boilers operating at more than one pressure should be treated so that conditions are consistent with the highest operating pressure.

2.4.2.3 *Once-through boilers*

Recommendations for once-through boilers are given in table 5.

Table 5. Recommended water characteristics of feed water at economizer inlet for once-through boilers

Feed water at economizer inlet (note 1)

Parameter	**Units**	**Values**
Conductivity at 25 °C after hydrogen cation exchange	µS/cm	0.2 max.
Oxygen (note 3)	mg/kg O_2	0.005 max.
Silica	mg/kg SiO_2	0.02 max.
Iron	mg/kg Fe	0.01 max.
Copper and nickel	mg/kg Cu + Ni	0.005 max.
pH (note 2)		8.5 to 9.5
Start up/load change weighted mean iron	mg/kg Fe	0.1 max.
Start up/load change weighted mean copper and nickel (note 4)	mg/kg Cu + Ni	0.03 max.

Notes to table 5.

NOTE 1. As there is no opportunity to blowdown or remove solids from these boilers it is necessary that the solids in the feed water be kept to a minimum and that any treatment chemicals used be volatile in nature.

NOTE 2. If copper alloys are used in either the feed or condensate system the pH of the feed water should be limited to 8.5 to 9.2. Otherwise, it should be 9.2 to 9.5.

NOTE 3. The oxygen limit given is measured after mechanical de-aeration and, in addition, it is recommended that a volatile chemical scavenger be used.

NOTE 4. The proportions of iron, copper and nickel in the feed water will depend on the materials of construction, the operating age of the plant and the water treatment employed. The maxima given relate to normal steady state operation; they will be exceeded during start-up and possibly also during significant load change. The weighted mean metal content should not exceed the figures in the table over any 4 h period.

2.4.3 Coil boilers

The type of boiler referred to as a coil boiler can have several different configurations which affect the water treatment requirements. The basic design is for feed water to be pumped to a single or multiple-start coil arrangement around a burner. The heat input and fluid flow produce steam at the coil exit of between 10 % and 20 % wetness. This steam can be passed through a separator and then through a superheater. The coil arrangement can include an economizer section in the exit flue gas. The feed water can be treated raw water or a mixture of this type of water and returned condensate. Separator drain water can be returned to the feed water tank or dumped, or the feed water can be added to the separator drain for recycling through the coil(s).

The arrangement of these boilers means that most should be able to carry very high dissolved solids in the water phase of the coil exit fluid without detriment to the steam purity. On the other hand, the inside surface of each coil in the furnace area should be properly wetted and cooled to ensure freedom from dryout, corrosion and deposition. Because feed water is turned to steam with no opportunity for dissolved oxygen and carbon dioxide to escape, the potential for corrosion is increased in this type of boiler. To prevent corrosion and deposition, therefore, good water treatment is essential.

Boilers that return steam separator water within the boiler circuit and boilers operating at over 40 bar should benefit from the inclusion of phosphate, whereas those operating at low pressure and steam/water mixtures away from the boiler circuit, do not benefit.

Where such boilers are operated on an intermittent basis special care should be taken to reduce the likelihood of corrosion. Reference should be made to **8.2** and the boiler manufacturer's instructions.

The following tables are based on these groups of boiler:

a) low pressure with separator drain dumped or recycled to feed tank;
b) low pressure with separator drain recycled within the boiler feed circuit;
c) high pressure boilers : coil pressures over 40 bar.

In coil boilers, control of dissolved solids should be exercised by dumping separator drain water in sufficient quantity to control the feed water solids to a level low enough to allow concentration through the coil.

Table 6. Recommended water characteristics for coil boilers

Type of boiler	**Low pressure (< 40 bar) integral recycle**	**Low pressure (< 40 bar) external recycle**	**High pressure (> 41 bar)**
Feed water at coil inlet			
Total hardness mg/kg $CaCO_3$ max.	1.0	1.0	Not detectable
pH value at 25 °C	8.5 to 9.5	8.5 to 9.5	8.5 to 9.5
Oxygen scavenger (note 1)			
Sulfite mg/kg Na_2SO_3	10 to 20	10 to 20	(note 1)
or Hydrazine mg/kg N_2H_2	0.05 to 0.1	0.05 to 0.1	0.02 to 0.05
or DEHA mg/kg	0.025 to 0.1	0.025 to 0.1	0.02 to 0.05
Iron, copper and nickel (each of) mg/kg max.			0.02
Coil exit water			
Phosphate mg/kg PO_4	30 to 70	10 max.	3 to 5
Caustic alkalinity mg/kg $CaCO_3$	300 min.	300 min.	150 min.
Silica mg/kg SiO_2 (note 2)	< 0.4 times caustic alkalinity	< 0.4 times caustic alkalinity	< 0.4 times caustic alkalinity

Table 6. Recommended water characteristics for coil boilers *(continued)*

Type of boiler	Low pressure (< 40 bar) integral recycle	Low pressure (< 40 bar) external recycle	High pressure (> 41 bar)
Coil exit water			
Dissolved solids mg/kg (note 2)	8000	8000	5000

Notes to table 6.

NOTE 1. It is imperative that the oxygen scavenger used in coil boilers remove all the oxygen in the feed water and so the use of a proportionally dosed, fully catalyzed chemical scavenger is essential. Sulfite can decompose at pressures higher than 50 bar and produce hydrogen sulfide or sulfur dioxide in the steam.

NOTE 2. The required silica and dissolved solids contents of the feed and boiler water of high pressure coil boilers depend upon the steam purity requirements. If a steam turbine is to be used, steam control elements can suffer from deposition. The silica and solids levels of the equivalent duty water tube boiler should be adhered to. See table 3.

2.4.4 Electrode boilers

2.4.4.1 *General*

Electrode and electrically heated boilers provide convenient small packaged units for generating relatively low volumes of steam economically and quickly at pressures of up to 25 bar. These boilers are of two separate types:

a) immersion electric boilers;

b) electric resistance boilers.

They can operate as steam boilers or hot water generators and typically operate at 440 V or 660 V 3-phase. Small immersion boilers can operate on 240 V single phase.

A further type is the jet steam boiler operating at up to 6000 V a.c. Jets of water are sprayed at the electrode and the resultant current flow generates steam.

The immersion type boilers operate in a similar manner to boilers described in **2.4.1**, but heat is provided from electricity, not by direct combustion of fuels and the feed water should therefore be chemically treated as described in **2.4.1**.

The electrical resistance boilers work by utilizing the internal resistance drop through the boiler water to generate heat, therefore the conductivity of the feed water is critical to the correct operation of the boiler and should be maintained within manufacturers' limits.

These boilers are manufactured to BS 1894 : 1992 which should be consulted for details. Electrical resistance boilers are prone to corrosion and scale build-up so only good quality feed water should be used. De-mineralized feed water with conductivity provided by electrolyte addition should be used for jet steam boilers. A feed water which is at least fully softened (e.g. by base exchange) should be used for most other electrode boilers.

Table 7. Recommended water characteristics for electrode boilers

Parameter	Units	Values
Feed water quality		
Hardness (note 1)	mg/kg $CaCO_3$	2 max.
pH		7.5 to 9.5
Iron (note 2)	mg/kg Fe	0.2 max.
Conductivity (note 4)	μS/cm	400 max.
Boiler water quality		
Hardness	mg/kg $CaCO_3$	0 to 10
Alkalinity Total (note 3) Caustic	 mg/kg $CaCO_3$ mg/kg $CaCO_3$	 600 max. 300 min.
pH value at 25 °C		9.5 min.
Conductivity (notes 4 and 5)	μS/cm	400 to 2000

Table 7. Recommended water characteristics for electrode boilers *(continued)*

Parameter	Units	Values
Dissolved oxygen	mg/kg O_2	Nil
Sulfite (note 6)	mg/kg Na_2SO_3	50 to 100

NOTE 1. External pre-treatment might be required to achieve this limit (see section **3**).

NOTE 2. Low iron levels in the feed are essential to avoid damage to the electrode from iron deposition. This can be achieved only by correct condensate line corrosion treatment (see section **6**). Polymer dispersants should be dosed to the feed line and boiler to ensure particulate iron is effectively removed with the blowdown.

NOTE 3. When porcelain insulators are used, an M alkalinity of less than 400 mg/kg should be maintained.

NOTE 4. Refer to manufacturer's recommendations.

NOTE 5. Optimum boiler conductivity should be maintained using sodium nitrate or sodium sulfite. If sodium sulfite is used, the conductivity should be maintained within the specified range, irrespective of whether the sulfite reserve is excessive. If sodium nitrate is used refer to figure 3 for the required dose rate.

NOTE 6. Some types of boiler demand use of volatile oxygen scavengers and also neutralizing amines to maintain pH. The recommendations of the suppliers of the volatile oxygen scavengers should be followed.

2.5 Sampling and testing

A correct sampling, testing and recording routine should be considered to be of paramount importance to achieve and maintain the recommendations given in tables 1 to 7 for the chemical compositions of feed water and boiler water. The record of test results should be correlated with details of the operation of the boiler plant. Thus the composition of the boiler water should be maintained to the desired standard and faults diagnosed before boiler failure occurs.

The tests to be carried out and their frequency should be determined for each individual boiler plant, if necessary in consultation with a specialist. The type and number of tests should be sufficient for full control of any water treatment and conditioning and to show that the compositions of the feed water and boiler water are being maintained within recommended limits. If there is any doubt about this most important subject, reference should be made to specialists and to BS 6068 : Section 6.7. BS 1427 and the appropriate Parts of BS 2690 and BS 6068 : Part 2 should be used as the basis for suitable methods of test.

As a minimum, boiler water, feed water and condensate should be tested once per day and the ion exchange plant should be tested three times a day.

Extreme care should be taken to obtain representative samples. In the case of the boiler water, a sample cooler is necessary in order to achieve this. Normally, the water passing through the cooler should be drawn from just below the extra low level alarm point, or from the continuous blowdown line.

