
Recommendations for
Treatment of water for land boilers

Recommandations relatives au traitement des eaux
destinées aux chaudières

Empfehlungen für die Behandlung von Wasser für Kessel

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Foreword

The first edition of this British Standard dealing with the treatment of water for land boilers was published in 1954 just nine years after the end of World War II. Economic conditions in the United Kingdom during and immediately following the War had largely restricted industrial investment in new boiler plant and many of the boilers in operation at the time of publication were of pre-World War II, and frequently pre-World War I vintage, and the majority were manually fired with solid fuel.

Treatment of feed water and boiler water was not new but in the past had often tended to be haphazard and for many boiler operators shrouded in mystery. New and improved methods of both internal and external water treatment had been developed but, owing to the tolerance of many of the older boilers to extremely poor water conditions, acceptance was slow, particularly for low pressure boilers. Technological developments made during the war years were beginning to have their effect on the design and fabrication of boiler plant. New boilers of entirely welded and stress-relieved construction were beginning to be installed rather than those of riveted construction, and automatic controls were becoming more reliable. These changes, together with the increase in the availability of alternative fuels, namely oil and gas, were opening the way to greater flexibility in boiler design and operation.

It was against this background that BS 2486 : 1954 was written, and there is little doubt that for many boiler users and operators it did much to lift the veil of mystery from feed water and boiler water treatment and control. Furthermore, it prepared the path for the treatment of water for boilers of more advanced design, employing higher heat flux densities, increased steam disengagement velocities and higher operating pressures. It is because of the changes in design and operating pressures that have occurred since 1954 that it has become necessary to revise the standard for water treatment in order to cater for the more stringent conditions demanded by boilers in general use today.

This revision is directed also to the needs of operators of industrial steam-generating plant but the limit for operating

pressure has been increased from 250 lb/in² (17.2 bar*) in the 1954 edition to 250 bar for once-through boilers. It is appreciated that the vast majority of industrial boilers operate in the lower pressure range. Users of boilers at very high sub-critical pressures may have their own standards which differ slightly and are possibly more stringent than the requirements recommended herein owing to the conditions imposed by the particular operating conditions of the system with which the boiler plant is associated. Conversely, some users of older boilers operated in the low pressure range may consider that they can depart from the recommendations in this standard in certain respects owing to the particular boiler design or operating conditions.

In preparing this revision it has been assumed that these recommendations will be used by engineers and boiler operators, who may not have had formal chemical training, as well as by chemists. Some chemical concepts have therefore been simplified and a number of appendices included to give additional explanations of chemical topics. These explanations may be supplemented by reference to general textbooks of chemistry and water treatment.

Nearly all water treatment processes involving the removal of impurities from the water result in the discharge of an effluent. Local regulations governing the discharge of effluents including boiler blowdown may influence the selection of a particular form of treatment.

Some of the processes described in this standard are claimed to be the subject of British patents. Many of the processes are offered commercially by companies who own or are licensed to use the patents. Readers are advised to satisfy themselves that they would not be infringing any patent before introducing a particular process into a treatment system.

NOTE. The system of units adopted by the International Organization for Standardization (ISO), known as the International System of units (SI), has been used in this revision. Siemens (S) is the name given to the unit formerly called the 'mho' (reciprocal ohm), and conductivities are accordingly expressed in terms of microsiemens per metre (µS/m), where 1 micromho/cm = 100 µS/m.

* 1 bar = 10⁵ N/m² = 100 kPa

British Standard Recommendations for Treatment of water for land boilers

Section one. General

1. Scope

These recommendations provide a guide for those concerned with the operation of industrial steam-raising boiler plant and the preparation of feed water for such plant. The principal natural impurities in water, the difficulties they may cause in boiler plant and the methods by which they may be removed or their effects mitigated, are described; information is also provided to aid the understanding of the chemical nature of the water treatment processes.

The prime objective has been to provide a British Standard against which the user may assess specific recommendations for water treatment for a particular combination of steam requirements, water supply and boiler plant; it is not intended to recommend which processes should be chosen.

Recommended limiting values are included for the concentrations of the principal chemical constituents in feed water and boiler water in relation to the following steam-raising plant.

- (a) Shell boilers at operating pressures up to 25 bar*.
- (b) Water-tube boilers operating up to the limit imposed by the critical pressure of steam.
- (c) Once-through boilers at operating pressures up to 250 bar.

This standard is not concerned with water treatment for nuclear-reactor boilers, electrode boilers or evaporators, or for plants that produce hot water only. It is not concerned with the methods of sampling, analytical determinations and routine control testing that are essential for satisfactory boiler operation; these are described in the following British Standards.

- BS 1328 Methods of sampling water used in industry
- BS 1374 Recommendations on the use of British Standard log sheets for steam and hot water boiler plants
- BS 1427 Routine control methods of testing water used in industry
- BS 2455 Methods of sampling and examining deposits from boilers and associated industrial plant Part 1 Water-side deposits
- BS 2690 Methods of testing water used in industry
- BS 3285 Methods of sampling superheated steam from steam generating units
- BS 3812 Recommendations for estimating the dryness of saturated steam

A description of water treatment processes involves the use of terms that have special meanings to water treatment chemists and those involved in the operation of water treatment plant. Brief explanations of these terms are given in appendix A.

2. References

The titles of the standards publications referred to in this standard are listed on the inside back cover.

3. Definitions

For the purposes of this British Standard the following definitions apply for types of water.

NOTE 1. Some other terms used in this standard are explained in appendix A.

NOTE 2. Further terms used in connection with boiler operation will be defined in a British Standard glossary, currently in course of preparation, dealing with terms used in the refrigeration, heating, ventilating and air-conditioning industries.

- 3.1 raw water.** Water as received by the user irrespective of any previous treatment.
- 3.2 treated water.** Water which has received any treatment on the user's premises.
- 3.3 softened water.** Water which has had its hardness substantially removed by the user.
- 3.4 condensate.** Condensed steam from power plant or process not mixed with any other water.
- 3.5 demineralized water.** Water from which nearly all of the ionizable dissolved solids have been removed by passing it through ion-exchange materials.
- 3.6 feed water.** The water passing through the feed pump or injector. It may consist of any mixture of the foregoing.
- 3.7 boiler water.** The water present in a boiler when steaming is or has been in progress.
- 3.8 make-up water.** Water which has to be added to the system in order to make up for losses.

Section two. Water quality

4. Objectives of water treatment

The two main functions of a boiler are to transfer heat to water to produce steam under pressure, and to separate the steam from the water in the boiler. The boiler can only carry out these two functions effectively if the qualities of the feed water and of the boiler water are properly controlled.

* 1 bar = 10^5 N/m² = 100 kPa

Impurities introduced into the boiler with the feed water can produce scale or other deposits which impede the transfer of heat and may restrict the flow of water. In addition to reducing boiler efficiency, either effect leads to insufficient cooling of the metal heat-transfer surface, which may then become so hot that it is no longer strong enough to withstand the operating pressure. Deposits may also lead to corrosion, by shielding the underlying metal from protective conditions in the water or steam.

Corrosion results from the interaction of a metal with its environment and, in a boiler plant, leads to the metal being either dissolved or converted to an insoluble product, e.g. an oxide; in either case, the metal is weakened and may fail. Corrosion also leads to the formation of deposits of metal oxide formed from the dissolved metal and deposited either at the site of corrosion or elsewhere in the system. Such deposits impede the transfer of heat and restrict the flow of water; consequently, corrosion in the feed system or in the steam and condensate system can lead to overheating and failure of the boiler.

When steam is produced from water containing dissolved solids the solids remain and concentrate in the boiler water. As the steam separates from the surface of the water in the boiler it tends to carry with it small droplets of the boiler water. Contamination of the steam is increased by such factors as increasing concentrations of dissolved and suspended solids and increasing steam disengagement velocity. The compositions of dissolved and suspended solids in the boiler water also have an effect on carryover. Because the droplets ejected from the water surface and carried out of the boiler with the steam contain dissolved and suspended solids, the purity of the steam is impaired.

The objectives of water treatment are to keep those parts of the plant that are in contact with water and steam clean and intact, and to facilitate the production of clean steam. The selection, application and control of water treatment should be consistent with these aims.

Steel in contact with water or steam quickly forms upon its surface a film of iron oxide, which may or may not be protective. Water treatment to prevent corrosion should so adjust the quality of the water that a film of *protective* oxide is maintained.

