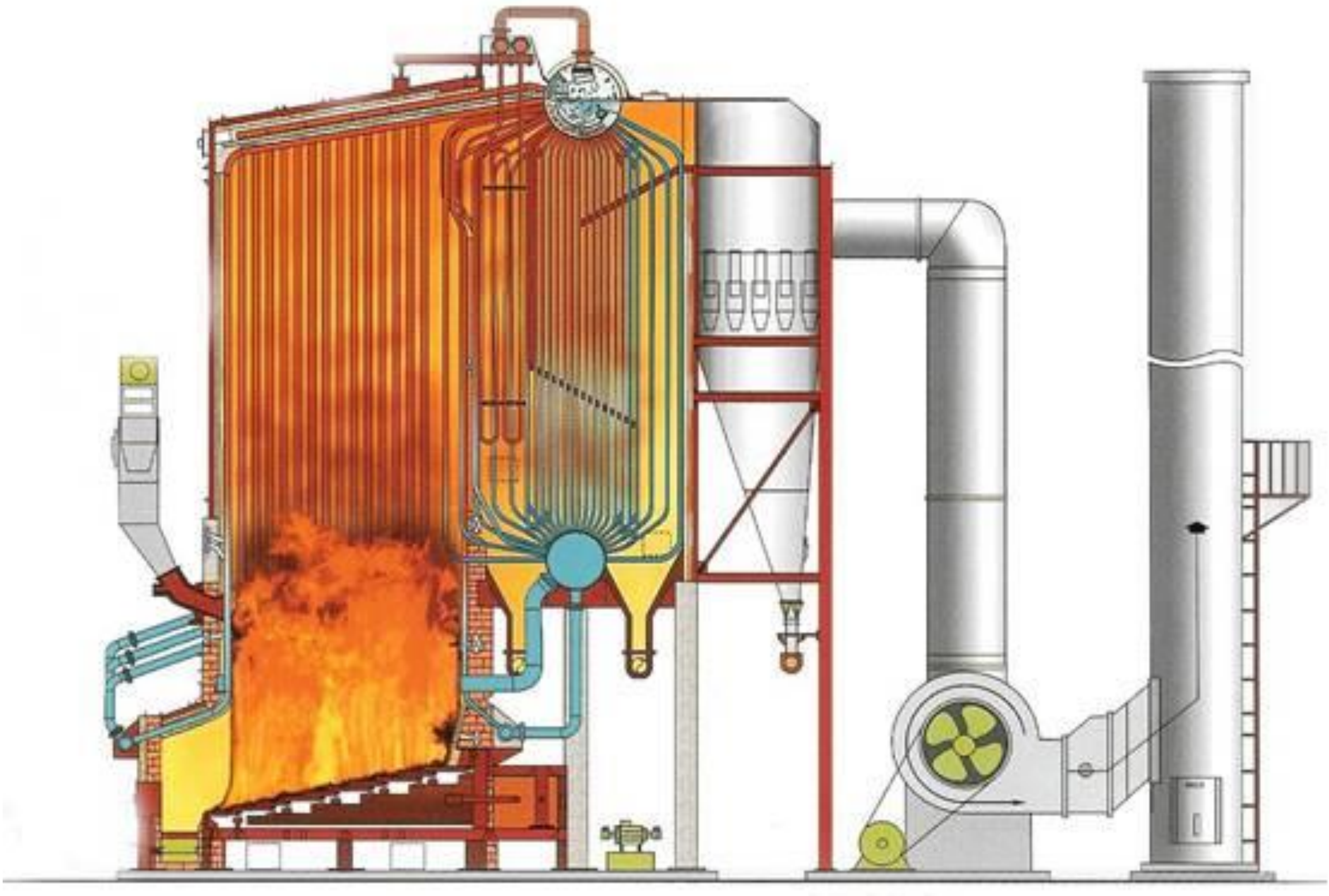
Guidance on Safe Operation of Water Tube Boilers

Ref: BG11



Combustion Engineering Association

Guidance on Safe Operation of Water Tube Boilers (Ref: BG11)

A document by The Combustion Engineering Association

Edition 1 – February 2021

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Foreword

This document, Guidance on the Safe Operation of Water Tube Boilers (Ref: BG11) has been developed and written by the Combustion Engineering Association (CEA) in consultation with other stakeholders within the boiler industry to help designers, managers and operators of new and existing water tube boiler systems make health and safety and environmental improvements in the industry.

This publication should not be regarded as an authoritative interpretation of the law, nor a mandatory legal requirement. However, if the guidance provided is followed, it will normally be regarded as sufficient to comply with the relevant health and safety duties.

The CEA is an educational charity which promotes the science of combustion engineering in commercial and industrial sectors. The CEA is concerned with industry good practice and the safe and efficient operation of combustion related plant and equipment.

In memory of our friend and colleague Malcolm Semple

Acknowledgments

The CEA acknowledges the contribution of several individuals, Member companies and partner organisations in the compiling of the information herein, including a number of BOAS Cat 3 Trainers and Assessors, and:

- Allianz UK
- British Engineering Services
- Deep Water Blue Ltd
- Delta-Mobrey
- Emerson Process Management
- Energy & Environmental Solutions
- Thermo Technology Ltd
- TJB Risk Engineering & Consultancy Ltd.
- Uniper Technologies Limited

Front cover picture courtesy of Thermo Technology Ltd.

In this document the following words convey specific meaning:

Should: Compliance with this clause is not essential where supported by risk assessment and/or design calculation.

Shall: Compliance with this clause is required in order to claim compliance with this document.

Must: Compliance with this clause is a legal requirement within the United Kingdom.

Legislation may not be the same for other jurisdictions, but the 'best practice' principles remain valid throughout the industry.

Unless otherwise stated, all pressures refer to gauge pressure.

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1 INTRODUCTION

Guidance on the Safe Operation of Water Tube Boilers (Ref: BG11) is a guidance document intended to assist the designers, managers, operators, maintenance personnel and Competent Persons (CP) of new and existing steam boiler systems in addressing the following issues:

- The safe and efficient use and operation of the boiler installation;
- Determining adequate supervision and maintenance requirements (levels and competence) that are consistent with the installed plant and its location;
- Reducing the likelihood of explosion or other dangers from events such as:
    - Loss of feed water or low water level;
    - Over-pressure;
    - Overheating e.g. due to excessive scale;
    - High wastage rates on metal surfaces;
    - Incomplete combustion of fuel;
- Using efficient boiler operation to avoid excessive pressure or thermal cycles and load swings which can accelerate component fatigue damage through to premature failure;
- Having the proper treatment and monitoring of the feed water and condensate to:
    - Minimise corrosion and scale; and
    - Avoid carry-over of water with the steam which in turn can cause steam hammer and other issues;
- Compliance with various legal requirements, in particular that for periodic examination by a CP in accordance with a Written Scheme of Examination (WSE) and all relevant environmental legislation.

Water tube boilers are large and expensive items of capital plant that frequently have a service life of 25 years or more. It is not possible in this document to cover every type of boiler or every installation scenario for water tube boilers, but the safe operation and maintenance of boilers that have been in service for many years is of equal importance to the design and operation of new boilers; references in the text may include plant items and techniques that are no longer available but still in daily use.

One important aspect of water tube boiler design and operation is the availability, maintenance and monitoring of appropriate high quality water supplies. Many volumes of excellent material exist that cover this subject in more detail, so the references to water treatment plant and water quality in this document are here as a reminder of the general principles and the reasons for maintaining good quality water and not a detailed explanation of the individual plant items or techniques required which will be bespoke to each and every installation.

Another significant consideration is the selection and treatment of the correct metals and alloys in various boiler parts commensurate with the type of fuel to be combusted. The vast majority of the damage that occurs in a water tube boiler results from corrosion and erosion effects which commonly act in combination to contribute to excessive local wastage rates on metal parts.

Water tube boilers come in many shapes and sizes, use a wider variety of fuels than any other boiler type, and serve a range of industries in many different sectors. It would be impossible to cover every aspect of design, operation and maintenance of all such installations in one document. The contributors to this guidance have used their combined years of experience to bring together as many elements as possible, but if errors are found or adjustments to the text are required, please contact the CEA for clarification and for amendments to be made.

This document will be kept under review and amended as necessary in the light of emerging technologies, improved working practices, new legislation or any other relevant aspect.

2 SCOPE

This document applies to all industrial and commercial water tube steam and hot water boiler plant operating at a working pressure up to 100 bar and utilising a wide variety of fuels or heat sources including fired and unfired heat recovery steam generators (HRSG) where appropriate. Whilst the cut off pressure for this guidance is set at 100 bar there are many aspects of boiler operation and maintenance herein which are equally applicable to higher pressure boilers.

For the purpose of this guidance, the boiler assembly includes:

- The water tube boiler including all the pressure parts from the feed water inlet (including the inlet valve) up to and including the steam or hot water outlet (including the outlet valve or, if there is no valve, the first circumferential weld or flange downstream of the outlet header);
- All superheaters, re-heaters, air heaters, economisers, their associated safety accessories and the interconnecting tubing that are heated by the gases and process of combustion and are not capable of isolation from the main system by interposing shut-off valves;
- The pipework that is connected to the boiler involved in services such as draining, venting, de-superheating, etc., up to and including the first isolating valve in the pipework downstream of the boiler;
- Re-heaters which are heated by the flue gas or independently fired, and are separately provided with their own safety accessories including all control and safety systems;
- Isolatable superheaters, re-heaters, economisers, air heaters and related interconnecting pipework;
- The heat supply or firing system;
- The means of feeding the fuel to the boiler including their control systems;
- The means of providing the boiler with feed water including the control system;
- The pressure expansion vessels and tanks of hot water generating plant.