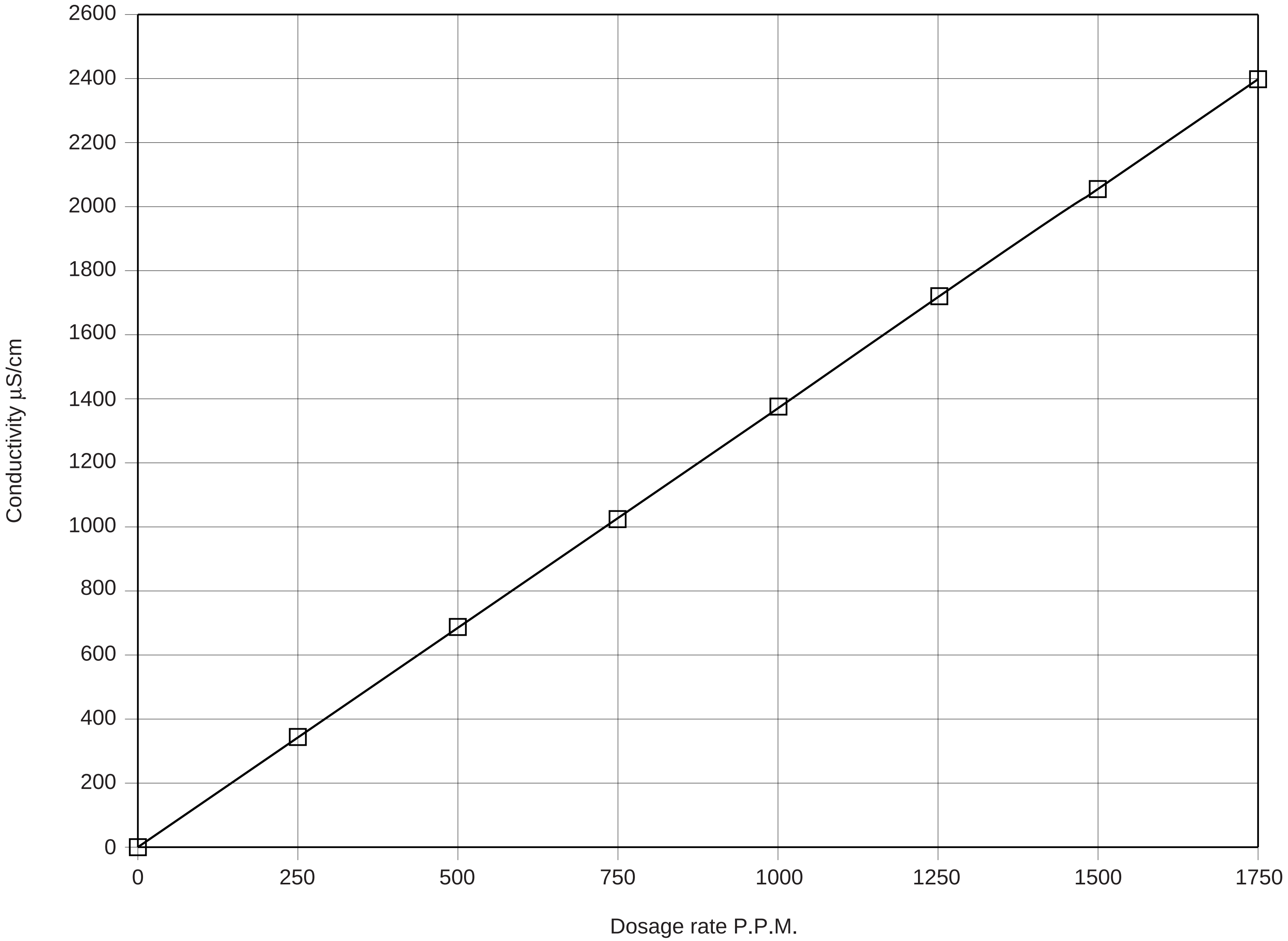


Figure 3. Conductivity of sodium nitrate solution

Section 3. External water treatment

3.1 Introduction

This term is used to describe the treatment of boiler make-up water.

Most natural waters require some form of treatment so that they can meet the treated water qualities detailed in tables 2 to 7.

It is essential that accurate water analyses be obtained before selecting suitable treatment. These should take into account seasonal variations, alternative supplies which might be used and anything else that could change the supply characteristics of the water, such as storm conditions in a river.

In some cases the feed water can include returned condensate which needs treatment. In the case of new plant no analyses will be available, therefore experience from a similar existing installation should be used.

3.2 Boiler feed water treatment options

NOTE. The following subclauses, together with figure 1, form a guide for the selection of appropriate equipment. It should not be considered exhaustive. There are many text books which can supply more comprehensive explanations.

3.2.1 Pre-treatment

3.2.1.1 *General*

If the feed water is cloudy, coloured or otherwise contaminated with suspended solids or 'oils', it should be given preliminary treatment. The degree of pre-treatment depends upon what downstream process is used. The methods of pre-treatment commonly encountered are sedimentation, clarification, flotation, and filtration.

3.2.1.2 *Sedimentation*

Passing the water into a settlement tank of sufficient size will give settleable suspended particles time to sink to the bottom while water is drawn off from the top. The deposited particles, in the form of a sludge, are removed from the bottom of the tank periodically. This process does not remove fine suspended particles.

3.2.1.3 *Clarification and flotation*

The particles of suspended matter carry negative electrical charges. These particles repel each other electrostatically and therefore remain dispersed. When added to the water, salts of aluminium or iron react with the alkalinity present (whether naturally present or deliberately added) to form precipitates with a positive electrical charge. These attract the dispersed particles and the charges are neutralized, a flocculant precipitate being formed. This can be settled out in a sedimentation unit/clarifier or floated off using micro bubbles of air in a flotation unit.

3.2.1.4 *Filtration*

Any insoluble material remaining can be removed by filtration. This is usually carried out by passing the water through a granular material such as sand. It is essential to clean filters periodically to prevent their becoming blocked by deposits; this is usually done by backwashing. For soluble manganese and iron removal, an aeration or chemical oxidation step should be included prior to filtration to convert them to insoluble compounds. Special types of filter media, such as activated carbon, are sometimes used to remove oil or other organic (carbon-containing) substances which could foul ion exchange resins or cause damage within the boiler itself.

3.2.2 Base exchange softening

This is the simplest of the water treatment processes and uses a strong acid cation exchanger in the sodium form. Calcium and magnesium ions in the raw water are exchanged for sodium ions on the resin. The resin, when exhausted, is regenerated by passing a concentrated solution of sodium chloride (common salt) through it. This method of regeneration gives rise to the alternative name of salt softener for this process. Virtually all the hardness is removed (the residual hardness is typically less than 5 mg/kg $CaCO_3$), but alkalinity is unchanged and dissolved solids slightly increased. The alkalinity in the form of the hydrogen carbonates (bicarbonates) will decompose in the boiler with the release of carbon dioxide. This will pass over with the steam and dissolve in the condensate, rendering it acidic and aggressive to pipework. Water containing high levels of alkalinity needs treatment to remove hydrogen carbonates.

3.2.3 Dealkalization

Dealkalization is usually accomplished by passing the water through a weak acid cation exchanger in the hydrogen form. Calcium and magnesium ions equivalent to the hydrogen carbonate content are exchanged for hydrogen ions. This converts the hydrogen carbonates to 'carbonic acid' (which may be considered as a solution of carbon dioxide in water) which is removed in a de-gassing tower by scrubbing with a countercurrent of air. The water leaving the exchanger can have an alkalinity of 0 to 20 mg/kg $CaCO_3$ consistent with a pH range 4.2 to 5.5 because of the presence of dissolved carbon dioxide. The dissolved solids content will be reduced by an amount equivalent to the alkalinity.

After degassing, the pH value of the water rises. The non-alkaline (permanent) hardness will remain unchanged and if this is less than 5 mg/kg $CaCO_3$ the water can be used without further treatment. If this is not the case, the water should be further treated by raising the pH value to 7.5 to 8.0 with sodium hydroxide followed by base exchange softening.

3.2.4 Two-stage demineralization

Demineralization, as its name implies, refers to the removal of virtually all mineral matter from the raw water. It is sometimes called de-ionization which is a misnomer, since all water, however pure, always contains a small amount of hydrogen and hydroxide ions.

The most common arrangement is a strong acid cation exchanger in the hydrogen form in series with a strong base anion exchanger in the hydroxide form, either with or without a degassing tower between them. Water passes first through the cation exchanger where it is converted to a solution of dilute acids. The partially treated water passes through the anion exchanger where the anions (chloride, nitrate, sulfate etc.) are exchanged for hydroxide ions. The hydrogen ions produced in the first stage react with the hydroxide ions produced in the second stage to produce water according to the equation:

$$H^+ + OH^- = H_2O$$

The resins are regenerated when exhausted. Cation resins are regenerated using dilute hydrochloric or sulfuric acids and the anion resin with dilute sodium hydroxide.

Lowest running costs and highest treated water quality are obtained if the resins are regenerated in the counterflow mode.

3.2.5 Two-stage demineralization with polishing

The last traces of impurities can be removed from a two-stage demineralized water by the use of a polishing unit. This is usually a mixed bed unit although cation polishers are sometimes used.

In mixed bed units the cation and anion resins are mixed in the same vessel. It is necessary to separate the resins before they can be regenerated. Regeneration is then carried out by the the same methods as described in the two stage demineralization process (see **3.2.4**).

Mixed bed polishers can be used to improve the quality of any water fed to them and are often used for condensate polishing (see **6.3**).

Cation polishers rely on the fact that virtually the only impurity contained in water produced from a counterflow regenerated two-stage unit is a trace of sodium hydroxide. Passing such a water through a strong acid cation resin in the hydrogen form causes the sodium ions to be exchanged for hydrogen ions. These react with the hydroxide ions to produce water.

3.2.6 Reverse osmosis (RO)

When solutions of differing concentrations are separated by a semi-permeable membrane, water from the less concentrated solution passes through the membrane until the concentrations of both solutions are equalized. A hydraulic pressure gradient thus builds up across the membrane. The process will continue until the hydraulic gradient is equal to the osmotic pressure, this being determined by the difference in concentration between the two solutions.

If a pressure greater than the osmotic pressure is applied to the more concentrated solution, the process is reversed. Water from the more concentrated solution is forced back through the semi-permeable membrane diluting the more dilute solution on the other side. The concentration of the stronger solution is thus increased. Water from the dilute side of the membrane passes to service while that from the concentrated side is either run to waste as brine or used for low grade purposes. This process is termed reverse osmosis (RO).

This treatment is capable of removing up to 90 % of dissolved solids dependent upon the age of the plant and its operating parameters. Further treatment is required if water of demineralized quality is to be produced.

Water containing high levels of hardness should be pre-treated prior to being fed to the RO membranes to prevent them becoming fouled with calcium salts or other foulants.

3.2.7 Electrodialysis

Electrodialysis employs thin flat sheet membranes of ion exchange materials placed one on top of the other and separated by spacers to allow a free flow of water between them. The pack of cells is arranged with alternate cation and anion exchange membranes, between end plates across which a d.c. voltage is applied.

When the d.c. voltage is applied, the cations in the water between the membranes migrate towards the negative electrode through the cation exchange membranes, and the anions migrate towards the positive electrode through the anion exchange membranes. As the membranes are arranged alternately cation and anion, the ions that have migrated from one cell cannot enter the next cell because the membranes are impermeable to them. Hence the ions that have migrated concentrate in the spaces between the cells and are rejected as brine while partially demineralized water is taken off from within the cells.

The applications for electrodialysis and the quality of water produced are similar to those for reverse osmosis.

Section 4. Removal of gaseous impurities

4.1 General

As cold feed water usually contains significant levels of corrosive gases, mainly carbon dioxide and oxygen, their concentration on entering a boiler should be controlled to limit corrosion. This control should be achieved by either physical or chemical treatment or more commonly by a combination of both. Some form of simple mechanical de-aeration, e.g. contact heater or feed tank should considerably reduce chemical treatment costs for low pressure plant. However, high pressure plant will require vacuum or pressure de-aeration which should be capable of giving feed water with less than 0.01 mg/l dissolved oxygen. Corrosive gases dissolved in water can be removed by either physical or chemical means, but when selecting the method to be adopted consideration should be given to the economics of operation. Physical de-aeration usually has a higher capital charge but should have a lower operating cost, therefore some form of physical de-aeration is usually practised prior to chemical de-aeration.

4.2 Physical de-aeration

Physical removal of corrosive gases is achieved by the application of Dalton's and Henry's laws. These laws govern all forms of physical de-aeration from simple feed tanks to pressure de-aerators. Each gas in a mixture exerts a partial pressure; the sum of the partial pressures equals the total pressure. The solubility of gases in a liquid is proportional to their partial pressures (Dalton's Law). If the concentration of oxygen in the gas over the surface of the water is reduced by replacing it with steam, the concentration in water should be reduced, provided that adequate venting and equilibrium is allowed. To accelerate the establishment of the new equilibrium, agitation and a large contact area should be provided, nevertheless, some residual dissolved gases will remain in the water, dependent on the type and design of de-aeration equipment.

Ammonia and carbon dioxide are especially difficult to remove by physical de-aeration since their solubilities in water are influenced by the formation of chemical compounds with the water.

Henry's Law states that the solubility of gases is inversely proportional to temperature (see figure 4) and therefore heating of feed water should reduce the solubility, provided adequate time and opportunity for equilibration is allowed. Suitable de-aeration should be achieved, dependent on the duty required of the water, by a correctly designed feed tank or hot well (see **7.1**), pressure or vacuum de-aerators.

Under suitable conditions, when water is passed from a higher to a lower pressure, the temperature of the water will exceed the boiling point at the lower pressure and vapour will be formed.

This principle is used in the flash-type de-aerator to de-aerate hot water. Such flash vessels can also be applied with advantage in condensate recovery systems.

Specialized low temperature, de-aeration equipment utilizing nitrogen gas in place of steam can also be used.