The total prevention of deposits requires the absence of suspended solids in the water and the steam, and that the concentrations of substances dissolved in the water are such that in passing through the plant none appears in solid form. If all the water entering the plant is evaporated to form steam as in a 'once-through' boiler, it is essential that suspended and dissolved solids are absent. If only part of the water is evaporated the remainder provides a sink in which a controlled degree of concentration of suspended and dissolved solids may be allowed.

Although the risks of corrosion and of deposit formation are common to all parts of the plant and to all plants, the consequences are liable to become more severe as operating pressure, temperature and heat flux density are increased. The methods of satisfying the objectives of water treatment thus depend upon the operating conditions of the plant.

5. Natural impurities in water supplies

The study of water treatment is the study of the impurities in water. It is necessary first to consider natural sources and to understand in what way they fall short of the requirements for a boiler feed water. As water is an almost

universal solvent, absolute freedom from impurities, which is in theory desirable, can hardly be attained in practice. Rain water when it reaches the ground contains materials dissolved out of the atmosphere; these are not only gases but also solids from dust and, on occasion during thunderstorms, ammonium nitrate and/or nitric acid.

The types of water that may be available are extremely varied. They range from sea water with a salinity of about 30 g/l to soft moorland water with a total solids content of only a few milligrams per litre. The various sources can be classified into three main categories: the sea, springs or wells, and rivers, some of which may feed lakes or reservoirs.

The sea need only be considered very briefly, as its high salinity makes it unsuitable as a boiler feed water except for certain specially designed low pressure evaporators intended to provide condensate as feed water for high pressure boilers. These evaporators are regarded as outside the scope of this standard.

Springs and wells are an important source of water in the United Kingdom and many have provided large quantities of water of uniform quality over many years. This water is often superior to river water in organic purity and freedom from suspended matter but frequently has a high calcium bicarbonate content.

The commonest source of water is river water, and fundamentally all rivers originate from rain or snow. The soluble impurities in them are dissolved out of the terrain over which they pass. Thus moorland rivers flowing over peaty terrain are low in dissolved salts, but are frequently brown in colour and slightly acidic from the humic acids derived from decaying heather and moss. Rivers in arid countries, on the other hand, are usually low in organic content and often high in dissolved salts such as calcium sulphate and sodium chloride. Most big rivers also carry down vast quantities of silt.

Natural waters contain dissolved gases. Since all gases are to some extent soluble in water, surface waters contain traces of all the normal constituents of the atmosphere and on occasion free ammonia. Water may also contain hydrogen sulphide or methane. The gases of importance from the point of view of this standard are oxygen and carbon dioxide.

Many rivers undergo seasonal variations in composition. This is least marked in temperate climates, where rain falls all the year round, and is very pronounced in desert regions of low and seasonal rainfall. It is not possible to generalize on this subject; each river which is being used as a source of raw water must be studied individually.

The amount of any individual impurity picked up by the water depends not only on the concentration of the particular mineral in the ground but also on the geological form in which it is present. Certain minerals are only sparingly soluble in pure water but their solubilities may be increased if the water already contains other dissolved salts. For instance the solubility of silica from sand or clay may be increased considerably by the presence of alkaline impurities such as sodium bicarbonate. Calcium carbonate, which is frequently present in the ground as chalk or limestone, has a maximum solubility of about 30 mg/l but may react with carbonic acid to form highly soluble calcium bicarbonate. The carbonic acid required for this reaction is formed by the solution in rain water of carbon dioxide, which is produced in large amounts by respiration

and decay of surface vegetation. The importance of the reaction of these impurities on water quality may be judged by the fact that many waters contain calcium bicarbonate equivalent to several hundreds of milligrams of calcium carbonate per litre (see 6.2(b)).

6. Methods of expressing concentrations of impurities in water

6.1 Description of impurities. The saline impurities are described by names having two words, for example calcium sulphate, sodium chloride, calcium bicarbonate, indicating that they are composed of two parts, namely a metallic component and an acidic component. In mineral salts found in water the main metallic components are normally calcium, magnesium and sodium; they carry positive electrical charges and are referred to as 'cations'. The acidic components or radicals are mainly bicarbonate, chloride, nitrate and sulphate; they carry negative electrical charges and are referred to as 'anions'.

In the solid salt the mutual attraction of the opposing electrical charges holds the cations and anions together in a fixed proportion to maintain electrical neutrality. When a salt is dissolved in water the mutual attraction between anions and cations is weakened and the salt breaks up into the component ions which move freely and independently throughout the water, whilst nevertheless maintaining overall electrical neutrality. This dissociation into cations and anions applies to each and every salt dissolved in the water so that if, for example, sodium chloride and calcium sulphate are both dissolved, the water will contain the cations calcium (Ca^{2+}) and sodium (Na^+), and the anions sulphate (SO_4^{2-}) and chloride (Cl^-).

If in a mixed solution of salts any combination of cation and anion corresponds to a salt that is insoluble in the water, these particular ions will combine to form the insoluble salt and be precipitated. For example, if water containing calcium sulphate is mixed with water to which sodium carbonate (Na_2CO_3) has been added the resultant mixture should contain cations Ca^{2+} and Na^+ , and anions SO_4^{2-} and CO_3^{2-} but the combination of Ca^{2+} and CO_3^{2-} corresponds to calcium carbonate (CaCO_3), which is only slightly soluble in water and if its concentration exceeds its solubility it will be precipitated. Hence these two ions will combine and calcium carbonate will be thrown out of solution as a solid salt, i.e. precipitated. The remaining solution will contain some calcium ions and carbonate ions equivalent to the solubility of calcium carbonate in water, together with the sodium and sulphate ions.

This description of the ionic reactions and precipitation mechanism is a considerable simplification but the basic principles outlined should make the water treatment processes more easily understood.

The major impurities present in natural water result from the solution of salts from the ground with which the water comes into contact. When these salts go into solution they dissociate into cations and anions. When the water is analysed the concentration of each individual cation and each individual anion is determined but this does not show which cation was originally associated with which anion.

For example, a water may have dissolved:

$\text{Ca}(\text{HCO}_3)_2$	calcium bicarbonate
CaSO_4	calcium sulphate
MgSO_4	magnesium sulphate
MgCl_2	magnesium chloride
NaCl	sodium chloride
NaNO_3	sodium nitrate

The analyst will determine the following:

cations	{	Ca^{2+}	calcium ion concentration
		Mg^{2+}	magnesium ion concentration
		Na^+	sodium ion concentration
anions	{	HCO_3^-	bicarbonate ion concentration
		SO_4^{2-}	sulphate ion concentration
		Cl^-	chloride ion concentration
		NO_3^-	nitrate ion concentration.

6.2 Concentration in terms of calcium carbonate. The analyst's report may express the concentrations of impurities in terms of the individual cations (Ca^{2+} , Mg^{2+} , Na^+) and anions (HCO_3^- , SO_4^{2-} , Cl^- , NO_3^-) in milligrams per litre or parts per million. It is frequently more convenient to express each constituent in the form of an equivalent amount of calcium carbonate. This is analogous to converting various currencies such as dollars, guilders, marks, francs etc., into a common currency such as pound sterling on the basis of their equivalent purchasing power.

Calcium carbonate (CaCO_3) was originally selected because it has a convenient relative molecular mass* of 100 and an 'equivalent weight' of 50, and also because it is the major impurity responsible for scale formation and so-called 'hardness' in water.

The concentration of any dissolved impurity that is determined may be reported in terms of CaCO_3 by applying the appropriate factor. Some examples are as follows:

Calcium	as Ca^{2+}	$\text{mg/l} \times 2.50$	} $\equiv$ expressed in terms of CaCO_3
Magnesium	as Mg^{2+}	$\text{mg/l} \times 4.11$	
Sodium	as Na^+	$\text{mg/l} \times 2.17$	
Bicarbonate	as HCO_3^-	$\text{mg/l} \times 0.82$	
Chloride	as Cl^-	$\text{mg/l} \times 1.41$	
Nitrate	as NO_3^-	$\text{mg/l} \times 0.81$	
Sulphate	as SO_4^{2-}	$\text{mg/l} \times 1.04$	

* The relative molecular mass of a substance, formerly called its 'molecular weight', is the sum of the relative atomic masses (atomic weights) of all the atoms in the molecule. In simplified terms the relative atomic mass relates the mass of an atom of an element to the masses of atoms of other elements on an arbitrary scale. The unit of mass on this scale is one twelfth the mass of an atom of carbon (C^{12}). The concept of equivalent weight is now obsolete but was used to relate the relative masses of atoms and ions entering into combination by reaction.