Auxiliary components associated with the operation of the boiler and the User's system are included as indicated in the text. The delivery and storage of different fuels are specifically **not included**, nor is the handling of any related waste arising, such as ash.

A detailed description of water treatment plant and water treatment techniques is not provided in this document. For more information please refer to CEA's BG04, Guidance on Boiler Water Treatment, for boilers up to 32 bar, and other standards such as BS 2486 referenced in Appendix. 1.

The following boilers are **specifically excluded** from the scope of this guidance document:

- Shell and tube steam boilers (see BG01);
- Domestic and commercial hot water boilers (see BG02);
- Boilers heated by electricity;
- Coil type steam generators;
- Boilers other than stationary boilers;
- Nuclear primary circuits, the failure of which can cause an emission of radioactivity.

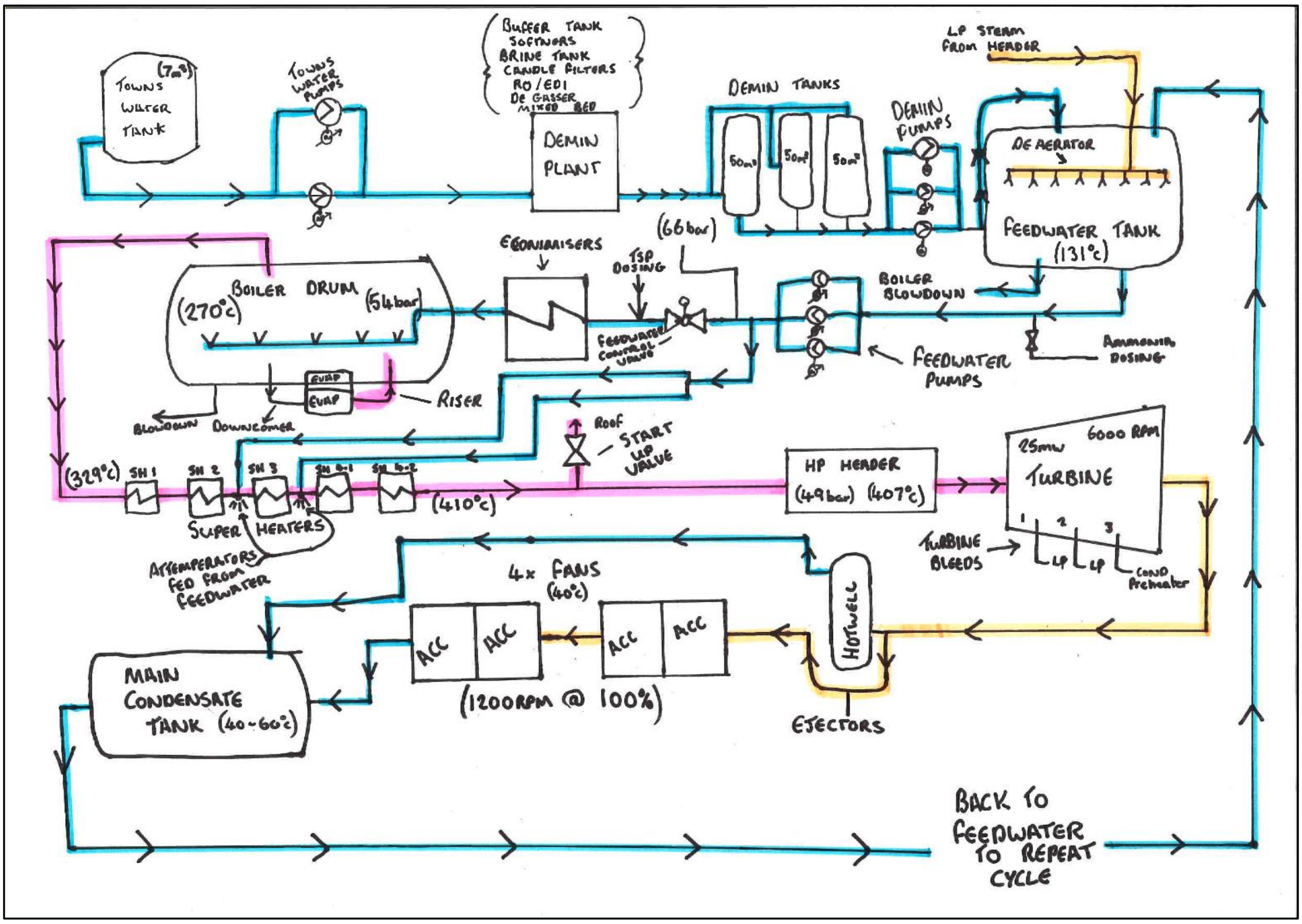
The purpose of this document is to provide water tube boiler system designers, operators and maintainers with a better understanding of how water tube boiler systems are designed and operated, and to assist those who operate, service and maintain the boiler system to do so safely, efficiently, and in a way that provides for protection of the environment.

It is not, however, a design manual nor is it a catalogue of manufacturer's individual items of equipment, and to ensure safe operation, sufficient procedures for all normal and abnormal activities (start-up, shut down action in emergency etc) need to be developed and documented for each boiler at each site. These procedures shall reflect the requirements of manufacturers' operating instructions and the site operational needs. The overall responsibility for the safe operation and maintenance of the plant rests solely with the Employer and owner of the plant.

This document has been compiled by CEA members and boiler industry specialists with reference to legislation and practices specifically relevant to installations in the UK. Regulations and guidance in other jurisdictions will differ, although many of the general principles and best practice guidelines herein may be relevant and equally applicable outside the UK.

Typical Water Tube Boilerhouse Schematic

Hand drawn diagram provided by Cat 3 BOAS candidate



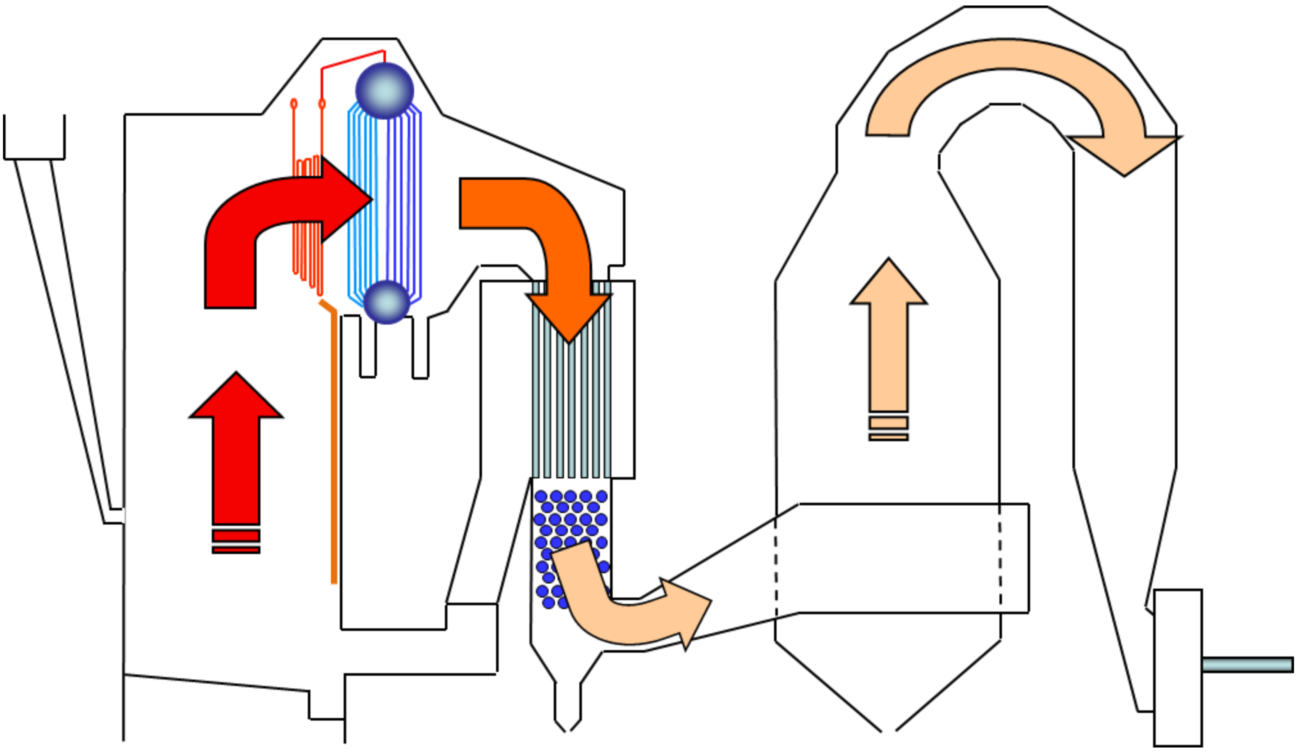
3 DESIGN AND INSTALLATION

It is not the purpose of this document to be a design manual for water tube boilers and their ancillaries, nor is it a list of different manufacturers' equipment, but there are design considerations that will impact on the final solution of new installations and some design concepts and equipment that operators of existing plants might find useful to consider when maintaining or improving their plants.