4.3 Chemical de-aeration

There are several commonly used oxygen scavengers and there can be limitations or advantages in their application to a particular system. The reaction rate of all oxygen scavengers is dependent on feed water temperature and pH value.

Chemical oxygen scavengers should be used as the second stage of de-aeration to remove residual levels of dissolved oxygen. They can be divided into two groups: those that are totally volatile and those that are non-volatile. Examples can be found in tables 1 to 7 with recommended control values; they are discussed in **5.3.2**.

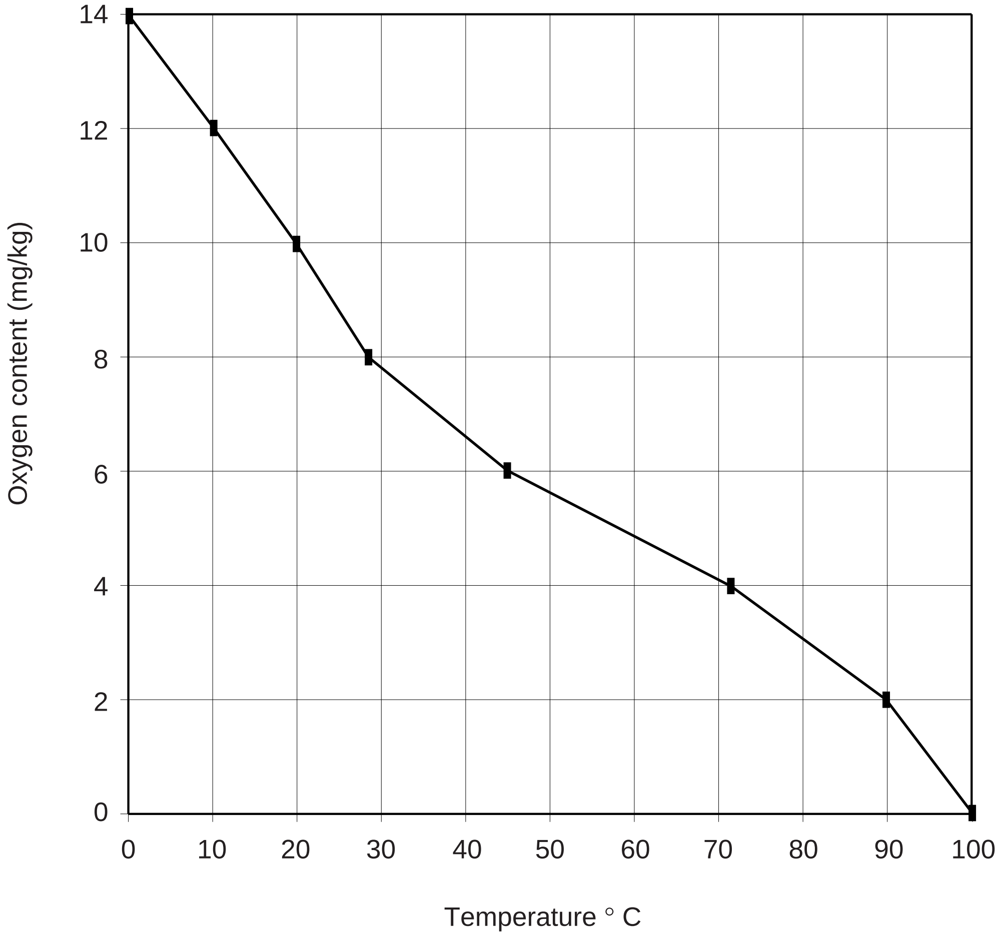


Figure 4. Variation in the concentration of dissolved oxygen in water with temperature

Section 5. Boiler water conditioning

5.1 General

In addition to adequate pre-treatment (see **3.2.1**) controlled reserves of treatment (conditioning chemicals) should be maintained within the boiler water to ensure that the water will remain non-corrosive and that any traces of deposit-forming chemicals such as salts of calcium or iron are prevented, as far as practicable, from forming hard scales or baked on sludges. A complete water treatment programme should include adequate external treatment including, if necessary, de-aeration, an oxygen scavenger, a corrosion control alkali, a precipitant, a sludge dispersant and condensate line treatments. Additionally, it is considered essential to control the level of dissolved solids in the boiler water. This is the most critical parameter for regular and effective control of boiler water chemistry.

Tables 1 to 7 recommend the control parameters that should be maintained in order to minimize corrosion and deposition.

It has been common practice to monitor total dissolved solids in boiler water by applying a conversion factor to a conductivity measurement on a neutralized sample. Since automatic blowdown control equipment can only measure un-neutralized conductivity, confusing discrepancies arise. It is therefore recommended that all control and monitoring of dissolved solids in boiler water be carried out on un-neutralized samples. The exact relationship between conductivity and total dissolved solids can be determined if desired.

5.2 Control of concentration of solids in boiler water

5.2.1 General

When water containing dissolved impurities is boiled and the vapour (steam) is driven off, the solids remain and concentrate in the bulk of water; thus the dissolved solids content increases. If the evaporation is continued some of the impurities will come out of solution as scale or as suspended solids.

In boiler design it can be difficult to prevent the entrainment of small amounts of boiler water with the steam. This entrainment will normally increase with continuing concentration of dissolved and suspended solids and alkalinity. In order to limit the amount of solids in the steam the alkalinity, conductivity and suspended solids should be controlled in the boiler water.

The steam purity and the cleanliness of the heating surfaces in some types of boiler, where steam is generated from a bulk of circulating boiler water, should be controlled by limiting the conductivity in the boiler water. This can be achieved by removing a portion of the solids concentrating in the boiler water (by ‘blowing down’) and replacing this lost water with feed water. Blowdown is wasteful of heat and treated water but, especially in boilers of conservative design working at low or medium pressures, it can be a cheaper alternative than the provision of extremely pure feed water. In practice, it should be recognized that one of the several impurities in the boiler feed water can be critical with respect to its concentration in the boiler water.

The following are examples:

a) the conductivity: this should be restricted to maintain steam purity and keep sodium salts in solution;

b) alkalinity: the level of alkalinity should be limited to maintain steam purity and minimize caustic attack;

c) silica: the silica content should be restricted to limit the level of silica in the steam or the formation of silicate scales in the boiler;

d) chloride: in high pressure boilers the level of chloride ion should be limited to minimize corrosion;

e) suspended solids: these should be restricted to below that at which adherent deposits form, otherwise steam purity or circulation are impaired.

At pressures greater than 40 bar some solids have a significant solubility in steam. In once-through boilers, in which all the water entering is converted to steam, the cleanliness of the heating surfaces should be maintained by controlling feed water purity.

NOTE. It is necessary that the installation and operation of blowdown systems meet certain requirements of the Health and Safety at Work etc. Act 1974. [5] operation of blowdown valves in certain positions on the boiler should be followed.

5.2.2 Continuous blowdown

This is the continuous removal of boiler water, controlled by a specially designed adjustable valve or orifice plate, which can become blocked or eroded by suspended solids. Continuous blowdown is therefore usually limited to the control of dissolved solids. Suspended solids, which may otherwise form sludge, should be controlled by additional manual blowdown from the lowest point of the boiler (see **5.2.3**.)

If economically justifiable, consideration should be given to the installation of heat recovery equipment.

5.2.3 Intermittent blowdown

Intermittent blowdown can be effected by specially designed valves either operated by hand or controlled automatically, for example, by timers, feed water flow or conductivity. Where automatic valves are installed the manual blowdown valves should be operated at intervals to ensure that the latter are clear. It should be noted that the most effective and economic use of all types of intermittent blowdown valve is achieved by frequent full-open operation for short periods rather than extended use at infrequent intervals, and that it is usually not practicable to recover waste heat from infrequent intermittent blowdown.

5.2.4 Calculation of continuous blowdown

This formula should be used to estimate the minimum quantity of water that should be removed from a boiler during blowdown, where:

B is the blowdown rate as a percentage of the evaporation rate;

S is the solids content of feed water (in mg/kg) (see note 2 and **5.1**);

C is the maximum permitted concentration of solids in boiler water (in mg/kg).

The formula should be applied only when the solids content of the feed water is reasonably constant and is measurable by conventional means.

$$B = \frac{100S}{(C - S)}$$

NOTE 1. This formula is based on steady load conditions and on the assumption that priming and carryover conditions are absent or negligible. It is also assumed that the feed water treatment is such that all the dissolved solids in the feed water remain in solution in the boiler and do not precipitate as scale or sludge.

NOTE 2. When calculating blowdown on the basis of dissolved solids it is essential to make allowance for the effect of the addition of treatment chemicals to the water.

NOTE 3. When considering new water treatment plant, or alternative feed waters, the blowdown required should not exceed the allowance made for it in the boiler plant design.

5.3 Prevention of corrosion

5.3.1 General

Corrosion in steam boilers can be minimized by two strategies:

a) by ensuring that there is an adequate but controlled alkalinity reserve in the water at all times;

b) by ensuring removal of dissolved gases by means of a physical deaerator, an adequately designed feed tank (see **7.1**), a suitable reserve in the feed water of a chemical oxygen scavenger, or a combination of these.

It should be noted that the water condition serves to maintain the protective magnetite film on the internal surfaces of the boiler.

As temperature or heat flux density increases, however, thermal and mechanical stresses make the protective film more susceptible to disruption, which can be aggravated by localized concentration of salts at the heat-transfer surfaces as a result of steam generation or an accumulation of deposits. In this way the metal can be exposed to concentrations of salts many hundreds of times greater than those in the bulk of the water. In such circumstances chloride ions are able to penetrate beneath any deposit, or what would normally be a protective film, producing localized acidic conditions. Hydrogen is then produced, causing a form of weakening known as hydrogen embrittlement. Boiler tube failure in these conditions takes the form of longitudinal splitting or the blowing-out of a piece of the tube metal.

For these reasons, deposits should be prevented and chlorides minimized (less importantly sulfates) at high operating pressures, as specified in table 3 and the accompanying note 7.

Metallic copper and nickel have been frequently found in corrosion products and although the significance of their presence as metals is not fully understood, these elements should be minimized in the feed water to boilers operating with high heat flux densities (see tables 3 to 6).

Hydroxyl ions, at high temperatures or at high heat densities, can also become damaging because of localized concentration effects, leading to dissolution of iron as sodium ferroate (sodium hypoferrite), which is soluble and hence non-protective. Again, hydrogen is liberated, but tube failure usually results from wastage of the metal.

In high pressure boilers high localized concentrations of mineral alkalis should be avoided. At steam generating surfaces, however, volatile alkalis will be present, mainly in the gaseous phase, but they will be inadequate to neutralize the acidity arising from dissolved chlorides, therefore the ingress of chlorides should be minimized.

Local concentrations of sodium hydroxide can also be avoided by adjusting the boiler water pH value with sodium phosphate so that no free sodium hydroxide is formed even in the event of complete evaporation.

Two methods of achieving this exist and are known as ‘coordinated phosphate’ and ‘congruent phosphate’ conditioning. Either method can be employed and they are discussed further in **5.3.5** b).

These methods have been successfully used to prevent caustic cracking (see **5.3.4**) and caustic attack but they can be unsuitable for boiler waters containing silica. The relatively low pH values would increase the steam-volatility of the silica (see figure 2) and there would be no free sodium hydroxide to keep silica in solution. Silicate scale formation can, therefore, be a problem.

Where the feed water is demineralized and the dissolved solids in the boiler water are derived almost entirely from the concentration of non-volatile conditioning chemicals used for corrosion control, the process is commonly known as ‘low solids treatment’. Where volatile conditioning chemicals are used with demineralized feed water, in order to maintain a virtual absence of solids in the boiler water, the process is known as ‘all volatile treatment’ (AVT) or ‘zero solids treatment’. It is essential to use this form of treatment for once-through boilers since any solids in the feed water would otherwise appear in the steam causing superheater and turbine deposits.

Strategy b) can also be used for the primary circuit of hot water heaters provided that an excess of chemical oxygen scavenger is maintained at all times. The oxygen scavengers most commonly used are sodium sulfite, hydrazine or tannin (see table 1).