The advantages of employing this uniform expression for individual impurities, salts, acids, etc., will be appreciated when interpreting or basing calculations on the results of a water analysis.

In this British Standard concentrations are expressed as follows:

- (a) individual ions, total and dissolved solids in milligrams per litre;
- (b) alkalinity and hardness in milligrams per litre expressed in terms of calcium carbonate;
- (c) where the concentrations of a number of different ions are required on a common basis they are expressed in milligrams per litre expressed in terms of calcium carbonate.

6.3 Electrical conductivity. Pure water is a poor conductor of electricity, but water containing ionized impurities such as salts, acids or alkalis may be highly conductive.

The electrical conductivity may therefore be used as an approximate measurement of the total ionized impurities present in water. Conversely, it can be used to define the degree of purity required from a treatment process, or the concentrations of dissolved solids permitted in feed water or boiler water.

The conductivity produced by the presence of a given concentration of impurity depends upon the nature of the impurity and on the temperature of the water. In mixtures of impurities the relationship between their total concentration and the conductivity requires to be determined for each mixture.

Electrical conductivity of water is measured in terms of microsiemens per metre ($\mu\text{S/m}$) at a stated temperature. Absolutely pure water contains only small amounts of hydrogen ions (H^+) and hydroxyl ions (OH^-) and has a very low conductivity, as illustrated in figure 1. Figure 2 illustrates the effect of various concentrations of sodium chloride in water on its electrical conductivity.

NOTE. When using the international system of units, electrical conductivity of solutions is often expressed as microsiemens per metre ($\mu\text{S/m}$) (see note in foreword) but if the value is expressed in microsiemens per centimetre ($\mu\text{S/cm}$) the numerical value is of the same order as the concentration of dissolved solids in milligrams per litre.

7. Effects of water impurities in boiler feed water

Difficulties can arise in boiler plant from the presence of added, adventitious or natural impurities in water supplies. The primary effect of such substances may be detrimental, either because of the large volume of feed water passing to the boiler, or owing to their concentration in the boiler water.

The feed water entering the boiler system may consist entirely of raw water suitably treated, or it may consist of condensate plus treated make-up water. Feed water is delivered by a feed pump or injector into the boiler plant. Sometimes it passes through a feed water heater and an economizer before entering the boiler. If hardness is present in the feed water, scaling of the heating surfaces will occur and there will be a reduced efficiency of steam production by reason of poor heat transfer with a consequent wastage of fuel as well as possible damage to the boiler. If the water is not sufficiently alkaline or if it contains dissolved gases, corrosion of the feed pump, feed lines and the boiler is likely to occur.

The effects of the impurities may result in costs far exceeding the cost of removing or controlling the offending substances.

The following list sets out most of those troubles experienced in feed, boiler, steam and condensate systems that may cause premature shutting down of boiler plant or associated equipment, and for which the condition of the water is the principal cause.

(a) Feed system and economizer

(1) Corrosion of the feed tank, feed pump, feed heater, feed line or economizer can result in perforation of the plant or restriction of flow through the feed system. Even if this corrosion is slight, the products of corrosion carried forward may form deposits in the economizer and boiler. Corrosion in economizers or feed heaters can be either graphitic wasting of cast iron or corrosion fatigue cracking of steel, either of which may lead to failure.

(2) Deposition of scale in the feed pump, feed line, economizer, feed valve or internal feed pipe orifice may lead to loss of efficiency at the economizer, restriction of flow of feed water and ultimately failure to get water into the boiler.

(b) Boiler

(1) Corrosion of both non-heat-transfer and heat-transfer surfaces, especially if localized, may dangerously weaken the boiler or lead to its failure by perforation.

(2) Priming or foaming, which lead to a decrease in steam purity.

(3) Corrosion of non-ferrous metals, which leads to failure of boiler fittings.

(4) Stress corrosion leading to failure, which may be catastrophic e.g. explosive failure.

(5) Deposition of sludge, corrosion products, soft scale and hard scale or even soluble salts that can result in:

- (i) overheating and distortion of fire boxes, furnace tubes, smoke tubes, tube plates or water tubes, which lead to leakages at joints, at tube ends or at riveted seams;
- (ii) bulging and rupture of water tubes as a result of overheating;
- (iii) blockage of water tubes causing water starvation, followed by bulging or bursting;
- (iv) failure of automatic devices leading to shortage of water, overheating, furnace tube collapse and explosion;
- (v) blockage or jamming of blowdown valves;
- (vi) impaired heat transfer and lowered efficiency, with consequent wastage of fuel;
- (vii) corrosion of metal surfaces.

(c) Superheater

(1) Pitting corrosion leading to perforation.

(2) Deposition of salts from attemperator spray water or impure steam leading to overheating and rupture.

(3) Stress corrosion, especially of austenitic steels, leading to sudden failure.

(d) Turbine

(1) Deposition of salts, or of silica, which may cause damage and premature shut-down.

(2) Stress corrosion of turbine blades leading to sudden failure.

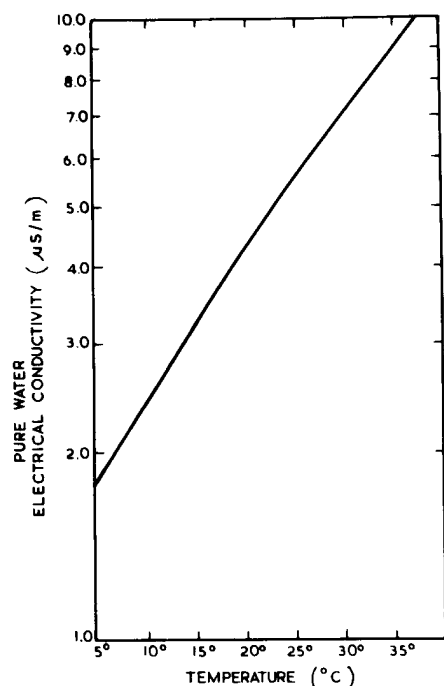


Figure 1. Variation of electrical conductivity of pure water with temperature

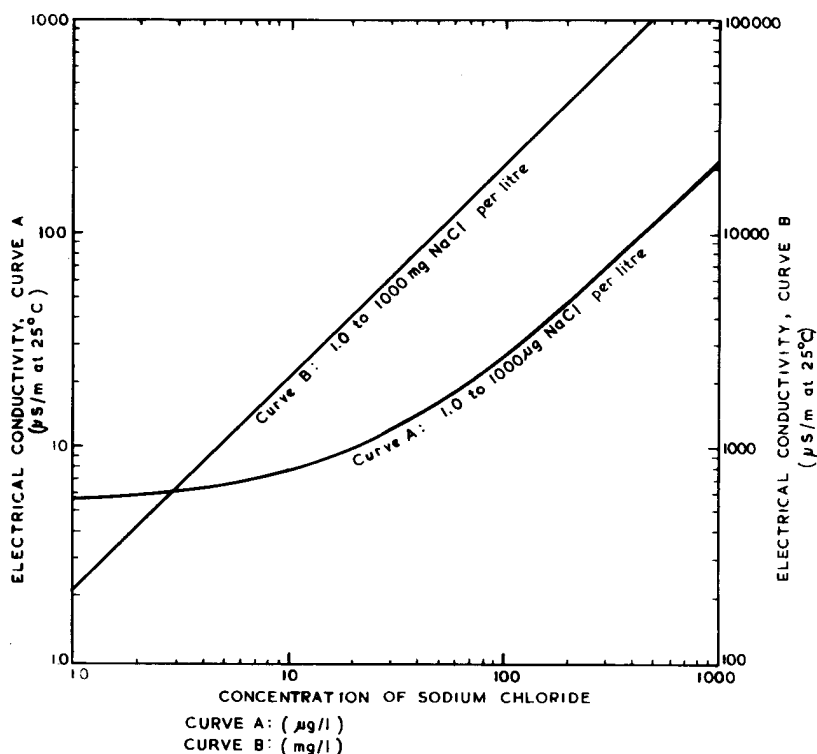


Figure 2. Variation of electrical conductivity of water with concentration of sodium chloride

(e) Condensate system

- (1) Corrosion of metals, including steel, alloys of copper, and alloys of aluminium, leading to leakage and contamination of the condensate by cooling water.
- (2) Stress corrosion of stainless steel leading to sudden failure.

Calcium and magnesium compounds together with silica may, in certain circumstances, produce scales or sludges in the feed system and boiler.