Water tube boilers and associated components might be designed to comply with UK (British Standards, BS) and European Standards (Euro Norm, EN) or standards from other jurisdictions such as the American Society of Mechanical Engineers (ASME). However, if the equipment is supplied to a site in the UK, all new and substantially modified steam raising boilers and relevant hot water boilers must be designed to satisfy all relevant requirements of the Pressure Equipment (Safety) Regulations (PER) as well as other relevant UK legislation.

Plants in the UK have been designed and installed to the ASME codes which are not the same as BS EN 12952 and have different requirements; reference will be made herein to the ASME codes where appropriate. BS EN 12952 applies equally for steam and hot water boilers.

When repairs or modifications, including changes to control systems or commissioning of a new system, are undertaken, the risk assessments must be reviewed with a view to eliminating the risks or reducing them to a level as low as reasonably practicable (ALARP).



Typical general arrangement of solid fuelled single pass water tube boiler with superheater, air heater, economiser and scrubber – Thermo Technology Ltd

This document is generally intended to cover fired boilers - boilers which are unfired and/or supplementary/auxiliary fired such as Heat Recovery Steam Generators (HRSG) are not covered in detail. Controls such as the low water level limiters will not necessarily shut off the gas turbine or other heat source and an HRSG may be designed with a boiler gas bypass damper which ensures the boiler is isolated from the hot gases when the water level is below an acceptable level. Bypassing the boiler in these circumstances might give rise to other considerations in the design such as noise levels (indicating the use of silencers) and damper control.

EN 12952-Water tube boilers and auxiliary installations

The European Standard series EN 12952 concerning water tube boilers and auxiliary installations consists of the following parts:

- Part 1: General;
- Part 2: Materials for pressure parts of boilers and accessories;
- Part 3: Design and calculation for pressure parts;
- Part 4: In service boiler life expectancy calculations;
- Part 5: Workmanship and construction of pressure parts of the boiler;
- Part 6: Inspection during construction, documentation and marking of pressure parts of the boiler;
- Part 7: Requirements for equipment for the boiler;
- Part 8: Requirements for firing systems for liquid and gaseous fuels for the boiler;
- Part 9: Requirements for firing systems for pulverized solid fuels for the boiler;
- Part 10: Requirements for safeguards against excessive pressure;
- Part 11: Requirements for limiting devices of the boiler and accessories;
- Part 12: Requirements for boiler feed water and boiler water quality;
- Part 13: Requirements for flue gas cleaning systems;
- Part 14: Requirements for flue gas DENOX systems using liquefied pressurized ammonia and ammonia water solution;
- Part 15: Acceptance tests;
- Part 16: Requirements for grate and fluidized-bed firing systems for solid fuels for the boiler;
- Part 17: Guideline for the involvement of an inspection body independent of the manufacturer; CR 12952.

3.1 Design Considerations – General Principles

Many trades and professions are involved in the design, construction, operation and maintenance of a water tube boiler system, so it is essential that all items of equipment, instrumentation and controls are designed and installed by suitably qualified and experienced personnel in accordance with the manufacturers' instructions.

The designs of components, systems and the overall scheme shall be based on the results of a hazard and operability study (HAZOP) or risk assessment at every stage, and use relevant information from the appropriate design standards which provide further detail on the construction of water tube boilers and their equipment.

When a system is designed, all of the operational aspects shall be taken into consideration at the conception or HAZOP stage; it is usually far more complicated and expensive to make corrections once a new plant is being built or is in operation.

Boiler system conceptual designs shall address the following safety issues as a minimum:

- Boiler house ventilation - ensure adequate air supply for combustion. Designs shall comply with IGEM UP/10, IGEM UP/16 and BS 6644 as appropriate;
- The source of the boiler feed water, its effective treatment, and means for efficient monitoring of the water treatment plant, all in accordance with BS 2486:1997, BS EN 12952-12 and the manufacturers' instructions;
- Electrical installation - designs and installations to comply with BS 7671 IET Wiring Regulations;

  Note: Consideration should be given to the operating environment, ensuring that cable type, size, routing and connections will prevent erroneous operation and maintain the required integrity of the control system;
- Boilers shall fail-safe, i.e. ensuring that boilers enter a safe mode under automatic control on failure of any part without requiring manual intervention. They shall also have control integrity appropriate to their mode of operation;
- Critical alarms/limiters relating to plant safety shall default to lock-out and require manual reset as defined by BS EN 12952-11;
- Interruption of the electrical supply to water level and firing control equipment shall cut off the boiler automatically. In some circumstances it is necessary to provide a UPS (Uninterruptible Power Supply) for maintaining electrical supplies to specified items of plant (control system, FD/ID fans, feed water pumps, grate drive motors or other critical components) to prevent the boiler from catastrophic failure if electrical mains power is lost;
- Normal, abnormal and transient conditions including safe start-up and shut-down; automatic restart shall only be possible if the normal requirements for start-up are met and the boiler system has been designed to do so;
- Management of boiler blowdown (see BG03).

Other considerations in boiler and boiler house design include:

- Emergency procedures, including means for routine testing thereof;
- Appropriate types of controls and safety-related systems, both individual items and integrated systems of control;
- Site manning levels and competency;
- Testing and maintenance requirements;
- Safe access for operation and maintenance;
- Relevant aspects of the Construction Design and Management Regulations (CDM).

3.2 Water Tube Boiler Construction

Water tube boilers differ from shell type boilers in that the water is circulated inside tubes which are surrounded by the heat and the products of combustion. Small water tube boilers may be manufactured and assembled into a single unit, whereas larger units are usually manufactured in sections for assembly on site. Appendix 3 has diagrams of typical water tube boiler arrangements.

Water tube boilers mostly operate on the principle of natural water circulation however some boilers are forced circulation where natural circulation will not create sufficient water flow - particularly boilers with horizontal tubes where a pump is often provided to improve and ensure sufficient water circulation.

Steam generating tubes require adequate water flow to cool the tube metal temperature to an acceptable level. This can be achieved by natural circulation, forced circulation, or a combination of the two. Natural circulation is driven by the difference in density between steam and water, and is the normal choice where all steam generating tubes in the boiler are inclined or vertical.

In some natural circulation boilers, saturated water in the steam drum flows downwards, through lightly heated tubes, then up through more strongly heated tubes, before returning to the steam drum as a steam/water mixture. The average steam content of this mixture will be mainly dependant on boiler height and boiler pressure. Typical values of circulation ratio (the ratio of water to steam in a particular riser) will range from 3 water:1 steam for high pressure boilers to 20:1 for medium pressure boilers – to achieve the desired circulation ratio many water tube boilers are provided with unheated downcomers.

Steam drum internals are designed to separate the steam and water mixture rising up the tubes. Primary separation usually consists of perforated plates or cyclone separators. Before the steam leaves the steam drum, secondary separation using demisters or chevron driers will normally take place.

The heated tubes comprise multiple parallel paths, each containing different steam/water mixtures. The steam content of the mixture in a given tube will vary with the quantity of heat received by the tube and the mass flow entering the tube.

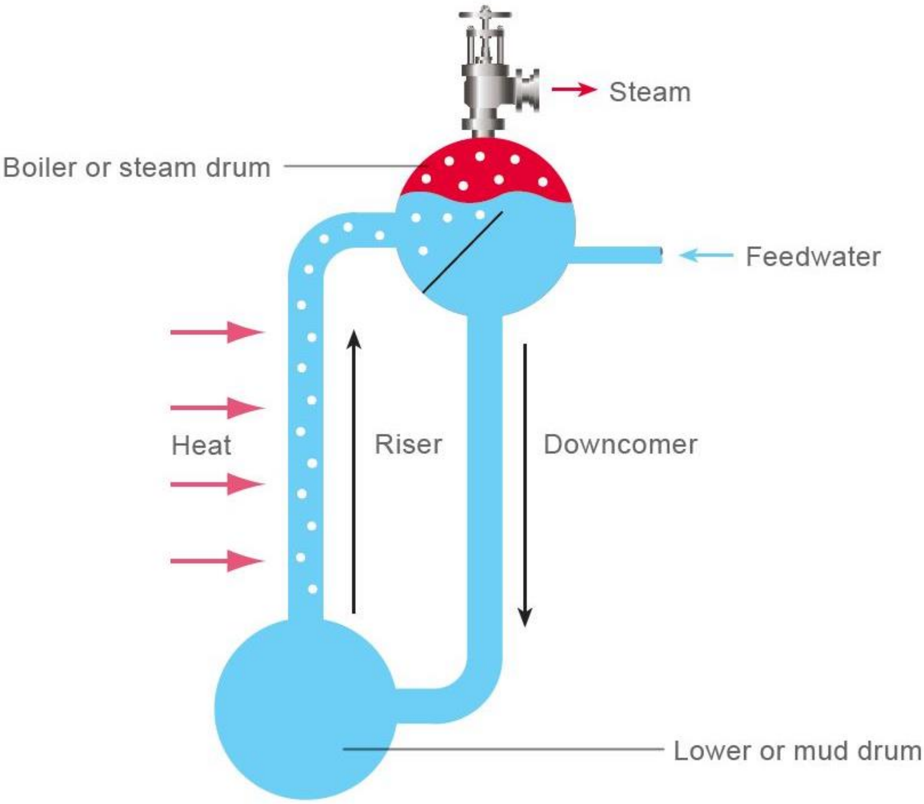
Some of the tubes generating less steam will have a higher hydrostatic head and these tubes operating under such conditions will become downcomers; conversely, tubes receiving more heat will generate more steam and are most likely to be risers. The circulation system will naturally balance so that the total downcomer flow will equal the total riser flow.