The alternative approach is to use proprietary inhibitor blends. Such blends can contain nitrite/borate, zinc salts, polyphosphates, phosphonates, molybdates or benzoates. Inhibitor blends should only be used where they are unlikely to cause environmental problems; chromates, which were once widely used, should not be employed owing to their high toxicity.

It is essential that the concentration of inhibitor in the water be maintained in accordance with the manufacturer's instructions. The use of inhibitor blends, as detailed in the above paragraph is not recommended for HTHW systems.

5.3.2 Oxygen scavengers

5.3.2.1 *General*

A wide variety of chemicals can be used as oxygen scavengers, and they can be broadly divided into non-volatile and volatile chemicals, examples of which are:

non-volatile — sodium sulfite, tannins

volatile — hydrazine, diethyl hydroxylamine (DEHA) and carbohydrazide

To ensure that the iron oxide film on the inner wetted surfaces of the boiler is protected and enhanced, it is essential that good de-aeration and an adequate alkalinity be maintained at all times. The stable oxide of iron is magnetite which is most stable between pH values of 8.5 and 11.0; consequently feed and boiler waters should be maintained within this range by operating within the values given in tables 1 to 7.

5.3.2.2 *Non-volatile oxygen scavengers*

a) Sodium sulfite

Sodium sulfite reacts slowly with oxygen to form sodium sulfate. A catalyst, usually a cobalt salt, is added to ensure that the reaction is complete before the feed water enters the boiler. Sodium sulfite reacts stoichiometrically with oxygen, 8 mg/kg Na_2SO_3 being required for every 1 mg/kg oxygen.

Sodium sulfite should not be used at high temperatures or at pressures greater than 60 bar since at these temperatures and pressures it will decompose producing sulfur dioxide or sulfides.

b) Tannin

Tannins in alkaline solution liberate sodium pyrogallates which are effective oxygen scavengers. Tannins are natural polyphenolic products derived from plant materials, mainly tree barks. Quebracho tannin has the best oxygen scavenging properties but commercial blends can combine a mixture of a number of tannins. Synthetic tannins and lignosulfonates containing sugars should be avoided. The amount of tannin to be added should be determined for the blend in use, and a small reserve of unoxidized tannin should be present in the boiler water to prevent corrosion.

In the presence of ferrous metals and copper, tannins react to give corrosion inhibiting films which should make them particularly suitable for protecting feed systems operating at temperatures below 50 °C. Tannins can also be used for the protection of idle or intermittently used boilers (see section **8**). High temperatures or high heat flux should be avoided because the tannins can decompose to give corrosive products (see tables 2, 3 and 4). In addition, tannins can also act as sludge conditioners.

c) Iso ascorbic acid (erythorbic acid)

Typically this is used as the ammonium salt in boiler water applications. It is of low toxicity and compares favourably in efficiency with sodium sulfite. Its application cost can be higher than other treatments and it does have some passivation properties to carbon steel. It reacts stoichiometrically and therefore requires 10 mg/kg iso ascorbic acid for each 1 mg/kg of oxygen.

5.3.2.3 *Volatile oxygen scavengers*

a) Hydrazine

Hydrazine reacts with oxygen at feed water pH values to produce nitrogen and water. Hydrazine also reacts with ferrous metal oxides to give a magnetite film.

In practice the reaction rate can be speeded up at temperatures exceeding 80 °C by the use of quinones. Hydrazine is toxic and is a suspected carcinogen. 1 mg/kg hydrazine reacts with 1 mg/kg oxygen.

b) Diethylhydroxylamine (DEHA) (N,N'-diethylhydroxylamine)

DEHA has a low toxicity and slowly reacts with oxygen to produce acetaldehyde at low pressures and acetaldoxime at pressures over 70 bar, together with traces of acetate. It reacts with ferrous metal oxides to give a magnetite film.

DEHA is volatile with the steam and thus acts as an oxygen scavenger in the full water/steam/condensate cycle. 2.8 mg/kg of DEHA is required per 1 mg/kg of oxygen.

c) Carbohydrazide (carbonohydrazide)

Carbohydrazide is a low volatility source of hydrazine. It reacts in a similar way but when heated liberates carbon dioxide and hydrazine.

d) Methylethylketoxime (MEKO) (ethylmethylketoxime, butanone oxime)

MEKO is a low toxicity volatile oxygen scavenger which breaks down to form a range of carboxy compounds in proportions that vary with pressure.

5.3.3 On-load corrosion

As the pressure of generated steam increases, the associated water temperature and the tolerance of the boiler metal to aggressive conditions decreases. Therefore, in higher pressure boilers which are usually of the drum variety, much higher feed water quality and lower allowable levels of impurities are necessary.

Above 60 bar, on-load corrosion becomes a significant hazard due to the solubility of magnetite in hot dilute sodium hydroxide solutions and also due to the aggressive nature of chloride ions; therefore strict control of the feed alkalinity and the alkalinity to chloride ratio should be considered essential to ensure freedom from this form of corrosion. Adherence to the values in table 3 and the associated note 7 should ensure prolonged service life of high pressure plant.

5.3.4 Caustic cracking

5.3.4.1 *General*

This type of failure most commonly occurred in boilers of riveted seam construction. The advent of all-welded, stress-relieved boilers has drastically reduced the incidence of this type of failure.

This is a form of stress corrosion cracking typified by the attack on carbide particles at grain boundaries and is most commonly associated with rivet holes, tube expansions and other high-stress points. The most common agent which produces this effect is the hydroxide ion OH^- which is normally present as sodium hydroxide (caustic soda).

Typically a local hydroxide ion concentration of 50 000 mg/kg is likely to bring about this condition and it is usually found in places where boiler water can leak and flash off as steam leaving behind a highly concentrated solution of sodium hydroxide.

5.3.4.2 *Prevention of caustic cracking*

Congruent phosphate treatment (see **5.3.5**b)) should ensure that there are no free hydroxide ions in solution. This gives protection against caustic cracking. It should be noted that this procedure cannot be used where phosphate hideout is known to occur. Traditionally, maintenance of a ratio of $Na_2SO_4 : NaOH$ of 2.5 : 1 or a ratio of $NaNO_3 : NaOH$ of 0.4 : 1 has been used to control this phenomenon. Certain tannins can also be used.

It should be realized that any such cracking, once initiated, cannot be prevented from extending even by correcting the water condition. Any boiler with a persistent history of leakage should be examined by a competent person using appropriate non-destructive inspection techniques.

5.3.5 Caustic gouging

This form of caustic corrosion is known to occur in water tube boilers of high heat flux. It should not be confused with caustic cracking, as the mechanism is different and it is not stress related. Where deposits are present in high heat flux water tube boilers, sodium hydroxide in the boiler water can concentrate beneath the deposit, particularly where film boiling is taking place. Concentration of sodium hydroxide can also occur in conditions of hideout (see **5.5**). The concentrated solution dissolves iron as an alkaline salt so that the metal is eventually thinned to a point to which it cannot withstand the boiler operating pressure and failure occurs. The tube metal bulges and can eventually burst. One of the two following categories of treatment should be used to control caustic attack:

a) All-volatile treatment. This avoids the use of sodium hydroxide by using volatile compounds which cannot concentrate under deposits. Hydrazine and ammonia have been used for many years. Hydrazine can be replaced by one of the hydrazine substitutes (see **5.3.2**) and ammonia can be replaced by a suitable neutralizing amine (see **6.1.3**). Corrosive anions, particularly chloride, should be minimized in the boiler water, by for example, condensate polishing or avoiding contamination caused by leaking of water-cooled condensers.

b) Coordinated phosphate and congruent phosphate treatment. If all the alkalinity in the boiler water is present as sodium phosphate, then free hydroxide ions will be absent. The term coordinated phosphate refers to the use of a molar ratio of $Na : PO_4$ of 3 : 1. The term congruent phosphate refers to the maintenance of a molar ratio of sodium to phosphate of 2.6 : 1. These refer to trisodium phosphate and disodium monohydrogen phosphate respectively. By utilizing the chart shown in figure 5 and controlling boiler water pH and phosphate in accordance with the chart, these conditions should be achieved.

Congruent phosphate is preferred, as studies have shown that crystals deposited from trisodium phosphate solutions contain some disodium hydrogen phosphate and the supernatant liquid contains sodium hydroxide. This form of treatment should be used only where demineralized or other water with very low silica levels is available.

NOTE. Coordinated or congruent phosphate treatment is not advisable when phosphate hideout is known to occur. The causes of this phenomenon are not clearly understood, but it is demonstrated by the loss of phosphate from the boiler water when the load is increased, and its reappearance when the load is decreased. In itself it may not be harmful, but it has been linked with corrosion. In these circumstances the all-volatile approach should be used.

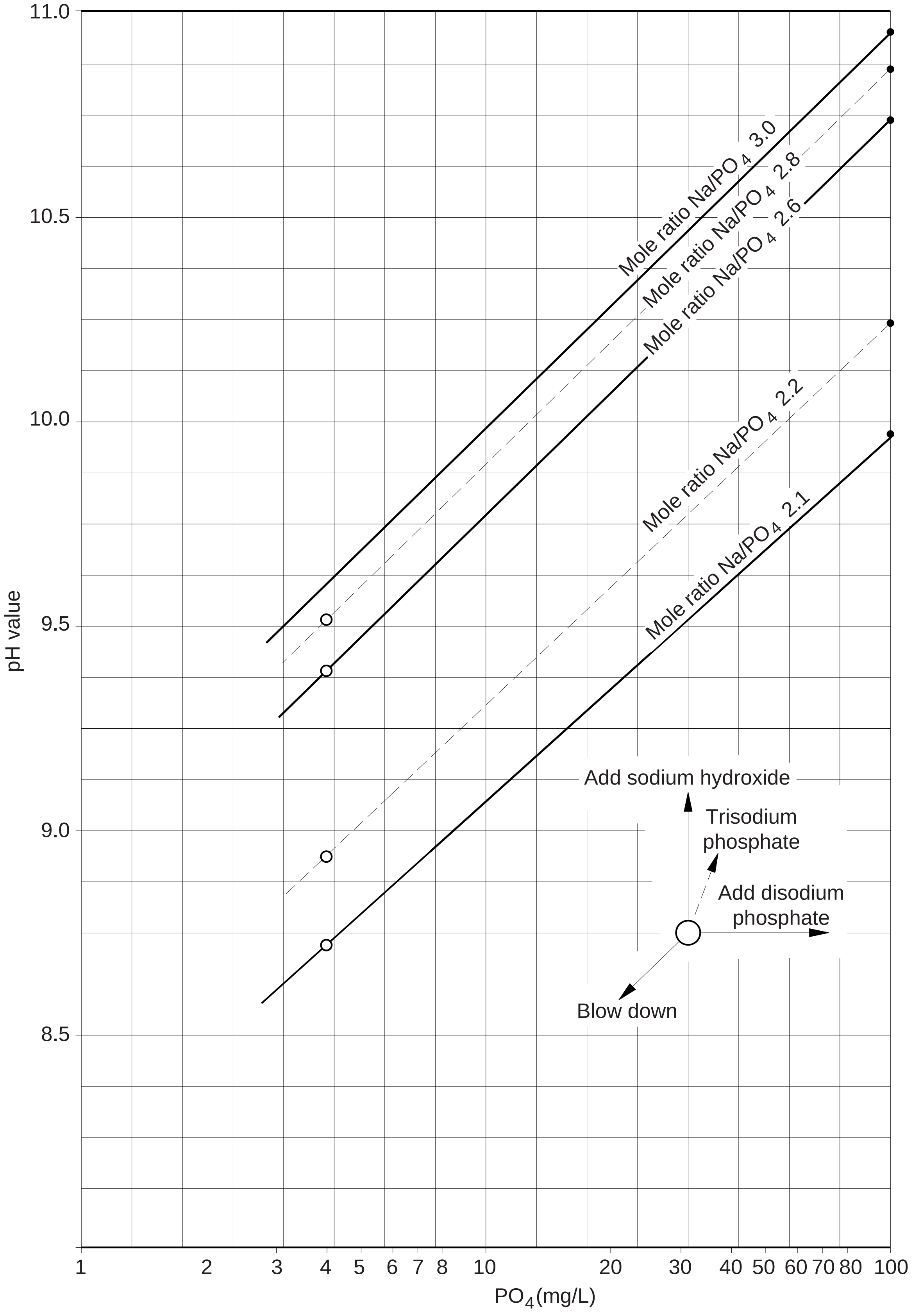


Figure 5. Coordinated and congruent phosphate treatments

5.4 Prevention and control of deposition in boilers

5.4.1 General

As with corrosion control, the dual approach of adequate pre-treatment and correct chemical control is essential, as deposits in boiler systems originate only from the feed water or feed system. Corrosion products from the condensate system can also contribute to boiler deposition and condensate system corrosion should be controlled.