Sodium compounds are also present in water but, being soluble, they generally do not lead to difficulties. However, sodium as well as magnesium and calcium can, with silicon, be constituents of complex scales containing iron or aluminium. These scales are hard and adherent in nature. Sodium bicarbonate decomposes in the boiler water to form sodium hydroxide or sodium carbonate, or both, and amounts of these in excess of the amounts recommended in tables 2 and 3 may be undesirable and lead to foaming. Insufficient sodium hydroxide in the boiler water may, however, lead to the deposition of silica.

Corrosion is frequently caused by carbon dioxide or oxygen dissolved in the water; the former may be present as free carbon dioxide or derived from the breakdown of the bicarbonates of calcium, magnesium or sodium.

The kinds of salts, their number and quantities, in addition to the amount of carbon dioxide and/or oxygen dissolved in the water, determine in a complicated manner whether the water will be scale-forming or corrosive under operating conditions.

The impurities that may be found in feed water and their effects on boiler plant and associated equipment are summarized in table 1. Failure to deal with these substances in a suitable manner may lead to sludge, carryover, scale or corrosion, or a combination of all or any of these such that premature failures as enumerated above may occur.

8. Recommended feed and boiler water characteristics

8.1 Introduction. The characteristics recommended in tables 2, 3 and 4 for boiler waters and the feed waters from which they derive represent the limits or the ranges of conditions that should exist following the correct application and control of appropriate water treatment.

The number of parameters precludes presentation in other than tabular form but it would be misleading to read the values as if they were 'ideal' water analyses.

The tables indicate the trend of the recommended parameters whether they result from a natural impurity or from the addition of treatment chemicals. Where single values of limits are shown they represent points in a continuous series and have no other special significance.

8.2 Shell boilers

8.2.1 Recommended characteristics. 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.

The advice of the boiler manufacturer should be obtained with regard to the maximum limit recommended for suspended solids, and hence for feed water hardness, that may be tolerated in the particular type of boiler employed, taking into consideration the following factors:

- (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.

Table 1. Some impurities found in feed water and the difficulties they cause in boiler plant

Substance causing difficulty in boiler plant	Physical form of substance in boiler plant	Source of substance related to impurity in feed water	Principal troubles in				
			Feed system	Economizer	Boiler	Superheater	Turbine Condensate system
(1) Calcium carbonate	Sludge	Calcium hardness			X		
	Scale	Calcium hardness	X	X	X		
(2) Calcium sulphate	Scale	Calcium hardness			X		
(3) Calcium silicate	Scale	Calcium hardness and silica			X		
(4) Complex calcium phosphates	Sludge	Calcium hardness			X		
	Scale	Calcium hardness	X	X	X		
(5) Magnesium hydroxide	Sludge	Magnesium hardness			X		
(6) Magnesium silicate	Sludge	Magnesium hardness and silica	X	X	X		
(7) Acid chlorides	Solution	Chlorides			X		
(8) Iron oxides	Sludge or scale	Corrosion products in system. Soluble or insoluble iron in feed water			X		
(9) Sodium iron silicate	Scale	Iron and silica			X		
(10) Aluminium oxide or hydroxide	Sludge or scale	Aluminium in raw water, treated water and condensate			X		
(11) Sodium aluminium silicate	Scale	Aluminium and silica			X		
(12) Silica	Scale	Silica			X	X	
(13) Oil	Soaps and oil-bound sludges	Contamination			X	X	X
(14) Copper and copper oxides	Metal and oxides	Corrosion within condensate or feed system			X		
(15) Oxygen	Corrosion products	Dissolved or entrained oxygen in feed water	X	X	X	X	X
(16) Carbon dioxide	Corrosion products	Free CO ₂ and decomposition of carbonates and bicarbonates	X	X			X
(17) Ammonia (see clauses 32 and 33)	Corrosion products of copper	Make-up water and returned condensate	X				X
(18) Natural organic matter	Deposit or solution	Humic and fulvic acids and derived materials in the make-up water			X		
(19) Surfactants	Solution	Synthetic detergents in raw water, feed water or condensate			X	X	X
(20) Sodium hydroxide (caustic soda) (see clause 34)	Solution	Sodium hydroxide, sodium carbonate and sodium bicarbonate			X	X	X
(21) Dissolved solids	Solution	Accumulation of all soluble substances			X	X	X
(22) Suspended solids	Solids in suspension	{ Insoluble substances already present or insoluble substances formed by chemical action			X	X	X
	Settled sludge		X	X	X		

The limit may be increased or decreased by factors (a) and (b) but can only be decreased by factors (c) and (d) (see 9.3).

The values given in table 2 under the various levels of feed water hardness take into consideration the collective effect on steam purity of dissolved solids, of alkalinity and of suspended solids produced as a result of hardness precipitation.

Because of these variations in boiler tolerance to feed water hardness and suspended solids, table 2 is divided into three categories which cover three qualities of feed water. These are 2 mg/l hardness, as for example from a sodium ion exchange softening; 20 mg/l hardness, as for example from a lime/soda softener; and 40 mg/l hardness, as from an unsoftened supply, but these water qualities may arise from other treatments or by mixing waters of suitable qualities.

Where the feed water hardness is likely to be in excess of 40 mg/l, expressed in terms of CaCO₃, the raw make-up water should be treated by external treatment methods.

Chemical precautions against caustic cracking are generally not necessary for boilers of welded and stress-relieved construction (but see 34.3) but they should be applied for older boilers of riveted construction.

8.2.2 Comments on table 2. When applying the recommendations in table 2 the following additional comments are also relevant.

(a) **Feed water hardness.** Boilers with high output relative to water content and/or employing high heat flux density usually require feed water of low hardness, not only to avoid scale formation on heat transfer surfaces but also to minimize the formation of suspended solids or sludge in the boilers. Consequently water with the characteristics given for the 2 mg/l category of table 2 should be used in these situations.

Table 2. Recommended water characteristics for shell boilers

For pressures up to 25 bar*

The letters in parentheses in the final column refer to comments in 8.2.2.

Total hardness in feed water, mg/l in terms of CaCO ₃ max.	2	20	40	(a)
Feed water				
pH value	7.5 to 9.5	7.5 to 9.5	7.5 to 9.5	—
Oxygen	†	†	†	(b)
Total solids, alkalinity, silica	†	†	†	(c)
Organic matter	†	†	†	(d)
Boiler water				
Total hardness, mg/l in terms of CaCO ₃ max.	ND‡	ND	ND	—
Sodium phosphate, mg/l as Na ₃ PO ₄ §	50 to 100	50 to 100	50 to 100	(e)
Caustic alkalinity, mg/l in terms of CaCO ₃ min.	350	300	200	—
Total alkalinity, mg/l in terms of CaCO ₃ max.	1200	700	700	—
Silica, mg/l as SiO ₂ max.	Less than 0.4 of the caustic alkalinity			
Sodium sulphite, mg/l as Na ₂ SO ₃ or	30 to 70	30 to 70	30 to 70	(b)
Hydrazine, mg/l as N ₂ H ₄	0.1 to 1.0	0.1 to 1.0	0.1 to 1.0	(b)
Suspended solids, mg/l max.	50	200	300	(f)
Dissolved solids, mg/l max.	3500	3000	2000	—

— Not applicable.

* 1 bar = 10⁵ N/m² = 100 kPa.

† Numerical values depend upon circumstances but the comments are relevant.

‡ ND not detectable.

§ Phosphate is usually added as sodium phosphate but determined as phosphate (PO₄³⁻); Na₃PO₄ = 1.73 × PO₄³⁻.

(b) **Oxygen.** Dissolved oxygen in the feed water should be reduced to the lowest practicable level before adding an oxygen scavenger (see clause 15, section six, 32.3 and 34.2).

Hydrazine is recommended as an alternative to sodium sulphite only when it is dosed to the feed water at a substantial distance from the boiler and where the feed water is sufficiently hot to enable the removal of oxygen to be 90 % complete before entry to the boiler (see clause 31).

CAUTION. Hydrazine is toxic, and suitable precautions for its handling should be observed. Its use is usually prohibited in hospitals, the food manufacturing industry and where steam may come into contact with food or beverages. The use of sodium sulphite may also be unacceptable in some of these applications. The existence of any regulations governing the use of either should be ascertained and they should be observed.

(c) **Solids, alkalinity and silica in feed water.** The concentrations of these constituents in the feed water should not be so high as to require blowdown of boiler water in quantities exceeding the boiler design value or exceeding the feed pump capacity (see 9.2 and clause 10).