Each heated tube should maintain sufficient water flow to ensure that its entire circumference is effectively cooled by nucleate boiling. Nucleate boiling can be disrupted (Departure from Nucleate Boiling - DNB) by high heat flux or low flow, leading to tube failure. To ensure DNB does not occur, the circulation system should undergo theoretical modelling to estimate the water flow and steam content in each tube. Correlations can then be used to determine how close each tube is to the critical heat flux before DNB is predicted.

If a good margin on critical heat flux is not anticipated for all tubes, the design should be reviewed. Reducing friction and shock losses in suspect tube geometries will improve circulation. There are many other ways of improving circulation including:

- The addition of large bore, unheated downcomers.
- Segregation of selected parallel paths using steam drum baffles.

Continued heating creates steam bubbles in the riser tubes, the steam bubbles are separated from the hot water in the steam drum, and steam is taken off to a turbine or other steam process.



Simple layout of risers, downcomers, steam drum and mud drum - Spirax Sarco

Water tube boilers have several advantages over “shell and tube” or other boiler types:

- They have a relatively small water content for similar outputs, and therefore respond rapidly to load change and heat input; this also means any loss of pressure containment will likely be much less catastrophic compared to a shell boiler;
- The small diameter tubes and steam drum mean that much higher steam pressures can be tolerated; up to 160 bar may be used in power stations and 220 bar for ‘supercritical’ applications;
- A very wide range of different fuels can be burned, from traditional gas and oil through to many types of solid fuel and various biomass options.

However there are disadvantages:

- They are not as simple to make in the packaged form as shell boilers, which means that more work is required on site and capital costs may be significant;
- The option of multiple burners may give flexibility, but with many separate burners used in some installations, very complex control systems are necessary.

The detailed requirements for the construction of the boiler can be found in various parts of BS EN 12952.

The design may include multiple burners in any of the walls or roof, giving horizontal, or vertical firing options, along with facilities to control the steam temperature in between the superheater sections using attemperators or de-superheaters (either spray or drum type). This is particularly important to ensure the superheater tubes do not overheat and ensure that the temperature of the superheated steam is controlled within the limits of the steam users.

Other designs suitable for solid fuels will have a grate arrangement at the bottom of the furnace, either moving or fixed inclined, and may have additional burners in the walls or roof. Waste burning installations will usually require an incineration pass where exhaust gases are raised to a minimum of 850°C for typically at least 2 seconds, known as the residence time, which is for control of pollutants such as Persistent Organic Particles (POPs), dioxins and furans, and this may be achieved by the inclusion of additional gas or oil fired burners in a pass which is refractory lined. Some classes of waste, for example certain types of clinical waste, sometimes need even higher incineration temperatures.

Water tube boilers provide steam and heat to a wide variety of industrial processes. Early decisions relating to the use of the steam or hot water, the amount of condensate anticipated to be returned to the boiler, the fuel to be used, the demands of the process and the cycle of operation are all important aspects that might affect the design. A 90 bar 'once through' total loss pharmaceutical batch process requires a very different approach in every area of the design compared to a municipal waste burning boiler with a steam turbine where most of the condensate is recovered and re-used in the boiler.

High operating temperatures will often lead to selection of 'exotic' materials for certain parts of the boiler or its ancillaries. Operating temperatures in the boiler, and especially in associated pipework and components, of greater than 420ºC (Class 1 pipework) will require careful consideration of correct material selection and the effect of 'creep' on the material. Creep is the tendency of a solid material to slowly move or deform permanently as a result of long-term exposure to levels of stress below the yield strength. Creep deformation is "time-dependent" deformation which generally becomes noticeable at approximately 40% of the absolute melting temperature (Kelvin Scale) for metals and will considerably reduce the life cycle of the installation. Useful information regarding the operating life of the boiler can be obtained by carrying out creep assessments in conjunction with the CP during routine inspections.

Carbon steel is used in parts of the boiler where the material temperature can be kept to around 400ºC – where material temperatures greater than 400ºC are likely to be encountered (for example in the superheaters) pressure vessel grade chrome molybdenum steel alloys are used.

There is a potential risk from graphitisation and subsequent failure in carbon steel and 15Mo3/16Mo3 pressure parts (pressure vessel grade chrome molybdenum steel alloys). Chrome molybdenum steel based on 1% Chrome (13CrMo 4.5) or 2¼% Chrome material (10CrMo9.10) is suitable for operating between 410ºC and 510ºC, typically giving a creep life of approximately 100,000 hours of operation. This life is dependent on operating the superheaters at material temperatures within their design tolerance – any exposure to higher temperatures will reduce the creep life of the tubes so exposed. If superheater tubes are likely to be subjected to higher temperatures than the original design conditions it may be necessary to consider higher grade alloys – for example when converting a boiler from oil to gas firing.

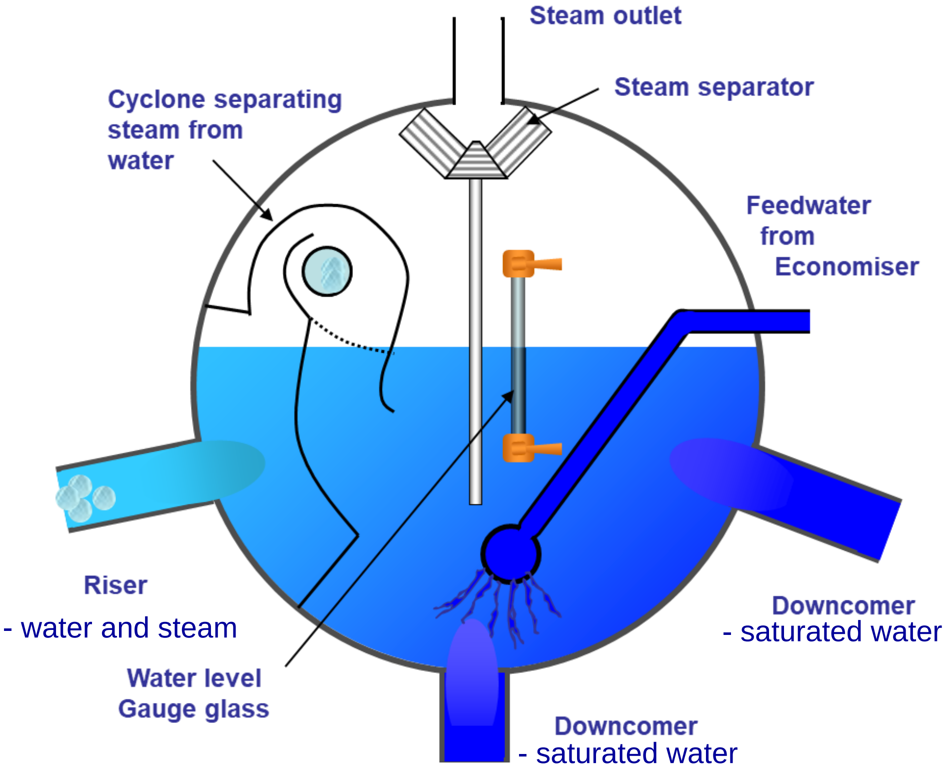
To operate at temperatures above 550ºC to 560ºC, steels with a higher chromium content are often employed, such as Grade 91, and more highly alloyed and austenitic grades where fireside corrosion represents a concern at elevated operating temperatures.

3.3 Boiler Ancillary Items

3.3.1 Steam Drum

The steam drum provides an important reservoir of water and steam at the upper end of the tubes. The drum collects the steam generated in the water tubes and acts as a phase-separator for the steam/water mixture. The drum will generally incorporate equipment to dry the steam before it leaves the drum such as a cyclone separator or demisting plates. Other important aspects related to the steam drum are internal feed water distributors, boiler water sample points, and chemical addition connection points.

Instrument tappings into the drum require special care; pipe diameters and pipe lengths specified by manufacturers and relevant standards shall be adhered to. It is recommended that all instruments and drum mounted devices have their own tappings. Some designs have been observed with common connection points for all instruments into one drum connection point, and any failure or fouling of the connection will render all connected instrumentation inaccurate and therefore useless.



Typical steam drum arrangement - Thermo Technology Ltd

BS EN 12952-10 makes specific provisions for safety valves on the boiler. Each steam drum and each isolatable heated compartment (e.g. reheater, superheater, economiser) shall be provided with at least one suitable safety device which shall ensure against excessive pressure. The total certified discharge capacity of all safety devices mounted on the boiler shall be at least equal to the maximum continuous rating (MCR) of the boiler. It is highly recommended that the number and position of safety valves is carefully considered at an early stage in the design to ensure that all parts of the boiler and its associated components remain properly protected under all normal and abnormal operating conditions.