Scale formation in boilers up to 10 bar operating pressure can be minimized by adopting one of two principal treatment types based on maintaining a controlled reserve of either carbonate or phosphate in the boiler water. In either case, in addition to adequate pre-treatment (see section **3**), the use of sludge-conditioning chemicals is recommended.

5.4.2 Carbonate control

If a minimum carbonate alkalinity of 250 mg/kg as $CaCO_3$ is consistently maintained, a reserve of soluble phosphate need not be maintained in boilers operating below 10 bar.

An excess of carbonate ion should be maintained in the boiler water sufficient to precipitate calcium hardness as calcium carbonate in the boiler water, rather than upon surfaces. This can be obtained by the use of sodium ion exchange (base exchange) softening of a hard make-up water. Scale formation can be minimized by the use of appropriate polymeric conditioning chemicals, such polymers acting as weak chelating agents and thus retaining hardness salts in solution in the boiler water.

A disadvantage of carbonate control is that natural carbonates introduced to the boiler water via the feed readily decompose to carbon dioxide and sodium hydroxide and, although the sodium hydroxide is beneficial, the carbon dioxide can cause severe corrosion in the condensate system.

NOTE. Typically sodium carbonate will be 50 % decomposed at 6 bar and 80 % decomposed at 10 bar.

5.4.3 Phosphate control

This treatment requires that a controlled reserve of soluble phosphate and alkalinity should be continuously maintained in the boiler water (see tables 2 to 5).

The phosphate can be derived from sodium phosphate or condensed phosphates, the latter being useful in preventing precipitation of trace levels of hardness salts in the feed system.

Should hardness salts be precipitated in the boiler as a sludge composed of basic calcium phosphate (hydroxyapatite), it can be rendered free-flowing with an appropriate conditioning polymer and, provided a sufficient alkalinity is maintained, magnesium will be precipitated as magnesium hydroxide.

NOTE. Magnesium phosphate precipitation can be prevented by operating with a PO_4 to caustic alkalinity ratio of 1 : 10. The phosphate cycle operates best when the caustic alkalinity of the boiler water is 10 % to 15 % of the dissolved solids. Under these conditions, magnesium will precipitate as magnesium hydroxide and, if sufficient silica is present, as magnesium silicate; neither of these is adherent.

5.4.4 Silicate scale prevention

Silicate scales can easily be formed in boilers at moderate temperatures and pressures. They are particularly likely where the feed water silica content is a high proportion of the dissolved solids and the feed alkalinity is low.

Due to their tenacious nature and low thermal conductivity, silicate scales can be particularly damaging and should be prevented by adopting all of the following measures:

- – adequate pre-treatment;
- – maintenance of an adequate phosphate or carbonate reserve;
- – maintenance of a silica: caustic alkalinity ratio of 0.4 : 1;
- – limitation of the boiler water silica level (table 3).

5.4.5 Polymeric chemicals for deposit control

Scale formation can be minimized by the use of an appropriate polymeric conditioning chemical. In the past, natural polymers such as starch and tannins were used, but many synthetic polymers have now been produced to control deposits of calcium carbonate, calcium phosphate, iron oxide, silicates and silica in boiler conditions. These are generally based on acrylic acid (ethenoic acid) but other co-monomers can be included to control more difficult deposits. The design and synthesis of these polymers is probably the most significant advance in boiler water conditioning in the last 20 years.

The performance of these chemicals is now such that it is possible to use them to transport deposit-forming substances through the boiler during normal operation. They will then be discharged via the blowdown without precipitation.

The use of this type of conditioning is dependent on the following:

a) good external pre-treatment, so as not to put an excessive demand on the chemicals;

b) good analytical control to ensure that adequate polymer levels are maintained; and

c) conformity with the suspended solids requirements given in table 2.

5.5 Hideout

In water-tube boilers it is sometimes observed that, when the load on the boiler is increased, the concentration of certain soluble salts in the bulk of the boiler water does not increase at the same rate as that of other soluble salts. The apparent loss of these normally soluble salts is called 'hideout' and is characterized by their reappearance in the bulk of the boiler water when the load is subsequently reduced. This reappearance is often the first confirmation that the phenomenon has occurred. The physical circumstances under which hideout occurs are not fully understood. Relevant factors include localized heat flux, rate of circulation, tube diameter, the slope of the tube, surface roughness and the presence of deposits.

Addition of extra treatment chemicals to the boiler water to maintain required levels should be made only after due consideration of the cause of the loss of chemicals.

Hideout is particularly marked when sodium phosphate is used owing to its rapidly decreasing solubility at temperatures above 250 °C, so that should the load on the boiler increase, the equilibrium conditions change and more and more sodium phosphate is precipitated on the heat-transfer surface.

Should hard water contaminate the feed water during hideout, a reduction in the phosphate level in the boiler water might not show until several hours later since, as the hardness removes the phosphate in solution, the precipitated sodium phosphate may redissolve to restore the equilibrium condition.

Although the solubility of sodium hydroxide does not decrease with increasing temperature, it can be subject to hideout in the form of a concentrated solution at the heat-transfer surfaces. Concentrated solutions of sodium hydroxide will cause corrosion of mild steel at high temperatures (caustic gouging).

Sodium sulfate and sodium silicates also show hideout characteristics and their presence should be considered undesirable in high pressure boilers.

If it is not possible to confirm the condition by reducing the load on the boiler, analysis of water and steam samples to obtain a sodium mass balance across the boiler should help to identify hideout and assess its extent.

If hideout occurs, it can indicate a condition that could lead to boiler failure. The use of sodium phosphate or sodium hydroxide as a primary alkali is not advisable. Phosphate should not be employed at pressures above 130 bar except in emergencies. With volatile alkali treatment in boilers operating at pressures greater than 100 bar, sodium phosphate should be considered for use in limited amounts as a safeguard against adventitious scale-forming impurities and chlorides from condenser leakage. As an alternative, sodium hydroxide can be used as a short-term palliative to combat trace chloride ingress.

5.6 Once-through boilers

In order to prevent scaling and deposition, once-through boilers should be supplied with a feed water containing no solids that would produce a dry residue on evaporation.

The condition given in table 5 should be generally acceptable for normal continuous operation, although higher values can be tolerated for short periods, such as during start-up. Permissible deviation from the values given should be based on the plant design, e.g. the diameter of boiler tubes, the provision for blowing down and the extent and nature of condensate polishing.

The values given should generally permit operation for at least three years before acid cleaning is required. Guidance on whether cleaning is necessary should be obtained from regular analysis for solid matter entering with the feed water. The continuous conversion of the tube surface to magnetite can be equally important in determining the frequency of acid cleaning. As magnetite is less dense than steel the tube bore is reduced. This build-up can cause a significant increase in pressure drop over the unit, requiring a higher feed water inlet pressure to maintain the same outlet conditions.

In consequence, the concentrations of solid matter in the feed water should be kept within strictly regulated limits and the dosing of volatile chemicals for adjustment of pH value should also be precise, with no excessive overdosing.

The feed water should be continuously dosed with a volatile oxygen scavenger. Ammonia or a neutralizing amine should be added to raise the pH value of the feed water to the recommended range.

5.7 Method of dosing boiler water conditioning chemicals

5.7.1 General

The method used for dosing particular chemicals and their solutions to boiler water systems depends upon the following factors:

a) the function of the chemical;

b) the quality of the feed water;

c) the individual boiler system, particularly where economizers and pre-heaters are installed.

Pumps used for chemical dosing should be of adequate capacity and manufactured from materials which are not affected by the chemicals they handle.

The quality of water used for mixing and diluting chemicals and the solution concentrations should be as recommended by the suppliers.

5.7.2 Oxygen scavenging chemicals

These should always be dosed continuously. The feed point should be selected so that it gives the maximum possible time for reaction. This will normally mean dosing to the storage section of the de-aerator or, where there is no de-aerator, to the outlet of the boiler feed tank/hot well.

Solutions of catalyzed sodium sulfite or sodium hydrogen sulfite should not be mixed with other chemicals as these can deactivate the catalyst. Hydrazine should be handled in a totally enclosed pressurized feed system so that the liquid or its vapour cannot come into contact with the surrounding area or personnel.

5.7.3 Neutralizing amines

These should be dosed continuously into the storage section of the de-aerator or, where there is no de-aerator, into the suction side of the feed pump. Dosage may be made into the boiler feed tank provided it is adequately covered.

5.7.4 Phosphates

Where there are no economizers or pre-heaters and the feed water quality meets the recommendations of this standard, phosphates can be dosed into the system without risk of undue deposition. Dosage should be continuous or intermittent to meet the phosphate requirements of tables 2 to 4.

Where economizers or pre-heaters are fitted, phosphates should be dosed directly into the boiler drum or shell at a point below the waterline. Boilers will normally be supplied with fittings to permit this and the advice of the boiler manufacturers should be followed. Where there is more than one boiler, one solution tank can be used with a multiple-headed pump.

5.7.5 Sludge conditioners

These compounds are normally mixed with other chemicals and do not require separate dosing facilities. If they are utilized separately, they should be dosed continuously to a convenient location in the boiler feed system as recommended by the chemical treatment suppliers.

5.7.6 Chelating agents

These compounds are corrosive to feed pumps in the presence of dissolved oxygen. They should be dosed continuously to the delivery side of the feed pump and as far downstream as possible from the oxygen scavenger feed point.

Section 6. Condensate treatment and purification

6.1 Condensate treatment

6.1.1 General

The corrosive effect of condensed steam is caused by the presence of dissolved oxygen and/or carbon dioxide. These can be derived from the feed water but can also be drawn into the system at later stages. One of two chemical treatment methods can be used to reduce this corrosion.

6.1.2 Filming amines

These are compounds which form a non-wettable film on the metal surfaces as the steam condenses. This film acts as a barrier to the corrosive condensate. The dosage rate required to maintain the film will vary with the length and complexity of the system but should normally be in the range 0.5 g to 3.0 g per tonne of steam.

Octadecylamine has been the most widely used compound, although some secondary and tertiary amines have also been used. High pressure pumps should be used to inject the amine into the steam main or boiler drum.

If overdosed, this type of amine has shown a tendency to form sticky deposits when combined with corrosion products.

6.1.3 Neutralizing amines

Increasing the pH value of the condensate to a point where free carbon dioxide is absent greatly reduces its corrosive tendency. Volatile neutralizing amines can be used to increase pH values.

The pH value should be maintained in the range of 8.3 to 9.2. Below this range free carbon dioxide can be present and at values above 9.2 copper alloys material can be attacked.

Several organic amines can be used for this purpose. The selection of the most appropriate amine or blend of amines depends partly upon the distribution ratio which is the extent to which the amine distributes itself between steam and condensate.

A low ratio indicates that the amine is of low volatility and will distribute itself preferentially in the condensate. A high ratio signifies high volatility and the amine will be distributed preferentially in the steam.