(d) **Organic matter.** Organic matter other than oil may be innocuous in a boiler depending on the temperature of operation and the amount and type of the organic matter.

Maximum values that would be universally applicable cannot be stated and the operator should therefore be alert to the operating difficulties that may be associated with the presence of organic matter; these are as follows.

- (1) Interference with heat transfer, usually attributable to the presence of organic matter that is immiscible with water, e.g. hydrocarbons.
- (2) Foaming, attributable to organic surface-active agents.
- (3) Diminished alkalinity, attributable to thermal decomposition of organic matter to acidic compounds.
- (4) Impairment of steam purity, attributable to thermal decomposition of organic matter to volatile compounds. This is especially important where steam is used directly in processing food, pharmaceuticals or beverages.
- (5) Modification of suspended solids to form adherent deposits or intractable sludges.

Where such difficulties can be positively associated with the presence of organic matter a practical limit to its amount should be set if it is not possible to eliminate the contamination. Some amelioration may be gained by rejection of contaminated condensate, by extra blowdown or by washing out the boiler.

(e) **Carbonate and phosphate control.** If a minimum carbonate alkalinity of 250 mg/l expressed in terms of CaCO_3 is consistently maintained when carbonate control or sodium ion exchange softening is used, a reserve of soluble phosphate need not be maintained. A residual of soluble hardness up to 5 mg/l expressed in terms of CaCO_3 is then usually found in the boiler water but scale formation may be minimized by conditioning treatment as described in clause 30. Polymers may act as weak chelating agents and thus retain hardness salts in solution in boiler water. In this event the hardness as determined by the EDTA methods described in BS 2690 : Part 4 is measurable and particular attention should then be given to maintaining the recommended level of carbonate or phosphate. In appropriate circumstances chelating agents may be used in place of phosphate (see clause 29).

(f) **Suspended solids.** These figures represent theoretical values, and are not necessarily measurable in practice. They can be used as one basis for calculating boiler blowdown requirements, based on the actual feed water hardness.

8.3 Water-tube boilers

8.3.1 Recommended characteristics. The recommendations in table 3 apply to water-tube boilers of the integral furnace type and of current design and rating. Boilers with lower heat flux ratings may tolerate higher concentrations of hardness. Similarly, future designs may have higher flux ratings and might require lower levels of hardness and other impurities that can lead to the formation of scale or deposits and interference with heat transfer.

Chemical precautions against caustic cracking are generally not necessary for boilers of welded and stress-relieved construction (but see 34.3) but they should be applied for older boilers of riveted construction.

Where the heat flux density at localized 'hot spots' is expected to exceed about 300 kW/m² in boilers operating at a pressure below 40 bar, hardness in the feed water should be strictly limited to less than 0.3 mg/l in terms of CaCO_3 , and iron, copper and nickel should be limited as for an operating pressure of 60 bar.

High pressure boiler plant, operating at above about 80 bar, is generally more sensitive than low pressure plant to on-load corrosion and the circumstances that may allow corrosion to occur are less well understood. In general, the concentrations of all constituents in the feed and boiler water should be as low as practicable. Furthermore, should it be found that boiler water salts are subject to 'hideout' (see clause 35), every endeavour should be made to operate at the lowest practicable concentration.

The values tabulated are for normal, steady operation. It is acknowledged that, for economic reasons, higher concentrations of total solids, iron, copper, silica, have to be tolerated during periods of starting-up. For boilers operating above 130 bar, consideration should be given to condensate polishing (see clause 22).

The operation of boilers at a pressure less than designed may adversely affect the performance of steam-purifying equipment so that it may be necessary to adopt lower concentrations in the boiler water than the maxima listed for total alkalinity, suspended solids and dissolved solids (see 9.3).

8.3.2 Comments on table 3. When applying the recommendations in table 3 the following additional comments are also relevant.

(a) **pH value of feed water.** With feed water heaters made from copper or copper alloys the range of pH values should be limited to between 8.5 and 9.2 and otherwise to between 9.2 and 9.5. For spray attemperation (see (d) below) the feed water should be dosed only with volatile chemical; if necessary, caustic soda should be injected direct to the boiler drum.

(b) **Oxygen.** The oxygen limits in table 3 are those obtained after physical deaeration. In addition to physical deaeration, the use of a chemical oxygen scavenger is recommended.

Sodium sulphite should not be used in boilers operating above 80 bar except where hydrazine cannot be used and then only if strict control is maintained to prevent damage due to its decomposition.

Sodium sulphite should not be added to water used for spray attemperation.

For low pressure plant, hydrazine is recommended as an alternative to sodium sulphite only when it is dosed to the feed water at a substantial distance from the boiler and where the feed water is sufficiently hot to enable the reaction with oxygen to be 90 % complete before entry to the boiler (see clause 31). Thus, for smaller industrial plant sodium sulphite would generally be preferred.

Concentrations of hydrazine in the boiler water are not given for operation above 80 bar because, owing to its decomposition and/or volatilization, low concentrations remain in the boiler water and are extremely difficult to determine; thus the residual concentration is not a practical basis for controlling the dose. In such cases, the feed water should be dosed with hydrazine equivalent to twice the residual oxygen remaining after physical deaeration.

CAUTION. Hydrazine is toxic, and suitable precautions for its handling should be observed. Its use is usually prohibited in hospitals, the food manufacturing industry and where the steam may come into contact with food or beverages. The use of sodium sulphite may also be unacceptable in some of these applications. The existence of any regulations governing the use of either should be ascertained and they should be observed.

(c) **Iron, copper, nickel.** The maxima for the sum of these impurities should be regarded as concentrations not to be exceeded during continuous running conditions.

(d) **Solids, alkalinity and silica in feed water.** The concentrations of these impurities should not require blowdown of boiler water in quantities exceeding the design value or exceeding the feed pump capacity (see 9.2 and clause 10). Where spray attemperation is employed, the spray water should contain as little solid matter and silica as possible. In general, in order to prevent deposition in the superheater, the spray attemperator should not be fed with water containing more than 3 mg/l solid matter. If the superheater contains an austenitic steel section, solids in the spray water should be less than 0.1 mg/l. When steaming a turbine, the spray water should contain less than 0.02 mg/l silica.

(e) **Organic matter.** See 8.2.2(d).

(f) **Phosphate.** Phosphate need not be employed if hardness is completely eliminated at all times and should not be employed when operating above 130 bar except in an emergency. In any case, phosphate should not be employed above the value at which it is found to 'hideout' (see clause 35). In appropriate circumstances chelating agents or polymers may be used (see clause 29).

Table 3. Recommended water characteristics for water-tube boilers

Pressure at boiler outlet bar*	20	40	60	80	100	120	Above 130	Comments in 8.3.2
Feed water at economizer inlet								
Total hardness, mg/l in terms of CaCO ₃ max.	10	2	0.5	ND†	ND	ND	ND	—
pH value	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	(a)
Oxygen, mg/l as O ₂ max.	0.05	0.02	0.01	0.01	0.005	0.005	0.005	(b)
Iron + copper + nickel, mg/l max.	—	—	0.02	0.02	0.01	0.01	0.01	(c)
Total solids, alkalinity, silica	†	†	†	†	†	†	†	(d)
Oil	ND	ND	ND	ND	ND	ND	ND	—
Organic matter	†	†	†	†	†	†	†	(e)
Boiler water								
Sodium phosphate, mg/l as Na ₃ PO ₄ §	50 to 100	30 to 70	20 to 50	10 to 40	5 to 20	3 to 10	†	(f)
Caustic alkalinity, mg/l in terms of CaCO ₃ min.	300	150	60	30	10	5	2	(a)
Total alkalinity, mg/l in terms of CaCO ₃ max.	700	500	300	200	100	40	10	(g)
Silica†, mg/l as SiO ₂ max.	Less than 0.4 of the caustic alkalinity		20	10	†	†	†	(h)
Sodium sulphite, mg/l as Na ₂ SO ₃	30 to 50	20 to 40	15 to 30	10 to 20	†	†	—	(b)
or								
Hydrazine, mg/l as N ₂ H ₄	0.1 to 1.0	0.1 to 0.5	0.05 to 0.3	0.05 to 0.1	†	†	†	(b)
Suspended solids, mg/l max.	200	50	—	—	—	—	—	(g)
Dissolved solids, mg/l max.	3000	2000	1200	700	350	100	15	(g)
Chloride, mg/l as Cl ⁻ max.	—	—	—	—	10	5	1	—

— Not applicable.