The number and type of safety devices to be installed shall be specified by the boiler manufacturer; various different types and arrangements of safety valves may be specified, including direct-loaded safety valves, assisted safety valves or supplementary-loaded safety valves. If pilot-operated safety valves (POSV), consisting of a main valve controlled by signals from 3 pilot valves, or a controlled safety pressure relief system (CSPRS), consisting of a main valve controlled by signals from 3 sensing lines, are provided, particular care shall be taken to ensure that the control and safety features operate under all foreseeable circumstances and when the sensing devices or control units have defects.

The precise arrangement and number of safety valves fitted to the boiler and its ancillaries shall be determined by reference to the relevant standards. In the case of boilers without superheaters the safety valves or main valves of POSV or CSPRS shall be connected to the steam space.

Different rules apply for superheaters that cannot be isolated separately and superheaters that are separately isolatable, and every reheater shall have at least one safety valve or main valve of POSV or CSPRS with a total discharge capacity of not less than the maximum steam flow for which the reheater is designed.

There shall be no shut off devices or excessive restrictions between the steam drum or other isolatable heated compartment and its protective safety devices or between the safety devices and their points of discharge. All safety devices shall be accessible for functional testing and maintenance. The suitability of the safety devices shall be demonstrated by a hot test on the assembled boiler.

3.3.2 Superheaters

The value of superheated steam is in its internal energy that can be used, for example, in mechanical expansion against turbine blades, reducing condensate formation or promoting chemical reactions. The superheated steam in these applications can release very large quantities of internal energy whilst remaining above the condensation temperature of water vapour at the pressures at which reaction turbines operate. For driving turbines, a superheated steam cycle is more thermally efficient than one based on saturated steam.

Water vapour containing entrained liquid droplets is generally not compressible at high pressures. In a reciprocating engine or turbine, if steam doing work cools to a temperature at which liquid droplets form then the water droplets entrained in the fluid flow may cause droplet erosion in pipework and in-line components and could strike the mechanical parts with enough force to bend, crack or fracture them. Some steam turbines are designed for this eventuality, but it is still an undesirable operational risk.

Superheating and pressure reduction through expansion ensures that the steam flow remains as a compressible gas throughout its passage through a turbine, helping to prevent damage of the internal moving parts. Wet steam should be avoided and the design of the superheaters and the associated attemperation method should similarly be such that wet steam is avoided under all normal operating conditions.

Superheaters are designed and installed in different ways. In some water tube boilers, radiant tubes are placed hanging over the top of the boiler furnace, positioned in the boiler's combustion chamber so the superheater tubes instantly absorb the radiant heat from the combustion inside the furnace. These tubes will absorb the second greatest heat energy, after the wall tubes (risers).

Alternatively, superheater tubes placed in the flow of the flue gases that still contain heat from the combustion process will absorb heat from the exhaust gases by convection.

A further variation is to have a separately fired superheater that is placed apart from the main boiler and has own separate combustion system using additional burners in the area of superheater tubes.

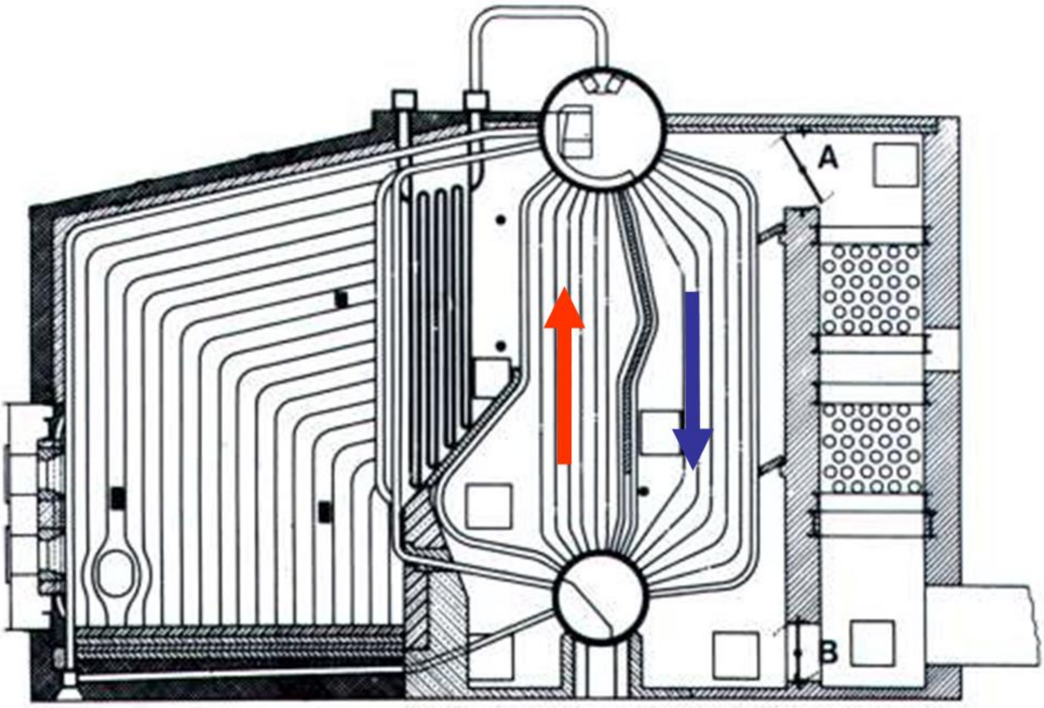
A typical arrangement is to combine the characteristics of radiant and convection superheaters, resulting in more homogeneous superheated steam temperature output at different steam flows. However recent designs tend to use convection superheaters which are protected from the radiant heat – this assists in controlling material temperatures particularly during start-up when there is no flow of steam through the superheaters, steam temperature being controlled with one or more spray attemperators which are arranged between superheater sections. A further method of controlling metal temperature in the superheaters is to use a parallel flow arrangement, where the steam and flue gas move in the same direction. Parallel flow is often found in the final superheater section which is usually located in the zone with the highest flue gas temperature.

Superheated steam at high pressure is invisible at the point of the leak and very dangerous when occurring outside the boiler casing. It is therefore unsafe to enter an area around the boiler where a superheated steam leak may be suspected but difficult to diagnose if the actual source of the leak is invisible. Local procedures should identify the most appropriate method of addressing this issue and should be strictly followed, including ensuring that more than one person is in attendance and that any devices used for leak detection are selected with personnel safety as the primary objective.

Superheaters need steam cooling, especially on start-up, which is often achieved through venting, usually on the outlet header, but the sequence of actions is important; superheater drains should always be open on start-up and this is critical for safe operation. As with all boiler start-up routines it is important to look for leaks and failures as the boiler warms up, and be aware of the risk of hydrogen fires when venting.

An initial shallow start-up curve is best, after which the heating can be ramped up at a faster rate; when steam starts to flow through the superheaters it provides a cooling effect and helps keep the superheater tubes within their design temperature. Prior to steam passing through the superheaters the only way this temperature can be controlled is by limiting the firing rate and gas temperature in the superheater zone.

Operators shall follow the manufacturer's start up curve to allow circulation to develop within the boiler and also even out the mechanical expansion of the boiler which can grow several centimetres as the temperature rises.



Water circulation – drum risers and downcomers – steam drum at the top, water (or mud) drum at the bottom - Thermo Technology Ltd

It is important to open the superheater vent on boiler start-up and also in the event of the turbine or other steam users no longer calling for steam – this ensures that whenever the boiler is firing there is a flow of steam though the superheaters, thus maintaining the superheater material temperature within design conditions. Also, the superheater safety valve should be set to lift prior to the drum safety valves to prevent the superheaters from being starved of saturated steam when the boiler is firing and to ensure a flow of steam through the superheaters to cool the tubes as the safety valve lifts.

It is also important that a good flow of steam is always maintained through a superheater to keep the superheater tubes cooled. Therefore, no auxiliary supply of steam should be taken off before or between the superheater sections, for example for sootblowing. If steam is required for any auxiliary purpose like sootblowing it is better to pass all the steam through the superheaters then step down using a desuperheater.

Many water tube boilers have drain valves near to the superheaters. When starting up the boiler the drain valves should be open so that as pressure builds up condensate is pushed out. The drain valves are usually closed by operators manually once the drum is above a certain pressure although this may be done automatically by the control system.

Fuel Changing and Superheater Construction

If the fuel used in a boiler is to be changed the materials of construction and the superheater surface may also need to change, particularly when considering changing from coal or oil firing to natural gas firing. This is because natural gas is a poor radiator of heat and the flue gas exit temperature is therefore higher, resulting in higher gas temperatures reaching the superheaters with accompanying higher superheated steam temperatures and metal temperatures in the superheaters.

Additional attemperation may be required and the suitability of the superheater materials of construction may need to be reviewed and, if necessary, higher grade alloys used. It is therefore essential a design study is undertaken when any modifications to the fuels burnt in the boiler are being considered.

3.3.3 Attemperators and De-superheaters/Pressure Reducers

If accurate control of the degree of superheat is required, such as when steam is to be used to drive turbines, then an attemperator or de-superheater is often fitted. The terms attemperator and de-superheater are frequently used to describe very similar processes and equipment – the term used in each case is usually decided by the manufacturer. They are often installed between superheater stages or sections to reduce steam temperature. Note that where water injection is used for attemperation or de-superheating a higher water quality is required than that fed to the steam drum as the injected water becomes part of the delivered steam output.