Amines with low distribution ratios are most appropriate for the initial and hottest stages of the condensing system, while those with high distribution ratios are best suited to the cooler end. Complex systems can require a blend of amines of differing distribution ratios. The amines most commonly employed are shown, together with their distribution ratios, in table 8. Ammonia has been included for comparison, but it is not widely used owing to its high volatility and its propensity to attack copper alloys, particularly in the presence of oxygen. Diethyl hydroxylamine (DEHA) can also function as a neutralizing amine in addition to its use as an oxygen scavenger.

Table 8. Some neutralizing amines with their distribution ratios

Amine	Distribution ratio at 1 bar
Ammonia	10.0
Aminomethylpropanol	0.1
Cyclohexylamine	2.0
DEHA	1.3
Diethylaminoethanol	1.0
Dimethylaminoethylpropanol	1.4
Dimethylaminopropanol	1.7
Morpholine	0.4

Neutralizing amines should be dosed continuously to the boiler feed system, preferably downstream of mechanical de-aerators.

6.1.4 Testing

The performance of condensate treatment chemicals should be monitored by direct measurement of corrosion rates utilizing corrosion coupons placed in the flowing condensate or by analysis of the condensate for corrodible metals.

6.2 Condensate contamination by oil

Every effort should be made to avoid contamination of feed water by oil. Condensates containing oils should be rejected for the following reasons:

a) vegetable oils introduced into alkaline boiler water are usually converted into soaps which can rapidly form a stable foam on the surface of the boiler water and can lead to severe contamination of the steam. Where this risk exists, continuous addition of an anti-foam is prudent even when contamination is not apparent;

b) mineral oil introduced into the boiler can form non-wettable films on heat-transfer surfaces and interfere with the detachment of steam bubbles so that the surfaces are inadequately cooled by the boiler water. As a consequence severe corrosion or overheating failure of such surfaces can occur. This may be a particular problem when steam is used to drive prime movers. Lubricating oil can be introduced and remain in the returned condensate, leading to build-up on the heat-transfer surfaces and consequent overheating;

c) if sludge in a boiler absorbs oil it can become less mobile and obstruct circulation. Similar obstruction can occur in condensate lines and steam traps owing to the presence of oil which is carried forward with the steam.

Vegetable and mineral oils cannot usually be removed by plant commonly employed for treatment of the make-up water.

6.3 Condensate polishing

Condensate polishing should be used to purify condensate in order to meet the quality requirements for high pressure and once-through boilers. This is employed where condensate is the major portion of the feed water, for example, in boiler plant used for power generation.

There are two specific types of impurity which should be removed:

a) corrosion products: the oxides of iron, copper and nickel, which can be both particulate and in solution, and can occur at particularly high levels during start-up conditions;

b) those arising from leakage of condenser cooling water into the condensing steam system.

Removal of suspended corrosion products should be effected by filtration of the condensate, by means of pre-coat filter or cartridge, and this can be all that is required in some cases. Where transport of corrosion products is excessive during start-up, then the filters need only be operated at that time.

Removal of soluble corrosion products and more especially contamination introduced by way of condenser leaks, requires the use of demineralizers which will frequently be used to polish the whole of the condensate flow. Usually these demineralizers should be of the mixed bed type although separate resin beds in a cation/anion/cation sequence can be used.

NOTE. Modern design and resin technology have made it possible for the demineralizers to be used for removal of particulate corrosion products, although older designs used preliminary filters upstream of the demineralization units.

In order to prevent any likelihood of contamination of the condensate by regenerant, the ion exchange resins used in the demineralizer should not be regenerated in situ, but hydraulically transferred to external regenerator units.

Regeneration should be carried out as with normal resins, commonly using dilute acid and alkali, and once regenerated, the resins can be held in a storage vessel for future use or transferred back to a condensate treatment vessel.

Section 7. Corrosion and deposit control

7.1 Feed water tanks

To minimize corrosion and for maximum economy in the use of oxygen scavengers, good design of the feed water tank or hot well should be considered essential. The feed water should be maintained at the highest temperature compatible with efficient operation of the feed pump, because the solubility of oxygen decreases with temperature (see figure 4); a temperature range of 80 °C to 85 °C being desirable.

This temperature can be achieved by:

a) returning hot condensate;

b) use of a supplementary steam or electric heater;

c) providing adequate lagging to maintain the temperature.

Other important design features should include:

1) the prevention of water cascading on to the surface, thus giving rise to unnecessary aeration;

2) hot condensate being returned at a lower level than the cold make-up water to encourage good mixing;

3) provision of an upstand on the offtake to the boilers to prevent deposits being carried forward to the feed pump;

4) the provision of a well-fitting cover to keep out extraneous material;

5) adequate venting.

The tank should have a minimum capacity equivalent to 1 h steaming at maximum continuous rating (MCR). Figure 6 shows a well-designed feed tank.

7.2 Protection of feed systems

7.2.1 General

NOTE 1. This clause describes only those operational problems in feed systems that are attributable to the quality of the feed water and not those difficulties such as flashing or cavitation, which are primarily caused by physical conditions.

The principal problems related to the chemical quality of the feed water are the formation of deposits and corrosive attack. They can be interrelated since corrosion can be caused by the presence of deposits, and deposits can consist of corrosion products. Deposition in the feed system can become apparent because of reduced flow rate.

NOTE 2. The boiler feed system comprises those parts of the plant between and including the point at which make-up water is introduced and the inlet to the economizer or, if there is no economizer, the inlet to the boiler.

The treatments described here for the protection of the feed system should normally afford protection to non-steaming economizers and maintain efficiency of feed heating. This should guard against a reduction in flow rate, a stoppage of the feed pump or a failure to get water into the boiler. Restriction of flow by deposits up-stream of the feed pump can so diminish the suction head at the pump that cavitation occurs. Deposition downstream of the pump can result in increased pressure at the feed pump discharge. Deposition in the feed check valve of the boiler can prevent it from seating properly and, if the feed pump operates intermittently, boiler pressure can then force alkaline boiler water back into the feed system, causing further deposition and overflow at the feed tank.

Corrosion can result in perforation of feedlines and feed heaters, wastage of feed pump parts and reduced pumping efficiency. The products of corrosion can also form obstructive deposits or be carried forward to the boiler, where they can form scale upon heating surfaces and eventually result in tube failure.

The cause should be identified and removed rather than an attempt made to alleviate the symptoms of deposition or corrosion in the feed system, since the latter approach transfers the offending impurities from the feed system to the boiler.

7.2.2 Deposition: causes and remedies

The precipitation and deposition of hardness salts in feed water to low pressure boilers is commonly a result of raising the feed water temperature or the pH value. The latter problem should be avoided by injecting alkalinity builders direct into the boiler shell or drum.

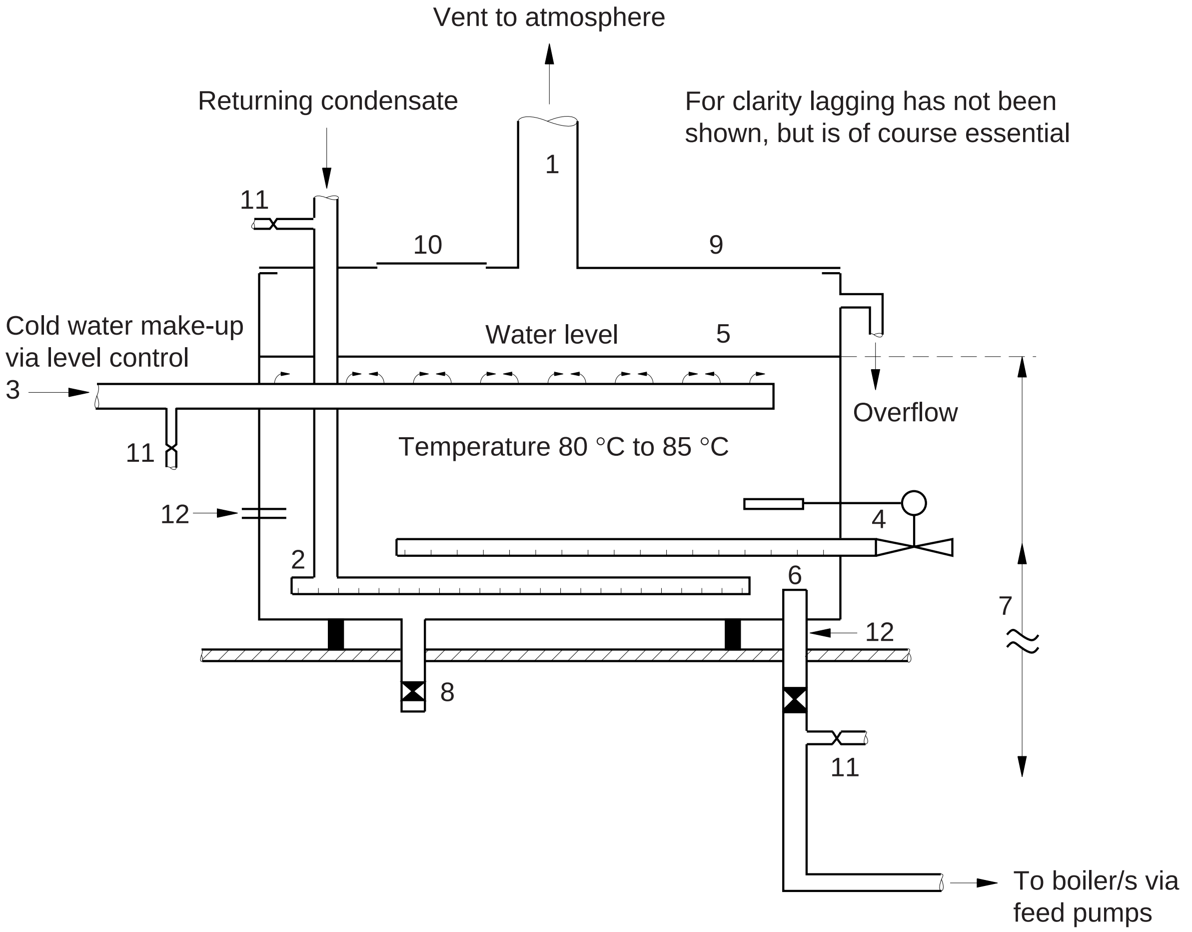
The offending hardness salts should be removed only by softening the make-up water (or the feed water if condenser leakage is the source of contamination).

7.2.3 Deposit thickness measurement

A significant factor in water-side corrosion of water tube boilers, particularly those operating at higher pressures, is the amount of deposit on the evaporator tube wall. Deposits restrict heat transfer and cause the temperature of the tube wall to increase. This increase in metal temperature can be sufficient to cause tube failure by overheating. Increasing the metal temperature promotes the concentration of any corrosive alkalis or contaminants beneath porous deposits, especially during abnormal boiler water chemistry excursions. Excessive build-up of scale or deposits should be removed by chemically cleaning the boiler periodically.

The optimum time for chemically cleaning a boiler is usually selected by considering the cost of cleaning against the likelihood of tube failures or forced outages. This involves knowledge of the operational history of the boiler including water chemistry, mode of operation, corrosion and water-side deposits.

Such factors as incidents of condenser leakage, chemistry excursions, previous tube leaks and chemical cleans should also be considered.



1 Good ventilation: 55 mm per m^3 up to a maximum of 150 mm. Install more than one vent if necessary.
2 Condensate entering at lowest possible level via sparge pipe.
3 Cold make-up entering at high level.
4 Supplementary steam heater to maintain constant temperature.
5 Room for surge returns of condensate.
6 Raised take-off at least 75 mm.
7 Net positive suction head to suit feed pump.
8 Drain to facilitate cleaning.
9 Close-fitting cover.
10 Access.
11 Sample points.
12 Dosing points.

NOTE. The tank should be sized for at least 1 h maximum demand.

Figure 6. A well-designed feed water tank

Thickness and distribution of deposits should be measured using a scale thickness gauge. Additionally, tube sampling can be conducted in order to determine the chemical composition of deposits and characterize their structure. Tube samples should be taken from the areas of highest heat flux, i.e. near the centre of the burner wall, rear, side and divisional water walls at the top burner elevation. Tube sampling can also be necessary to measure the amount of deposit in the boiler if construction limitations do not allow the use of a thickness gauge probe. The use of a thickness gauge is preferred, however, since it minimizes the number of tubes which have to be cropped out.