* 1 bar = 10⁵ N/m² = 100 kPa.

† Numerical values depend upon circumstances but the comments are relevant.

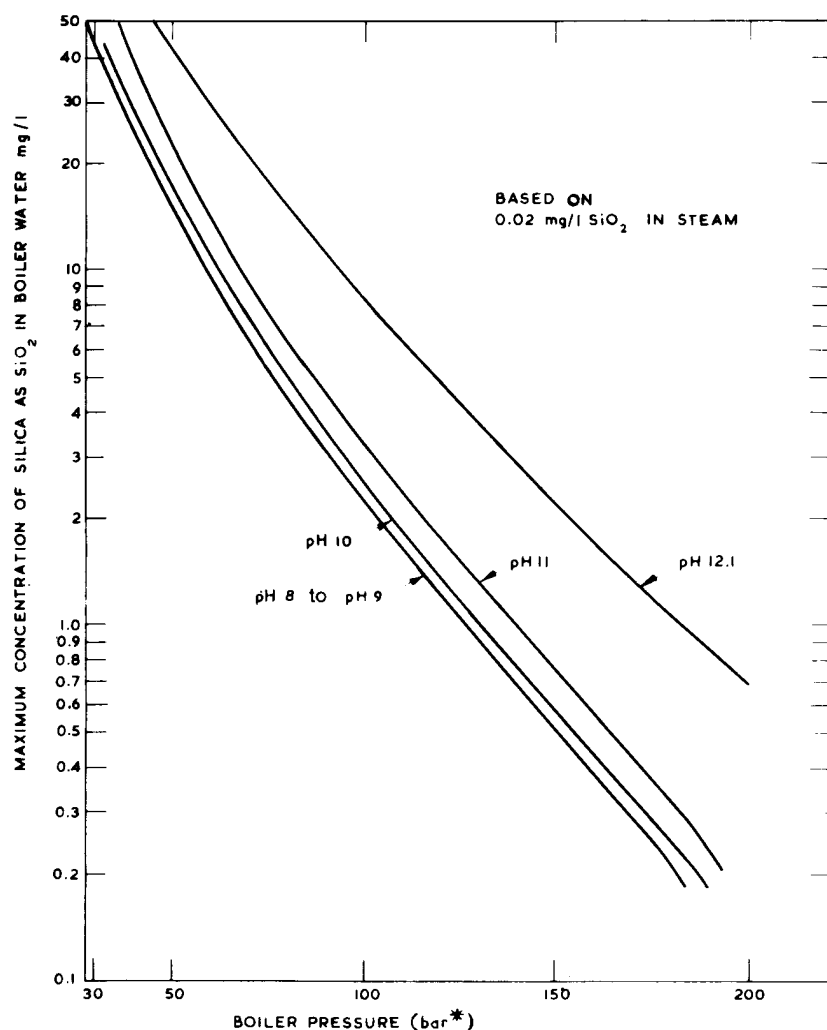
‡ ND not detectable.

§ Phosphate is usually added as sodium phosphate but determined as phosphate (PO₄³⁻); Na₃PO₄ = 1.73 × PO₄³⁻.

(g) **Solids and alkalinity in boiler water.** The maxima for total alkalinity, suspended solids and dissolved solids are set in relation to steam purity. Exceeding these values may lead to carryover of boiler water with the steam (see clause 11). The recommended alkalinity may require dealkalization of the make-up water.

Owing to the risk of on-load corrosion it is recommended that boilers at pressures in excess of about 80 bar should operate at the lowest practicable concentrations of impurities.

(h) **Silica in boiler water.** Lower concentrations of silica may be advisable for steam for turbines, which generally require less than 0.02 mg/l silica in steam. Figure 3 shows the maximum concentrations of silica in boiler water to ensure that this is achieved. These values should also be applied to all boilers operating above 80 bar. (See the fourth paragraph of 8.3.1.)



* 1 bar = 10^5 N/m^2 = 100 kPa

Figure 3. Maximum concentration of silica in boiler water

8.4 Once-through boilers. Ideally, in order to prevent scaling and deposition, once-through boilers require a feed water containing no solids that will produce a dry residue on evaporation.

The conditions given in table 4 are generally acceptable for normal continuous operation. Higher values may often be tolerated for short periods such as during start-up. The acceptable deviation from the values given depends on the plant design, e.g. the diameter of boiler tubes, the provision for blowing down, the extent and nature of condensate polishing.

The values given will generally permit operation for at least three years before acid cleaning. Guidance on whether cleaning is necessary should be obtained from regular analysis for solid matter entering with the feed water. However, the continuous conversion of the tube surface to magnetite may be equally important in determining the frequency of acid cleaning as magnetite (magnetic iron oxide (Fe_3O_4)) is less dense than steel and the tube bore is thereby reduced. This build-up may cause a significant increase in pressure drop over the unit, thus 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 the

Table 4. Recommended water characteristics for once-through boilers

Feed water at economizer inlet		
Total solids	mg/l max.	0.05
Conductivity at 20 °C after hydrogen cation exchange	$\mu\text{S/m}$ max.	20
Oxygen after physical deaeration	mg/l as O_2 max.	0.005
Silica	mg/l as SiO_2 max.	0.02
Iron	mg/l as Fe max.	0.01
Copper plus nickel	mg/l as Cu + Ni max.	0.002
pH value with copper or copper alloy feed heaters		8.5 to 9.2
pH value without copper or copper alloy feed heaters		9.2 to 9.5

pH value should also be precise, with no excessive over-dosing.

The feed water should be continuously dosed with hydrazine equivalent to twice the oxygen remaining after physical deaeration and with ammonia or a neutralizing amine to raise the pH value of the feed water to the recommended range or such pH range as is found by trial and analysis to minimize the concentrations of iron, copper and nickel in the condensate.

8.5 Sampling and testing. In tables 2, 3 and 4 a guide has been given to the chemical compositions required for feed water and boiler water. It cannot be too strongly emphasized how important it is to have a correct sampling, testing and recording routine. It is also essential to correlate the record of test results with details of the operation of the boiler plant. Only by these means can the composition of the boiler water be maintained to the desired standard and faults be diagnosed before boiler failure occurs.

Thought should be given not only to the position from which samples are to be taken but also to the timing, frequency and accuracy of the sampling. Each boiler plant should be considered individually and reference made to specialists if there is any doubt about this most important subject (see also BS 1328 and BS 3285). Suitable methods of test are described in BS 1427 and BS 2690.

The tests to be carried out 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.

9. Effect on required water quality of boiler plant design and operating conditions

9.1 Introduction. The recommended water qualities indicated in tables 2, 3 and 4 are generally applicable to boiler plant of current design. The manner in which design influences the necessary water conditions is described in this clause. For convenience the subject is considered under various headings but it should be borne in mind that these may be interrelated in some respect, e.g. deposits may form in the boiler as a result of corrosion in the condensate system.

The difficulties that may arise from the effects of impurities in feed water are described in clause 7. This clause follows the same sequence.

9.2 Feed system and economizer. The rating of the water treatment plant, the feed pump, the deaerator and the feed system generally should take into account the quantity of feed water required to replace the water lost by blowdown. Where blowdown would otherwise be excessive the method of treatment should be selected to reduce the concentration of the relevant impurity, e.g. silica, so that the blowdown may be decreased.

As far as the boiler is concerned, a continuous blowdown of up to 15 % of maximum continuous rating (MCR) is practicable for water-tube boilers in general, provided allowance is made in the boiler design for the small extra heat input required, but should a continuous blowdown of more than 1 % or 2 % be necessary, it is important that the

feed system be designed to provide for this. Particularly important is the feed pump capacity; a margin of 10 % to 15 % over boiler MCR is usually allowed to cater for boiler water level control and this margin should not be reduced by excessive blowdown.

In the case of shell boilers the available margin on the feed pump capacity depends on the temperature of the feed water and whether the operation of the pump is continuous or 'on/off'. The higher the feed temperature the greater the amount of steam that can be taken from the boiler and consequently the lower the margin available on the feed pump capacity in relation to the capacity of the boiler.

Frequently the composition of the feed water, the method of treatment of the make-up water and the percentage condensate return are not known when the boiler is manufactured. In these circumstances, if it becomes necessary to increase the blowdown above the design value, either the feed pump capacity should be increased or the amount of steam taken from the boiler reduced since the margin for water level control will be reduced by the amount of blowdown. However, a large percentage blowdown is not to be recommended in highly rated shell boilers and the water treatment plant should be designed accordingly. When continuous blowdown is employed, some heat recovery is possible by blowing down through a flash expansion chamber and feed heater.