An attemperator is generally used for controlling the superheat temperature as the steam leaves the boiler, either by spray in between the primary and secondary superheater or in an indirect heat exchanger. A de-superheater is used outside the boiler to reduce the superheated steam temperature close to the point of use.

- Spray attemperators use a modulating control valve mounted in the superheated steam line varying the amount of feed water injected directly into the superheated steam path in order to cool the steam.
- Drum attemperators work by using a proportion of the superheated steam that is recycled via pipework back through the steam drum, thereby giving up some heat energy back into the boiler drum water in order to cool the steam.

There are two general types of de-superheater:

- Spray type - direct contact – where water is sprayed into the superheated steam;
- Indirect – where superheated steam is passed through a heat exchanger.

Spray type - direct contact - attemperators and de-superheaters all work by introducing a fine mist of atomized feed water droplets into superheated steam flow. These water droplets evaporate and in so doing provide a cooling effect. After the point of introduction of the spray water there should be straight length of piping equivalent to at least 10 diameters after the point of introduction of the spray water; this allows time for the water to evaporate fully and avoids issues with erosion of bends caused by the impingement of water droplets.

It is usual for the upstream and downstream piping arrangements to be specified by the attemperator supplier. Note that spray water quality needs to be considered as some of the water treatment chemicals used in the boiler may not be suitable for use in the spray water. Most attemperators have a shield attached on the inside of the steam main at the point of atomisation to help stop erosion from impingement. This is frequently a point of interest for the CP during inspections, and often forms part of the WSE.

Indirect contact - The medium used to cool the superheated steam does not come into direct contact with it. A cooler liquid or gas may be employed as the cooling medium, for example, the surrounding air. Examples of this type of attemperator/de-superheater are shell and tube heat exchangers where the superheated steam is supplied to one side of the heat exchanger. This heat exchanger is often submerged in the water in either the boiler steam drum or the lower mud drum. The drum water is at saturation temperature and cools the superheated steam.

The temperature of the attemperated steam or de-superheated steam is normally controlled by measuring the temperature of the superheated steam after the attemperator/de-superheater and, where the steam then goes through a secondary superheater, measuring the steam temperature after this secondary superheater – the quantity of spray water is then automatically adjusted to achieve the set temperature. Where de-superheated steam is required it is normal to adjust the temperature to no less than 10ºC above the relevant saturation temperature thus avoiding wet saturation steam.

There are many designs of different types of de-superheater available, involving tube bundles, water baths, in-line sprays, water sprays, and single or multiple nozzle injection systems. All have advantages and disadvantages in cost, installation, use and maintenance, and manufacturers should be consulted for the best equipment for specific applications.

Pressure reducing and de-superheating stations (PRDS) are not normally installed as part of a boiler but as part of the steam system. PRDS can be used as a bypass of a process i.e. pass-out steam turbine, or to feed another lower pressure steam system. PRDS could be a combined functionality valve or two separate functional valves, but the Pressure Reducing (PR) function will be first in line to 'throttle' the steam down to the required working pressure at constant enthalpy, and then the de-superheating (DS) function will always be second by then spraying internally with water normally supplied by the boiler feed water system.

It is worth noting that Competent Persons (CP) inspecting water tube boilers are often very interested in looking for downstream erosion from badly atomised spray attemperators or de-superheaters.

3.3.4 Air pre-heating and economisers

Air preheaters are a type of heat exchanger where fresh incoming air to the boiler house is supplied through a heat exchange device positioned in the flue gas exit from the boiler. This air is fed to the burner as part of the combustion air supply in order to increase the efficiency of combustion.

Economisers are heat exchangers through which boiler feed water is pumped; the feed water arrives in the boiler drum at a higher temperature than would be the case if no economiser was fitted, and less energy is then required to raise the steam resulting in higher efficiency. It is normal for an economiser to be high pressure, running at the same pressure as the boiler, so the feed water comes from the high pressure boiler feed pumps through the economiser to pick up recovered heat energy and then into the boiler drum.

An important factor in economiser design is that it should not be so large that the flue gases are cooled below their dew point (the resulting liquor may be acidic and corrosive) or so that the feed water boils in the economiser (leading to uneven heating and higher stresses). To maximise the economiser heat recovery performance a continuous steady flow of boiler feed water through the economiser is required.

Where air heaters and economisers are both fitted, the air heater is normally last in line as the cooling medium is going to be 'fresh air' which is in the region of 10 to 30ºC whereas the cooling medium in the economiser is boiler feed water which is typically 110 to 130ºC so cannot pick up as much heat energy. On some installations using high moisture fuels it may be better to fit the economiser after the air heater to avoid the effects of high levels of condensation in the flue gas and achieve the greatest level of heat recovery.

Depending on the flue gas cleanliness, air heaters may be bypassed, particularly on multifuel boilers, for times when a less clean fuel is used, possibly a back-up fuel such as oil.

On some economisers automatic bypass valves are fitted that do not bring the feed water economiser into service until the boiler is sufficiently warm.

Apart from these constraints, these systems are usually operated at all times when the boiler is running, but if the stack temperature falls close to dew point the control system can apply constraints on combustion settings or economiser re-circulation can be instigated. This is typically needed during an infrequent cold snap.

3.3.5 Emissions Control Equipment - Bag Filters, Electrostatic Precipitators (ESP) and Injection Equipment (SCR and SNCR etc.).

The emissions to air from boiler installations will be regulated by various parts of environmental legislation according to the fuels burned, the size (net MWth rating) of the boiler(s), their location in relation to protected habitats, and other requirements. Early discussions with the Regulator responsible for the location of the installation are essential as the decisions relating to methods of air pollution management and control will affect the choice of abatement equipment.

Primary control of emissions from gas and light oil fired boilers will be by using low NOx burners in appropriately sized furnace spaces to reduce the NOx emissions at the burner, rather than generate the emissions and clean them up in the stack.

Flue gas recirculation is another technique that is commonly used for improving NOx performance on boiler plant. A proportion of the flue gas is taken through ducting back to the burner to help control thermal NOx.

For solid fuels, bag filters will be marginally more efficient for cleaning particulates from the exhaust gases but they do carry a risk of catching fire with certain fuel types. They require regular cleaning, maintenance and replacement which can affect continuity of boiler operation. Wet scrubbers are also used in some installations but they can have high power consumption and generally achieve lower dust removal efficiencies, especially for fine particles.

ESPs are an alternative to bag filters and can be cleaned more easily, but are marginally less efficient dealing with particulate matter. They may exhibit lower resistance to the passage of flue gases than a bag filter. Some installations have successfully used ESPs in line with bag filters. Installations with two parallel flue gas paths and sets of cleaning equipment with bypass arrangements in place have been used; this allows the cleaning equipment to be bypassed for maintenance purposes whilst keeping the boiler running, but may increase costs and complexity in terms of abatement equipment and the necessary control devices and interlocks.

Cyclones on their own are unlikely to provide for the reliable removal of small dust particles.

Scrubbing exhaust gases for NOx, SOx and other entrained air pollutants can be carried out in a number of different ways. Wet limestone based scrubbers are commonly used for SO_2 reduction, with dry sorbent injection offering an alternative. Selective catalytic reduction (SCR) using urea or ammonia and Selective Non Catalytic Reduction (SNCR) may both be suitable, used alone or together, to manage NOx emissions depending upon the constituents of the fuel and the combustion process employed. All these techniques should be used after the primary measures of flue gas recirculation, air preheat, fuel staging and low excess air have been considered.

Note that SCR is very temperature dependant and may not help during boiler warm up or if the boiler is being used as a warm standby.

Access platform for emissions monitoring testing – Thermo Technology Ltd

All abatement equipment takes up space in the boiler house or the area outside, requires good access for maintenance, needs electrical energy for increased fan power or ESP operation, and creates a waste product that has to be safely disposed of.