The amount of deposit can be expressed as a thickness (microns) or mass per unit area (g/m^2), 1 micron thickness being approximately equal to 3.6 g/m^2 for a magnetite deposit. Values for limiting thicknesses of deposit will depend on the boiler pressure, heat flux and the chemical composition of the scale.

Further information on sampling and examining deposits from boilers and associated industrial plant can be found in BS 2455.

7.2.4 Erosion corrosion

Erosion can be confined to regions where the velocity of the feed water is high as, for example, in the centrifugal pumps. The process is primarily physical but should the feed water contain suspended solids or is corrosive the situation will be aggravated, because erosion removes the natural protective film from metal surfaces. The remedies for erosion should include the removal of suspended solids, the use of more resistant material for the affected parts or, if necessary, reduction in water velocity by redesign of the plant.

Single phase erosion–corrosion can occur in power station HP carbon steel tubed feed heaters. This is particularly the case in unfavourable flow conditions with deoxygenated feed water. At temperatures between 100 °C and 200 °C steel surfaces in contact with deoxygenated feed water remain active and the dissolution of iron is controlled by diffusion through pores in the magnetite layer adjacent to the metal substrate. Under locally high flow conditions the diffusion-controlled iron dissolution changes to erosion-corrosion resulting in an increased rate of metal loss.

In addition to the local damage caused by erosion–corrosion in the low temperature region of the feed water system, the high temperature region of the feed/boiler water circuits becomes susceptible to deposition of corrosion products from the low temperature region. Palliatives include changing the material of the heat exchanger surfaces to a low chromium steel or the introduction of a trace amount of oxygen (approximately 0.01 mg/kg) into the feed water to form a less porous oxide film containing haematite (Fe_2O_3).

7.3 Protection of condensate lines

7.3.1 Corrosion

7.3.1.1 *Causes*

The following principal sources of corrosion should be noted.

a) Where dissimilar metals are in contact with one another, galvanic corrosion will occur forming deposits downstream of the corrosion site. This will lead to restricted flow in feed lines, economizers and associated equipment. If the condensate becomes contaminated with metallic compounds as a result of corrosion in the condensate system, deposition can occur. Failure of boiler tubes can result if this deposition takes place at heat transfer surfaces.

b) The presence of various substances dissolved in the condensed steam can render the condensate corrosive, the most common being carbon dioxide and oxygen. These can enter the system as a result of their presence in the feed water or if air is drawn in at a later stage. Further carbon dioxide can be formed by the thermal decomposition of carbonates or hydrogen carbonates in the boiler water. If both oxygen and carbon dioxide are present together their effect is worse than if either were present singly. Dissolved carbon dioxide reacts with steel to form iron carbonates. These can react with oxygen and form iron oxides thus liberating carbon dioxide which will cause further attack.

c) Carryover, foaming and priming (see annex C).

d) Contamination of condensate by leakage from process plant.

7.3.1.2 *Effects*

The effects of corrosion can take one of two forms. Either leakage can occur in the piping or blockages can restrict the flow of water in the return system. Failure of pipework is most likely at threaded joints where metal thicknesses have been reduced and stresses have been created by cutting the threads. Horizontal pipes, unless completely self-draining, are more susceptible to attack than vertical ones.

7.3.2 Treatment

Where additional protection is required, volatile amines should be used that either neutralize the acidity caused by carbon dioxide or form a protective film on the metal surfaces of the condensate system (see **6.1**).

NOTE 1. Ammonia is sometimes added to boiler systems or it can be present as the result of the decomposition of excess hydrazine. The ammonia will raise the pH value of the condensate and give protection to ferrous metals. Corrosion of copper and its alloys can arise but ammonia contents up to 10 mg/kg may be tolerated if oxygen is absent.

The advice of a water treatment specialist should be sought before a volatile amine treatment is applied to an installation where live steam is used for process purposes.

NOTE 2. The existence of any regulations governing the use of volatile treatment in relation to the end use of steam should be ascertained before putting these treatments into use.

7.4 Corrosion in boilers

7.4.1 General

Metallic corrosion results from the interaction of a metal with its environment in which the metal either dissolves or forms an insoluble reaction product such as an oxide. In boilers the surface reactions are generally between the steel and an aqueous solution. The major factors influencing the reactions are substances dissolved in the water. These can be either in the bulk of the water or locally concentrated at the metal/water interface. The main mechanism is electrochemical: metal passing into solution at the anode of a cell and a reaction taking place at the cathode to remove the electrons produced in the anodic reaction. Ions in the water increase its conductivity thereby facilitating the flow of corrosion currents. In addition, chlorides and sulfates tend to penetrate any protective films formed at the anode. If a soluble compound of the metal is formed at the anode, the metal remains exposed and is continuously dissolved as long as the cathode reaction continues to maintain the corrosion current.

To control corrosion the anodic and/or cathodic reactions should be inhibited as far as possible; failure to do so will result in localized corrosion such as pitting and this can lead to perforation and boiler failure.

The anodic reaction in boilers is often stifled or inhibited by the formation of a protective layer of magnetite (Fe_3O_4) which should be promoted by maintaining alkaline conditions and a chemically reducing environment in the boiler water.

Local concentrations of sodium hydroxide should also be avoided by controlling the pH value of the boiler water with sodium phosphate so that even in the event of total evaporation no free sodium hydroxide would be formed. The two methods of achieving this, namely congruent and coordinated phosphate conditioning are discussed in **5.3.5**.

Section 8. Water-side protection of idle boilers

8.1 General

Neglect of boilers during standing periods frequently leads to serious corrosion in the steam and water spaces. Further attack can develop during subsequent working periods. Various methods of corrosion protection can be applied, although the choice of method should depend upon the length of time for which the boiler is to be idle. Procedures for the protection of the fire side of an idle boiler are outside the scope of this British Standard.

8.2 Storage overnight or for a few days but not exporting steam

For short time intervals the boiler can be left on standby with the water conditions recommended for normal steaming, provided these are maintained during the idle period. Any feed water that is added subsequently, for example to compensate for thermal expansion and contraction, should have been adequately de-aerated. The steam outlet valve (before any superheaters that are installed), the boiler drains and (where possible) the feed water inlet valve before any economizer, should be closed and warning notices to this effect posted.

NOTE. This procedure is not suitable for automatic firing boilers.

Special precautions should be taken to protect superheaters and expert advice should be sought.

Coil boilers are usually shut down overnight. In the absence of any contrary advice from the manufacturer it is recommended that they be blown down while hot to remove all of the water, thus allowing the residual heat to dry out the coil.

8.3 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 feed water with a lower dissolved solids content and with low levels of water-conditioning chemicals. It is possible that the reserves of treatment chemicals will fall below the limits recommended in this standard, thereby increasing the risk of corrosion.

In most boilers the water-conditioning chemicals are added in proportion to feed water flow. Under standby conditions, therefore, chemical additions will be very low and can allow water containing small amounts of oxygen to pass to the boiler. This would have a detrimental effect in under-treated standby conditions. To minimize corrosion under these conditions, the level of oxygen scavenger should be increased to at least three times the maximum values listed in tables 2, 3 and 4. The pH value of the boiler water should be kept at a minimum of 10.5. To ensure full protection the treatment residuals should be compared with the specification each day.

8.4 Storage for extended periods

8.4.1 Wet method

If the boiler is likely to be out of service for more than a few days, but may be needed for steaming at short notice, all parts, including the economizer and superheater, should be completely filled with correctly conditioned water. Non-drainable superheaters should be filled only with condensate quality water treated with volatile chemicals such as hydrazine or ammonia. It is most important that pockets of air should not be allowed to remain in the boiler and that there should be no leakage.

When completely filling the boiler with water, sufficient sodium sulfite or hydrazine should be added to combine with the dissolved oxygen and leave an excess of 100 mg/kg to 200 mg/kg of sodium sulfite as Na_2SO_3 or 10 mg/kg to 20 mg/kg hydrazine as N_2H_4. In addition, sufficient alkali should be added to ensure that a pH value of 10.0 to 11.5 is maintained. 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.

It is recommended that any volumetric change be compensated for by connecting the aircock on the drum to a surge tank located at a higher level. This should also ensure a positive pressure, thus preventing admission of oxygen to the unit. This tank should be covered and kept dosed with oxygen scavenger and alkali. Alternatively, the pressure on the system can be maintained by using a small pump.

The oxygen scavenger reserve and the pH value or alkalinity should be checked regularly. Additional treatment chemicals should be added as necessary and distributed to maintain the treatment levels within the recommended range. Any additional water added to the boiler should contain the appropriate quantities of treatment chemicals.

When required for service, the boiler should be drained down to normal working level before firing. Phosphate or other conditioning reserves should be re-established as soon as possible.

If this method of storage is in use and there is a likelihood of sub-zero temperatures occurring, it is essential to take precautionary measures to avoid frost damage. Wet storage is not recommended for periods of longer than 2 to 3 months unless the treated water is circulated regularly in all parts of the boiler, including the economizer and superheater. Wet storage tends to promote condensation of atmospheric moisture and hence corrosion in the flue-gas side. Where this proves troublesome dry storage should be carried out.

8.4.2 Dry method

When a boiler is not likely to be required for more than two to three months it should be emptied completely and dried thoroughly. Particular attention should be paid to any parts that are not self-draining.

Where possible a stream of dehumidified air should be blown through the boiler to make sure that all surfaces are completely dry. The boiler can be considered dry when the relative humidity of the egress air is less than 30 %.

Any deposits should be removed since they tend to retain moisture. To avoid the ingress of moisture to the boiler all connections should be removed and blanked off.

Trays of silica gel or quicklime should be placed inside the boiler drum or shell, which should then be sealed. A typical quantity in practice is 1.5 kg/m^3. Inspections should be made at intervals, initially after one week, and the desiccant should be dried or replaced as necessary. The trays and their contents should be removed before the boiler is restored to service.

Alternative dry methods of protection against corrosion require that the boiler be dried thoroughly and either an inert gas or a vapour phase inhibitor (VPI) introduced. The boiler is then sealed.

If 'oxygen free' nitrogen is used as the inert atmosphere, at least four complete atmosphere replacements should be carried out for an empty boiler or the nitrogen used to empty a completely filled boiler. The final fill oxygen content should be less than 0.5 % and the gas pressure should be maintained at at least 1 bar (gauge) during the storage.

The most effective treatment is the use of both VPIs and positive pressure inert gas, by which means vessels can be stored indefinitely.

NOTE. In the case of dry storage it is essential to prevent entry by any person into the vessel until the proper ventilation procedures have been observed and a safe atmosphere confirmed.

WARNING. The vapours of some inhibitors are toxic. Expert advice should be sought before adopting this method; regulations relating to the safe entry of vessels include the following:

a) Health and Safety at Work etc. Act 1974 [5];

b) Factories Act 1961 : Section 30 [6].

8.4.3 Use of nitrite/borax for inhibition of retained water in drained plant

Non-draining parts of boilers, such as economizers and horizontal sections of boiler pipework, are subject to retention of pools of water when boilers are drained for overhaul. This leaves the wetted steel vulnerable to corrosion during the outage. Such corrosion can be prevented by replacing the water with a solution inhibited with sodium nitrite and disodium tetraborate (borax).

Where steel surfaces are covered with a service-formed protective oxide layer, the appropriate solution should contain 200 mg/kg each of sodium nitrite and borax dissolved in demineralized water. For steel surfaces which have been chemically cleaned the solution strength should be increased to 2000 mg/kg sodium nitrite and 1000 mg/kg borax. The plant item to be stored can be drained and refilled with the inhibitor solution. This can either be left in the plant as wet storage or can be drained to allow access for maintenance and repairs. Before returning to service the appropriate items of plant should be flushed with demineralized water until the nitrite content is less than 1.0 mg/kg.