The feed water temperature is important for other reasons. All centrifugal feed pumps require, on the impeller inlet, a pressure in excess of the vapour pressure of the liquid to be handled, to avoid any vaporization at this point. This 'over pressure' depends entirely on the pump design and is the minimum net positive suction head (NPSH) of the pump. If the feed water temperature becomes excessive for the particular pump then cavitation, loss in output and eventual damage to the pump will be experienced. The maximum permissible feed water temperature at a given head is thus dependent upon the pump design and the advice of the manufacturers should be sought.

In plant where a deaerator is not employed it is good practice, when arranging the layout of pipe work at a hot well, to avoid cold make-up water being fed to the tank in close proximity to the outlet connection. Make-up water at ambient temperature contains approximately 10 mg/l oxygen in solution and the make-up water should have the opportunity of mixing with hot returned condensate, but without undue reaeration, so that the final feed water will have as constant a composition as possible.

The prevention of corrosion during shut-down conditions is described in clause 36. With boilers of all types and pressures, deaeration should be brought into operation as soon as possible during start-up. Consideration should be given to providing a special pump for recycling the contents of the deaerator storage tank through the deaerator. With boilers operating at pressures above 80 bar it is important to limit the oxygen content of the feed water during start-up so as to prevent corrosion. Consideration should be given to installing, in the deaerator storage tank, means, such as electric heaters, of raising the temperature to boiling point so as to reduce the quantity of oxygen entering the boiler.

If a boiler is used intermittently it is, of course, necessary to ensure that the conditioning chemicals are applied in relation to the operation of the boiler.

If the rate of condensate return is very variable, a sufficiently large condensate/feed water tank should be provided and operated at a suitable water level so that condensate need not be discharged to waste. Such discharges lead to the need for additional make-up water and additional blowdown and thus to additional cost.

If a feed pump has glands designed to receive an inward flow of cooling water, impurities in the cooling water may contaminate the feed water. Relatively large quantities of oxygen may then pass to the previously deaerated feed water. In addition an 'auto-standby' pump will continue to leak its aerated cooling water into the suction pipework and to the working pump, thus aggravating the condition. The gland leakage is often constant so that at reduced load the contaminated feed water contains a proportionately higher concentration of oxygen. Dosing with sodium sulphite or hydrazine solution by means of a proportional dosing pump (i.e. the rate of dosing is proportional to the rate of flow of feed water) then becomes ineffective; the dose should be adjusted manually and a close supervision maintained. In such circumstances it is essential that samples for determination of dissolved oxygen in the feed water are taken downstream of the boiler feed pump while the dosage of the chemical oxygen scavenger is temporarily stopped.

If the feed pump is of the continuous running type with a variable rate of flow and a return flow (to a feed water tank for example), special consideration should be given to the method and equipment used for feed water conditioning in order to avoid over-treatment of the feed water during periods of reduced flow.

If an economizer is fitted, deaeration to the levels indicated in tables 3 and 4 is essential if serious corrosion of the economizer is to be prevented. If there is no economizer the tabulated values for oxygen after deaeration may, with discretion, be relaxed. It is generally desired that the feed water should be at a pH value of between 8.5 and 9.0 or as indicated in tables 2, 3 and 4. This minimizes corrosion of the feed lines and also the corrosion that is liable to occur when cold feed water comes into contact with hot boiler water, with the attendant release of the corrosive gases, carbon dioxide and oxygen.

At the lower pressures listed in table 3 small amounts of hardness in the feed water are permitted. It is unusual to have a 'steaming economizer' in boiler plant operating at low pressure, but should one be provided, then the feed water should contain as little hardness as possible, preferably less than 1 mg/l in terms of CaCO_3 , and phosphate should preferably be injected direct to the boiler drum or, less satisfactorily, intermittently to the feed water over short periods at regular intervals (slug addition). The phosphate should not be dosed continuously to the feed water. The point of injection into the drum should be remote from the steam off-take. If slug injection into the feed water is employed then the injection pump should be interlocked with the feed pump so that chemicals are introduced into the feed line only when the feed pump is running.

Economizers are generally made of cast iron, mild steel or low alloy steel but if made of austenitic steel, as are the economizers of some waste heat boilers associated with process plant, consideration should be given to the

possibility of stress corrosion. This may require extra measures to limit chloride and sodium hydroxide in the feed water and to ensure deaeration to a low level at all times including those of low flow rates through the deaerator, particularly, though not exclusively, during start-up.

9.3 Boiler. Heat-transfer surfaces are more prone to corrosion the higher the operating temperature, and hence pressure, and the higher the heat flux density. For these reasons tables 3 and 4 recommend lower oxygen concentrations and lower concentrations of salts in general at the higher operating pressures and at any heat flux density exceeding about 300 kW/m^2 . This represents an oversimplification, however, because other factors directly influence corrosion, such as the physical nature of the tube surfaces and the rate of circulation, the diameter of the tube and the proportions of steam and water. Advanced designs may need a still higher standard of water treatment.

Flame impingement on the highly rated furnace walls of a modern water-tube boiler or on the furnace tube of a shell boiler, is generally unlikely to lead directly to film-boiling and to overheating of tubes provided heat transfer is not impeded. Where a deposit is present, the metal temperature is increased, often leading to corrosion, or to the production of siliceous scale which has particularly low heat-transfer properties. Where the conditions in clause 8 are met, a deposit should not form to a thickness leading to failure in the event of intermittent flame impingement. However, where the conditions in the tables cannot be met, special care should be taken to avoid even intermittent flame impingement. If continuous flame impingement is unavoidable, the water quality has to be of an appropriately higher standard.

Steam purity is greatly influenced by turbulence of water and steam within the boiler shell or drum as well as by water quality. The detailed design and maintenance of steam-purifying equipment is beyond the scope of this British Standard, but their influence on steam purity should not be overlooked.

In general, shell boilers are not fitted with steam-purifying equipment. In order to maintain the desired steam purity it is important that, in addition to maintaining the recommended water conditions, the operating limits of pressure and output are observed (see clause 11).

The effect of operating a boiler at a pressure lower than designed is important because at the lower pressure the specific volume of steam is much increased. For example at 10 bar and 8 bar, respectively, the specific volumes are $0.198 \text{ m}^3/\text{kg}$ and $0.245 \text{ m}^3/\text{kg}$ (see figure 4). For the same evaporation rate, therefore, the steam velocity will be much greater at the lower pressure and in general there will be an adverse effect on steam purity and indeed severe priming may result. If it is not possible to install a pressure reducing valve in the steam line in order to operate the boiler at its design pressure, it may be necessary to limit the maximum rate of evaporation from the boiler. The boiler maker and water treatment specialist should be consulted.

It is also important that the boiler design is suited to the required operating conditions so that the change in water level and the general disturbance associated with load change (change in steam demand) do not seriously affect steam purity.

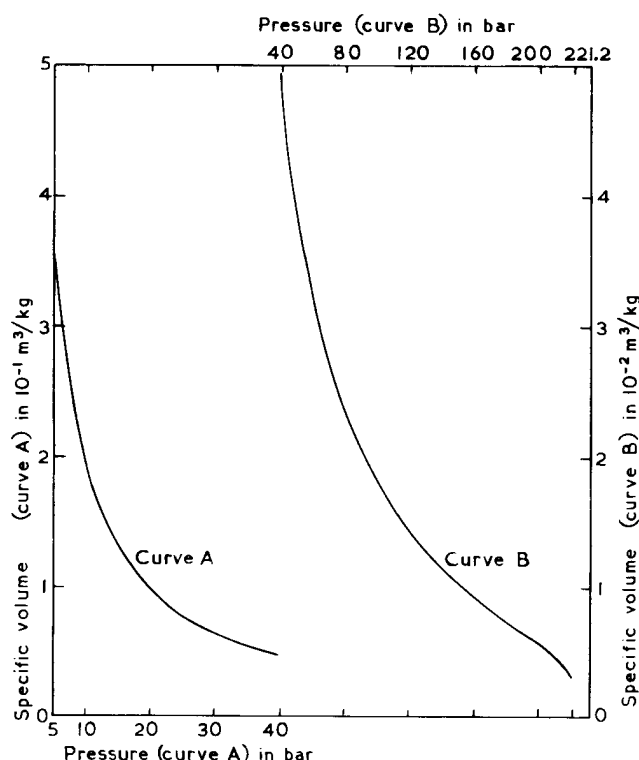


Figure 4. Variation of specific volume of steam with pressure

The effect of load change on steam purity depends on the sensitivity of the boiler automatic controls in response to the fall in boiler pressure and the maintenance of a suitable water level. A fall in boiler pressure leads to the formation of additional steam bubbles and possibly increased carry-over. More indirectly, the water level temporarily rises and this may affect the efficiency of primary steam-purifying equipment in water-tube boilers or, in shell boilers, entrainment of boiler water by the steam can result.