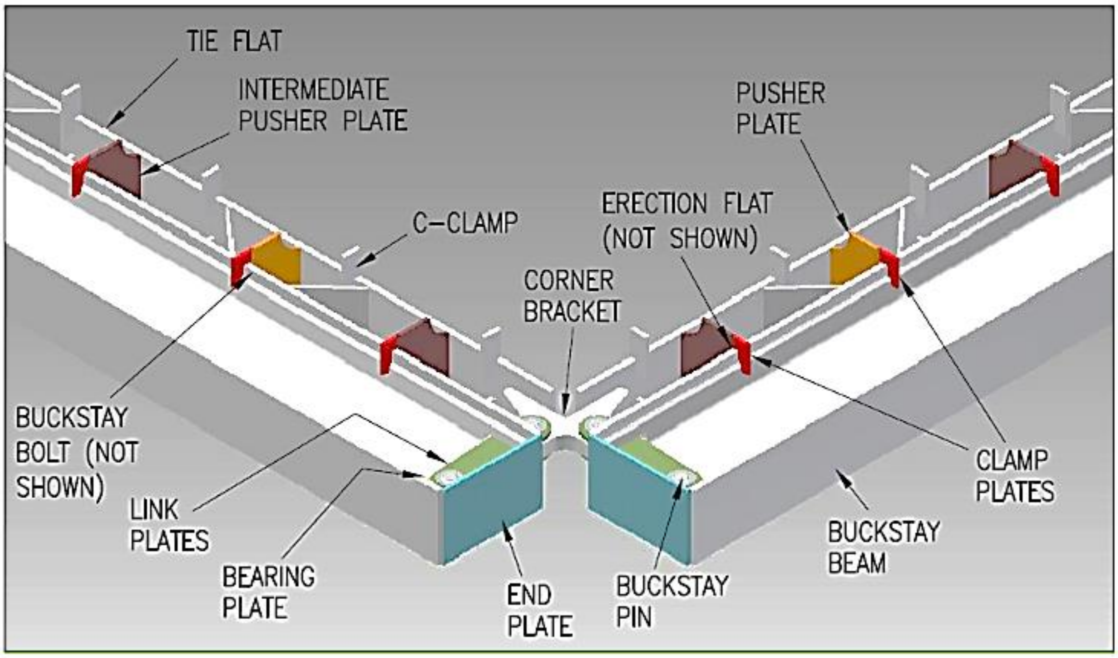
Environmental permits for water tube boiler installations will almost always require the operator to carry out continuous emissions monitoring (CEMS) and this necessitates the provision of suitably located measuring devices in the chimneys and flues, dedicated computerised recording and monitoring equipment, regular calibration and maintenance, and an access platform at the measuring point for routine testing of the accuracy of the installed CEMS equipment. The installation, maintenance, monitoring and reporting aspects of CEMS will all be subject to the conditions in the permit and the guidance in the Environment Agency Monitoring Certification Scheme (MCERTS) in England and Wales; other similar schemes operate elsewhere in the UK.

3.3.6 Boiler Stability and Support

The boiler will either be supported from below or suspended from above. Provision for expansion at the point of support may include sliding feet – these need to be routinely checked to ensure that expansion can take place, and on some boilers there is need to routinely lubricate the support feet.

Suspended boilers and suspended pipework will often have sprung supports which will have 'hot' and 'cold' positions marked and will need adjusting if not in the right position. Likewise some boilers and some pipework will be supported from below with sliding feet.

Buckstays are employed to maintain the structural integrity of the boiler furnace and should be periodically inspected to ensure good condition of plates, pins, beams and clamps etc., and ensure that means of expansion are not impaired. This is particularly important for boilers with furnaces operating at sub atmospheric pressures. Where other fuels are burned in the combustion chamber apart from the main fuel this can cause fluctuating combustion chamber pressures resulting in a disturbed flow through the boiler, and the boiler side walls move with the fluctuation in pressure (boiler 'panting'). Buckstay inspections under these operating conditions are particularly important.



Buckstay details

3.4 Control Systems and Instruments

Safe and efficient boiler operation depends on the boiler remaining within its safe parameters both during operation and under fault or emergency conditions. A wide range of additional equipment that can be fitted to the boilers is available to help ensure this.

Control equipment includes various sensors, limiters, control devices, relief devices and gauges for level, temperature, pressure etc. as well as the communication and alarm systems. The level of control and monitoring will depend on a variety of factors. In general, boilers with automatic control and remote monitoring systems will require more monitoring and control equipment than a locally manned boiler system.

New safety-related systems shall be designed, documented and applied according to the requirements of BS EN 61508 so that safety functions are determined, i.e. the Safety Integrity Level (SIL) of each safety function is specified and the measures used to achieve the specified SIL for each safety function are described. BS EN 50156, *Electrical Equipment for Furnaces and Ancillary Equipment* provides information on the application design and installation of electrical equipment.

Every employer shall ensure that, where appropriate, work equipment is provided with one or more readily accessible emergency stop control device (PUWER Reg 16). Large water tube boiler installations are likely to require more than one such device, but it is important that emergency devices are quickly and easily distinguishable as to their primary function since mal-operation or selecting and activating the wrong emergency control device may cause further harm or damage.

Control routines and instruments are frequently integrated into a combined computer based control and monitoring system. The relative reliability, repeatability and integrity of such systems is a distinct advantage, but no system is 100% fool proof. Operators should be able to check the operation of all systems with back-up transmitters or local devices to allow for calibration of instruments and maintenance of systems. It is also very good practice to include in the design a selection of maintenance controls built into the control philosophy so that authorised personnel can temporarily override sensor outputs and associated alarms for specified purposes during commissioning and fault finding activities, for example.

The control system should be designed to prevent erroneous data cascading through the controls causing a single point of failure for boiler operation. One example might be dealing with a temperature measurement that is used to correct a steam flow measurement; if the temperature measurement were to fail, the correction factor should be limited in the control algorithm and held at “last good value” or switched to nominal design conditions.

A thorough knowledge of the boiler design and the intended process is required in order for the controls engineer to design a comprehensive and safe control and instrumentation system. The inter-relationship and inter-dependence of integrated components is key to avoiding spurious trips and incompatible signals being produced.

Single points of failure, characterised often by single signals to multiple devices, should be avoided and ‘designed out’ at an early stage. It is often cheaper to provide a parallel path for a critical measurement in the original design than to retrofit such devices into a fully operational system.

Time for commissioning is essential – commissioning almost always takes longer than the programme allows, and is always the last element before plant start up, hence putting the commissioning engineers under unnecessary pressure. A thorough commissioning plan is required, covering all the elements documented at the HAZOP stage so that every control and monitoring device is checked and tested under normal and abnormal conditions to prove it works alone, and then checked again as part of a whole system.

It is essential to have a regular programme for the routine calibration of all critical instruments, and a requirement to test all critical instruments and any associated safety functionality as the boiler goes back into service following any shutdown or maintenance period. Instruments and control devices should be tested individually to ensure they perform the required function and then, more importantly, as part of an integrated system to demonstrate overall system functionality and safety.

3.4.1 Level Sensing Devices

BS EN 12952 part 7 section 5.4.1 says:

> *“All steam boilers, except once-through steam boilers, shall have at least two devices for indicating the boiler water level;*
>
> - *One device shall be a gauge, with an indicating column made of transparent material (the gauge glass); and either*
>   - *Two electronic or electrical devices for water level indication; or*
>   - *A water level controller indicating the water level; or*
>   - *A water level limiter indicating the water level.*
>
> *During operation, the boiler water level shall always be clearly indicated to the boiler attendant.*
>
> *A water gauge glass that is not used to indicate the water level to the boiler attendant during operation, may be isolated from the boiler.”*

Therefore, whenever the boiler is operating at least one operating sight glass which shows the water level in the steam drum must be available or another legally acceptable method of seeing the water level must be fitted for the operator to see where the water level is – the Hydrastep is one such alternative. Where boilers are overseen from a control room it is essential that the operator can see the water level either in the sight glass or the level derived from a legally approved alternative – this can be in the form of a monitor showing the sight glass or a repeat of the signal from a Hydrastep or equal.

Level Control and Limiters

Accurate boiler drum level control is critical to efficient and safe boiler operation. In large boiler installations, the water level in the boiler steam drum shall be precisely controlled to optimise steam production, maintain water circulation by ensuring the downcomers are always covered with water, maximise boiler efficiency and maintain safe operation. If the water level is too low, there is a risk of damage to the steam drum and the tubes, as well as a risk of the boiler overheating and exploding. If the level is too high, there is the possibility that water floods the superheaters causing damage, and in severe cases water will then be carried over into the turbine or process which otherwise relies upon the supply of clean dry steam. Even a small amount of water reaching a turbine can cause catastrophic damage to the turbine blades and the casing.

Boiler Codes (ASME) and BS EN standards recommend local level indicators combined with independent level transmitters to provide boiler drum level control and indication. No single fault shall lead to loss of the safety function, and safety function devices shall be independent of, or unaffected by, other functions i.e. control or monitoring. The safety function devices shall be designed to provide suitable and reliable protection, using principles such as redundancy, self-diagnosis, fail-safe and diversity.

For un-manned boilers the current revision of BS EN 12952-7:2012 requires 2 low level limiters and a High Level Limiter. On manned boilers only one low level limiter is required, and no high level limiter. Whilst a high-level alarm may not be mandatory on manned boilers it is still a useful aid to operators and therefore it is recommended that a reliable high-level alarm is fitted. Limiters using a “one out of two” voting system are required when analogue limiters are used instead of binary limiters.

Based on these requirements and the operational experiences of users, triple redundancy on boilers and feed water systems is becoming an industry standard.

Magnetic level indicators - provide a clearer indication of liquid level, but because they rely on a float they are not considered a ‘direct’ indication of level such as, for example, a glass gauge. However, magnetic level indicators are much easier to see and are often accepted as the secondary indication device.

Electronic steam/water gauging systems - can also be used to monitor water levels providing operators with a high visibility of boiler levels with very little maintenance and exceptional reliability.

DP (Differential Pressure) transmitters - are widely used for the control of boiler level as they meet the needs of the application for accuracy and reliability. However, because differential pressure transmitters are calibrated based upon a specific liquid density, errors are introduced into the level measurement as the density of the water and steam changes. These errors can be compensated within the control system to calculate the best possible level.

Guided Wave Radar (GWR) - For drum level control, GWR provides an excellent measurement solution because it is unaffected by changes in density and is able to operate under extreme conditions of pressure and temperature. This enables GWR, to provide accurate and reliable measurements, even when exposed to mechanical vibration and high turbulence. However, because GWR technology relies on the dielectric constant of the media, in this case steam, which changes as the temperature and pressure changes, dynamic compensation is required.