Annexes

Annex A (informative)

Methods of expressing concentrations of impurities in water

A.1 Description of impurities

Pure water does not exist in nature. Water falling as rain will dissolve gases from the air, chiefly oxygen, carbon dioxide and sulfur dioxide but other gases are also present. The resulting solution is a mixture of dilute acids. When this solution percolates through the rock strata it attacks them, thus taking material into solution as dissolved solids. The solids dissolved are chiefly the hydrogen carbonates (formerly called bicarbonates), sulfates, nitrates and chlorides of the metals calcium, magnesium, sodium and potassium. Silica is also present as are smaller amounts of compounds of aluminium, iron and other metals.

The hydrogen carbonates are responsible for the alkalinity of the water while the calcium and magnesium salts are responsible for the hardness of the water.

In this annex pure water should be considered the solvent. The dissolved impurities are called solutes. The impure water, consisting of solute and solvent, is referred to as the solution.

Gaseous impurities are not discussed further in this annex but more information can be found in section 4.

A.2 Units of concentration

In this standard the unit used for concentration is mg/kg. This means the number of milligrams of the component concerned present in one kilogram of solution. For most practical purposes mg/kg can be regarded as equivalent to mg/l, μg/ml or ppm.

Concentrations should be expressed either in terms of the solute itself or in terms of the equivalent amount of calcium carbonate, $CaCO_3$.

A.3 Analysis of water

Salts are composed of two parts: a metallic part and a non-metallic part. The two parts are called ions. The metallic ion is called the cation and is positively charged. The non-metallic ion is called the anion and is negatively charged. When salts are dissolved in water the ions separate or dissociate and behave as separate entities.

A typical water analysis will show the amounts of each ion in the water. Quantities of calcium, magnesium, sodium and potassium will be reported, together with hydrogen carbonate, sulfate, chloride and nitrate. There is, however, no way to determine which cation was originally associated with which anion.

The concentrations of individual ions in solution are usually expressed in terms of mg/kg of the ion concerned.

A.4 Alkalinity and hardness

Alkalinity in natural waters is caused by the presence of the dissolved hydrogen carbonates of calcium, magnesium, sodium and potassium. Hardness refers to the amounts of calcium and magnesium salts a water contains. The hardness salts present in a water are those which can give rise to scale formation in boiler plant.

Calcium and magnesium hydrogen carbonates are responsible for the alkaline (or temporary) hardness. This hardness can be removed by boiling the water. The other salts of calcium and magnesium are responsible for the non-alkaline (or permanent) hardness. This cannot be removed by boiling but only by chemical or physical processes listed in annex B of this standard.

If, in a sample of water, the total alkalinity exceeds the total hardness then all hardness is present as alkaline (temporary) hardness, i.e. all calcium and magnesium are present as hydrogen carbonates and the water will contain sodium and/or potassium hydrogen carbonates. If the total hardness exceeds the total alkalinity then hardness will be present in both the alkaline and non-alkaline forms. It follows, therefore, that in a water which contains zero alkalinity, or one which is acidic, all hardness will be present in the non-alkaline (permanent) form.

Because of the relationship between alkalinity and hardness it is usual to express the concentrations of these parameters in terms of mg/kg $CaCO_3$.

Annex B (informative)

Typical analyses of treated water

The treatment processes listed in A to F below give waters of different chemical composition for a given raw water. The composition of waters treated by precipitation processes can vary according to such factors as temperature, efficiency of water/precipitate separation etc. Typical analyses are not therefore given and this annex deals only with ion-exchange processes.

The effects of the six most common forms of external treatment outlined below on a water of given composition are shown in table B.1. The processes are as follows:

A Sodium ion exchange (base exchange softening)

B Dealkalization and carbon dioxide removal

C Dealkalization, carbon dioxide removal and base exchange softening

D Dealkalization, hardness and carbon dioxide removal (split stream process)

E Two stage demineralization

F Three stage demineralization (two stage plus mixed bed unit)

Table B.1 Analyses of water treated by systems A to F

	RW	A	B	C	D	E	F
Conductivity µS/cm at 20° C	540	560	234	252	252	10	0.1
Total alkalinity mg/kg $CaCO_3$	222	222	10	10	10	10	—
Carbon dioxide mg/kg $CaCO_3$	10	10	<5	<5	<5	<1	—
Hydrogen carbonate mg/kg $CaCO_3$	222	222	10	10	3	—	—
Sulfate mg/kg SO_4	70	72	72	72	72	<1	—
Chloride mg/kg Cl	31	31	31	31	31	<1	—
Nitrate mg/kg NO_3	5	5	5	5	5	<1	—
Silica mg/kg SiO_2	6	6	6	6	6	<0.5	<0.02
Calcium mg/kg $CaCO_3$	264	—	85	—	—	—	—
Magnesium mg/kg $CaCO_3$	48	—	15	—	—	—	—
Sodium mg/kg Na	14	157	14	60	60	<5	<0.02
Non-alkaline hardness mg/kg $CaCO_3$	90	—	90	—	—	—	—
Alkaline hardness mg/kg $CaCO_3$	222	<5	10	<5	<5	<1	—
Total hardness mg/kg $CaCO_3$	312	<5	100	<5	<5	<1	—
Dissolved solids mg/kg	376	388	164	176	176	<5	—

Annex C (informative)

Steam purity, carryover, foaming and priming

C.1 General

Carryover is the general term that describes all types of entrainment of water from the boiler into the steam. It can be caused by foaming, priming or mechanical separator inefficiency. Impurities in steam can arise from volatilization of dissolved salts in boiler waters. This possibility increases with increasing boiler pressure.

It is important to distinguish between steam wetness resulting from partial condensation of the steam and that resulting from entrainment of boiler water. It should be noted that the steam can contain substances such as silica, volatile amines and gases, such as ammonia and carbon dioxide, even in the absence of mechanical carryover.

A maximum total solids content in steam of 1 mg/kg is a common requirement for water tube boilers fitted with steam-separating equipment.

For shell boilers not fitted with steam-separating equipment, steam wetness is commonly determined by means of a throttling calorimeter and a minimum value of 97 % dry steam (3 % wetness) is usually specified. It is difficult to obtain a representative sample of saturated steam and the calorimetric method includes wetness from condensation The amount of solids in the steam from a shell boiler is much less than the 3 % of the dissolved solids in the boiler water implied by the usual guarantee. It is usual to measure the conductivity of such condensate and any value below 25 µS/cm is typical. Above 50 µS/cm, carryover is likely to be occurring.

C.2 Foaming

In a boiler steaming at sub-critical pressure, steam bubbles are continually bursting at the steam/water interface and ejecting droplets of boiler water into the steam space. The interface can be the normal working water level in a shell or drum or the interface in a steam-separating device. As the rate of steaming increases, a point is reached when steam bubbles are arriving at the interface faster than they are removed by bursting and they accumulate as foam.

Steam released from bursting bubbles moves towards the steam outlet carrying with it the smaller water droplets and sweeping any foam present in the same direction. The steam also drags the surface of the boiler water towards the steam outlet, so that the water level at that point can be higher than elsewhere. Depending upon the location of the water level indicators and controls this could be followed by the automatic or manual admission of more water to the boiler, further increasing the water level.

C.3 Priming

Several of the mechanical factors that tend to produce carryover can reinforce each other. As the general water level is raised, the volume of the steam space is decreased. The velocity of the steam across the surface is thereby increased and the cloud of water droplets and foam is brought nearer to the steam outlet. In addition, sudden large increases in steam demand cause a temporary reduction in pressure with a consequent increase in the specific volume of the steam. This can result in slugs of boiler water entering the steam outlet. This condition is known as priming. Operating the boiler below the design pressure will produce a similar effect.

C.4 Influencing factors

The operational factors that influence carryover are:

a) boiler water level;

b) steaming rate;

c) sudden changes in steam demand;

d) operation at less than the pressure for which the boiler is designed.

The effect of impurities in the boiler water is to increase the surface tension of the water and so impair the separation of steam from the water. This increases the tendency to form foam. Dissolved solids, particularly those causing caustic alkalinity, suspended solids, oil, detergents and organic impurities can stabilize the bubble film. Suspended solids provide additional nuclei for bubble information.

C.5 Antifoams

Small amounts of certain surface active agents (antifoams) in the boiler water can overcome foaming. The choice of a particular type depends on the operating conditions. The action of antifoam is restricted to preventing foam and does not affect other causes of carryover. If overdosed, antifoams can stabilize foams.

Annex D (informative)

The principal sources of contamination requiring condensate purification

A number of sources of contamination of the condensate are significant when the condensate is to be recycled as feed water.

a) During commissioning and early operation of a boiler plant the condensate is usually contaminated with mill scale and other debris which increase the risk of corrosion of the tubes in a water tube boiler. In a once-through boiler they can lead to abnormal pressure drops and unacceptable contamination of the steam. Silica can also be particularly troublesome during this period and the commissioning can be delayed by excessive demands for water brought about by the large amount of blowdown required to limit the levels of silica in boiler water and steam.

b) Condensate is often contaminated for a period of several hours after start-up following an overnight or weekend shut-down and it can be necessary to reject such condensate from the system with a consequent increase in demand on the water supply.

c) Some contamination of condensate by corrosion products from the construction materials may occur during normal operation. Even if other contamination is absent, purification plant can be necessary to meet the highest standards for chemical quality of feed water.

d) Leakage of the cooling water within the condenser.

e) Where steam is used for industrial process heating and is recovered as condensate, it can be contaminated by untreated water or by chemicals used in the industrial process. Precautions should be taken to prevent these contaminated condensates being returned to the boiler plant without first being treated. Wherever possible such contamination of condensate should be prevented at source.

List of references (see **1.3**)

Normative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 1427 : 1993	*Guide to field and on-site test methods for the analysis of waters*
BS 1894 : 1992	*Specification for design and manufacture of electric boilers of welded construction*
BS 2690	*Methods of testing water used in industry*
BS 6068	*Water quality*
BS 6068 : Part 1	*Glossary*
BS 6068 : Part 2	*Physical, chemical and biochemical methods*
BS 6068 : Part 6	*Sampling*
BS 6068 : Section 6.7 : 1994	*Guidance on sampling of water and steam in boiler plants*

Informative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 1113 : 1992	*Specification for design and manufacture of water-tube steam generating plant (including superheaters, reheaters and steel tube economizers)*
BS 1170 : 1983 (1990)	*Recommendations for treatment of water for marine boilers*
BS 2455	*Sampling and examining deposits from boilers and associated industrial plant*
BS 2455 : Part 1 : 1973	*Water-side deposits*
BS 2455 : Part 2 : 1983	*Methods for sampling and examining fire-side deposits*
BS 2790 : 1992	*Specification for the design and manufacture of shell boilers of welded construction*
BS 6880	*Code of practice for low temperature hot water heating systems of output greater than 45 kW*
BS 6880 : Part 3 : 1988	*Installation, commissioning and maintenance*
BS 7593 : 1992	*Code of practice for treatment of water in domestic hot water central heating systems*

Other publications

[1] GREAT BRITAIN. Control of Substances Hazardous to Health Regulations 1994. SI No. 3246. London: HMSO, 1994.

[2] GREAT BRITAIN. Pressure Systems and Transportable Gas Containers Regulations 1989. SI No. 2169. London: HMSO, 1989.

[3] HEALTH AND SAFETY EXECUTIVE. *Safety of Pressure Systems. Pressure Systems and Transportable Gas Containers Regulations 1989. Approved Code of Practice 1990*. London: HMSO, 1990. (ISBN 0-11-885514 X.)

[4] HEALTH AND SAFETY EXECUTIVE. *The Control of Substances Hazardous to Health Regulations 1994. (Control of substances hazardous to health) Carcinogens. Approved Code of Practice*. London: HMSO, 1995. (ISBN 0-7176-0819-0.)

[5] GREAT BRITAIN. Health and Safety at Work etc. Act 1974. London: HMSO, 1974.

[6] GREAT BRITAIN. Factories Act 1961. London: HMSO, 1961.

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