The operation of safety valves may have an effect similar to a severe load change. Steam bubbles are evolved, water level is affected and steam purity suffers.

The effect of load change and safety valve operation can be mitigated, if necessary, by operating the boiler at lower concentrations of solids in the boiler water than indicated in tables 2 and 3.

If a boiler such as a water-tube boiler is fitted with a mud-drum, the low water velocity in the drum may allow the innocuous settling of sludge, which can be readily removed by blowdown as described in clause 10. If a mud-drum is fitted, and if sludge is to be allowed to form, then clearly an effective method should be provided for scouring sludge from the drum.

If a mud-drum is not fitted, the formation of sludge should be avoided by eliminating the offending constituents from the make-up water and condensate. Small boxes incorporated in furnace wall water-circuits for distribution purposes are not suitable for sludge collection and blowing down; indeed, the operation of box drains for this purpose may lead to very severe damage to the wall concerned by its effect on the circulation of steam and water.

Boilers are sometimes designed so that distribution boxes are subject to direct heating. This may require feed water and boiler water of better qualities than those tabulated. The boiler maker should be consulted. Boilers fitted with nozzles or restrictors may require a standard of water

quality better than indicated in table 3. Nozzles may become blocked by scale formed from hardness salts, which are often formed in generating tubes and subsequently detached in the form of large flakes, or by iron oxide formed by corrosion of the feed system and detached in flake form, or by foreign matter such as weld splatter. Blockage caused by foreign matter and iron oxides is most likely to occur in the early months of service of new plant; appropriate mechanical and chemical cleaning methods should be applied along with the fitting of a protective strainer of suitable mesh.

Where a surface-type attemperator is incorporated in a furnace wall water-circuit, special consideration should be given to the removal of deposits by blowdown from the attemperator and the water quality should be such that the formation of deposits is minimized. Such equipment is particularly susceptible to corrosion beneath deposits and thus special attention should be given to corrosion of the feed and condensate systems as the major sources of deposited material.

Because of combustion considerations it is practicable to design water-tube boiler plant with higher heat flux densities for oil- and gas-firing than for coal-firing. This is an important consideration, particularly if coal-fired plant is converted to oil- or gas-firing, when localized areas of high heat transfer may be expected; improved water quality may be necessary and expert advice should be sought. Similar considerations apply when converting shell boilers from coal- to oil-firing although, owing to the design of mechanical stokers for coal-fired shell boilers, the heat flux densities are usually comparable with those of gas- or oil-fired shell boilers. When changing any boiler over to natural gas, improved water quality and boiler cleanliness are particularly important and expert advice should be sought.

9.4 Superheater. The avoidance of the deposition of salts in the superheater is contingent upon maintaining boiler water concentrations below those at which priming and foaming occur. It is also vital that where control of superheat temperature is by spray attemperation, the spray water should be of suitable quality (see 8.3.2(d) and table 3). In general, even horizontal superheater tubes do not drain perfectly and, under shut-down conditions, may be expected to retain condensed steam. The use of a neutralizing amine or ammonia could be advantageous in these circumstances since the condensate formed would tend to be alkaline.

9.5 Turbine. It is generally accepted that steam for condensing turbines should contain less than 0.02 mg/l silica; figure 3 gives the corresponding maximum concentrations of silica in boiler water. Non-condensing turbines may accept a higher concentration but, in general, it is considered prudent to specify less than 0.02 mg/l silica for them also. There is less agreement as to the precise 'total solids in steam' permissible. Turbine makers tend to call for 'no solids' but such a requirement is meaningless. The results of using modern analytical techniques such as sodium analysers for measuring steam purity suggest that a more realistic value to be aimed at would be 0.1 mg/l total solids. Indeed, a common guarantee requirement for a modern turbine is for less than 0.03 mg/l sodium in steam. Modern turbines tend to have small clearances and it is not advisable to depend on quoted nominal values of 0.5 mg/l to 1.0 mg/l for total solids, but to control the steam purity from analysis of steam samples. Where the efficiency of the

boiler's mechanical steam purifying equipment is doubtful or when turbine clearances are small, boiler water concentrations of total solids, total alkalinity etc., lower than tabulated may be necessary.

9.6 Condensate system. The prevention of corrosion in condensate systems is described generally in clause 33; this corrosion is caused by dissolved oxygen and carbon dioxide. Condensate systems should be designed so as to minimize the risk of condensate line corrosion, otherwise great difficulty may be met in remedying matters afterwards.

The solubilities of oxygen and carbon dioxide are less in hot water than in cold water, consequently condensate systems that are extensive and tend to run cool are more likely to suffer unacceptable corrosion than systems operating close to saturation temperature (i.e. systems from which the condensate is removed before it has time to cool). It follows that careful venting and selection of the type and number of steam traps will minimize corrosion. Where existing systems omit these features consideration should be given to the capital expenditure for a deaerator or make-up plant of the dealkalization type.

Precautions should also be taken to avoid contact between the condensate and air. Oxygen concentration is perhaps the most important single factor in condensate line corrosion and, therefore, the condensate should be maintained as hot as possible so that, if it comes into contact with the atmosphere, as little oxygen as possible is taken into solution.

Condensate systems running partly filled with cool aerated condensate are prone to corrosion and avoidance of this physical condition is the only real answer. Alleviation of corrosion may be obtained by chemical means described in clause 33.

10. Control of concentration of solids in boiler water

10.1 General. When water containing dissolved impurities is boiled and the vapour (steam) is driven off, most of the salts remain and concentrate in the diminishing 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. These particular impurities will cease to concentrate as dissolved solids, but the suspended solids so formed will concentrate.

In boiler design it is difficult to prevent the entrainment of small amounts of boiler water with the steam though this can be greatly limited. 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 it is necessary to control the concentrations of dissolved and suspended solids in the boiler water. At pressures greater than 40 bar some solids have a significant solubility in steam.

In a once-through boiler in which all the entering water is converted into steam, it is only by control of the feed water purity that the cleanliness of the heating surfaces and the purity of the steam can be controlled. In other types of boiler, steam is generated from a bulk of circulating boiler water; the steam purity and the cleanliness of the heating surfaces in this category of boiler can be controlled by limiting the concentrations of solids in the boiler water. This is 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 is often a cheaper alternative than the provision of extremely pure feed water.

In practice, one of several impurities in the boiler feed water may be critical with respect to its concentration in the boiler water. The following are examples.

- (a) The level of dissolved solids should be restricted to maintain steam purity and keep sodium salts in solution.
- (b) The silica content may have to be restricted to limit the level of silica in the steam or the formation of silica scales in the boiler.
- (c) In high pressure boilers the level of chloride ion should be limited to minimize corrosion.
- (d) The level of alkalinity should be limited to maintain steam purity and minimize caustic attack.
- (e) The level of suspended solids should be restricted to below that at which adherent deposits form, or steam purity or circulation are impaired.

The recommended limits for these and other critical constituents are given in tables 2, 3 and 4. In certain special cases of design or operation limitations may have to be imposed that are not covered by this British Standard; it is then normal for a boiler manufacturer to recommend values for the maximum concentrations. In general these limits may be set from experience or determined by trial. Once set they should be scrupulously observed. The test method used for checking the limiting concentration should be the same as the one used to determine the limit.

Blowdown may be continuous or intermittent, or a combination of both. It may be manually or automatically controlled.

NOTE. The installation and operation of blowdown systems must meet certain requirements of the Factories Act. In addition the boiler maker's recommendations on the operation of blowdown valves in certain positions on the boiler should be followed.

10.2 Continuous blowdown. Continuous blowdown is a continuous removal of boiler water controlled by a specially designed adjustable valve or by an orifice plate. The installation of heat recovery equipment may be economically justified. Suspended solids may block or erode the adjustable valve or orifice plate and continuous blowdown is therefore usually limited to the control of dissolved solids. Additional manual blowdown is necessary to control suspended solids and prevent the build-up of sludge.

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

10.4 Calculation of blowdown. The formulae in this subclause may be used to estimate the minimum quantity