When choosing GWR it is important to check that it incorporates static and/or dynamic methods of compensating for the changes in dielectric constant. GWR with dynamic compensation will maintain highly accurate level measurements in saturated steam conditions without the need to introduce any compensation in the control system.

Boiler Drum Level Indication

To monitor boiler water, operators need access to a visual indication of the drum level. This is both an important safety check and also a requirement of BS EN 12952 and the Boiler and Pressure Vessel Code (BPVC) issued by the American Society of Mechanical Engineers (ASME). This direct and independent indication helps protect against damage caused by low and high water levels. The operating water level shall always be visible and the indicator shall extend from 30 mm below the minimum permissible water level to above the highest permissible water level.

Note that drum level indicating devices will suffer from density error which is inherent in any system using a remote water column. It is recommended to keep the distance between the drum and any water column to a minimum to reduce any temperature differential and therefore density error which would result in a difference in level. Manufacturers generally advise a maximum of 2000mm of pipework length in these circumstances.

In some boiler designs, particularly those with axial furnaces when the flue gas flows along the axis of the drum, the actual water level may vary within the steam drum. As the heat release rate reduces, so does the water level, and in some cases the final tubes become downcomers and the water level can naturally vary by 50 – 100mm between ends of the drum.

Traditionally, visual indication has been provided by level gauge (sight) glasses. These would be installed at each end of the boiler for inspection during operator rounds. However, experience has shown that boiler sight glasses can suffer from discolouration from contamination in the water making them difficult to read, and requiring regular maintenance to ensure they remain easily readable.

To address the issue of difficulties reading sight glasses, some plants have installed magnetic level indicators on boiler drums and feed water heaters. These provide better visibility and also reduce maintenance. However magnetic indicators are prone to the float sticking and cannot be considered a reliable alternative to a gauge/sight glass.

An acceptable, reliable alternative to a sight glass is a Hydrastep (see below) which is approved as a legally acceptable alternative to the visual sight glass. The Hydrastep is based on a series of independent electrical resistance measurements made concurrently to determine the presence of water or of steam at discrete levels in a side-arm vessel.

Sight glass installation - Emerson Process Management

The introduction of refraction using a backlight will also improve visibility, but does not reduce the maintenance requirements, and the advent of CCTV now allows remote monitoring of the sight glass. Even so, steam water gauging systems based on conductivity probes such as the Hydrastep give a clear visual display both locally and remotely, and have become the preferred solution for steam drum level indication. Often the Hydrastep is also used to provide a source of high and low water level alarms.

Magnetic Level Indicators

Magnetic level indicators utilise a magnetic coupling to a float housed within an external 'float' chamber. The float moves up and down as the water level changes, activating a series of lightweight magnetised indicators or flags. The red colour of the flags makes it easy to determine the level of colourless fluids, with the indicator being visible to the operator from more than 30 metres away.

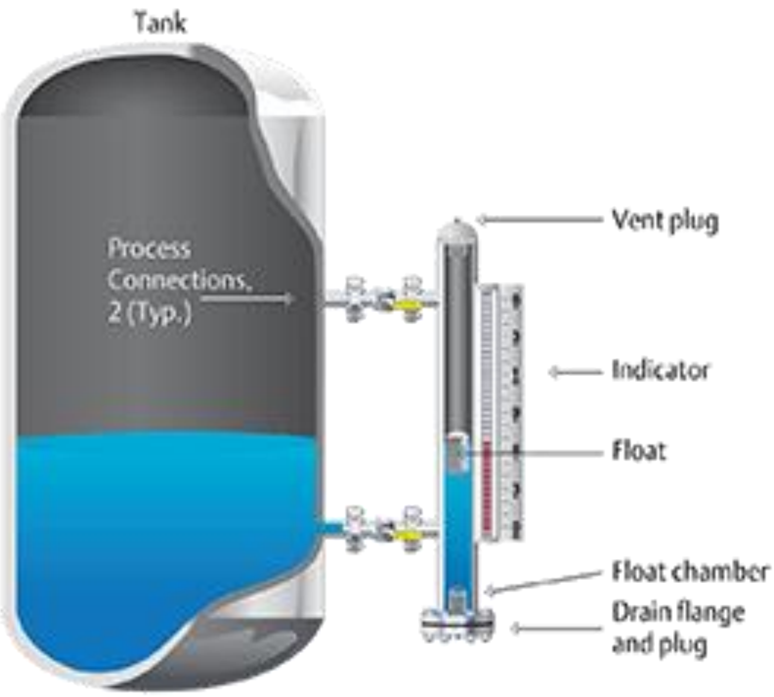
However, operation of these types of indicators may lead to false level indication; all level instruments mounted in a chamber separate from the drum are susceptible to floats sticking in the float chamber, blockages to either the water or the steam connection on the drum, and flaps sticking.

All these issues need to be considered and alternative more reliable indicators are recommended in addition to this type of indicator.

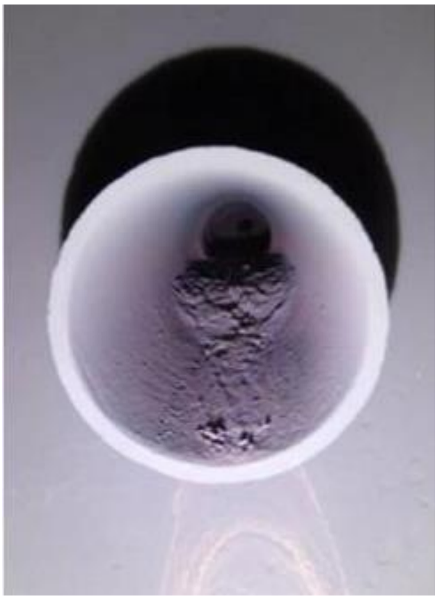
Magnetic level indicators offer a clear indication of liquid level and are usually installed in a chamber next to the boiler drum in which a magnetic float follows the drum water level. Because the contents of the steam drum do not come into contact with the glass surrounding the indicator flags, problems with coating, plating and fouling are eliminated, ensuring reliable level indication.

Because magnetic level indicators rely on a float to indicate the level, they are not considered a 'direct' indication of level like a gauge glass. Gauge glasses are still required, but because they can be hard to read, they are often valved off until needed. Since magnetic level indicators are much easier to see they are often accepted as the secondary indication device.

Note that the ASME code limits the use of magnetic level gauges to 900psi (62 bar).



Level gauge with flag indicators – Emerson Process Management



Deposit in pipes of drum level indicators

Hydrastep

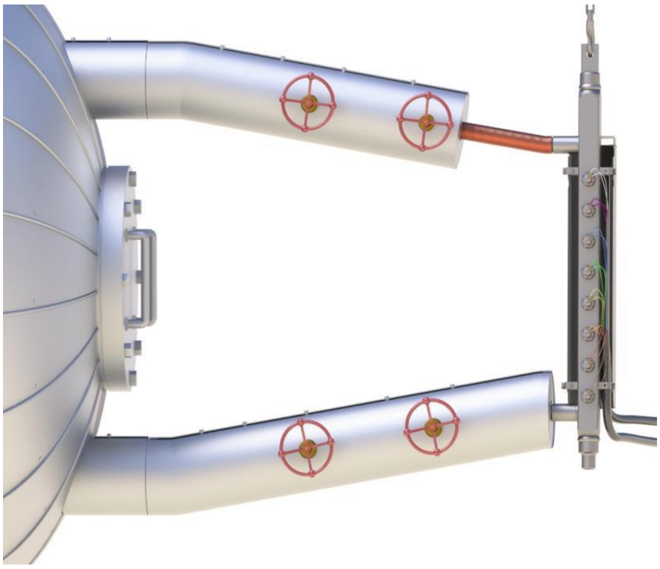
Electronic steam/water gauging systems can also be used to monitor water levels within the boiler drum. An example of this is Delta Mobrey's Hydrastep which consists of a number of electrodes installed within a water column attached to the drum. The electrodes are positioned above and below the water level and a step change in resistance between two adjacent electrodes identifies the water level. Local and remote displays are used to provide operators with high visibility of boiler drum levels. These systems feature a wide, accurate measuring range and are easily maintained, minimising operating costs. Hydrastep systems provide continuous monitoring of steam drum level with exceptional reliability.

Conductivity probe instruments such as Hydrastep were originally developed as an alternative to sight glasses and to introduce a means of monitoring from a remotely positioned control room. Even with the improvements in sight glass technology and CCTV, steam water gauging systems based on conductivity probe technology give a clear visual display both locally and remotely and have become the preferred solution for steam drum level indication.

Hydrastep Installation

Hydrastep shall be installed according to Delta Mobrey's recommendations. A good installation will prolong the life of the electrodes and minimise any density error which is inherent in any system using a remote water column. Any deviation from these recommendations may compromise performance.

- The water column shall be mounted vertically;
- The water column legs shall be a maximum length of 2000mm from column to drum;
- The steam leg shall slope down from the drum to the water column and the water leg shall slope up from the drum to the water column (minimum 1:50, or 40mm over 2000mm);
- The water leg shall be thermally insulated from the drum to the column;
- The steam leg shall be thermally insulated from the drum, but the last 0.5 to 1m is left uninsulated (between the last valve and the column);
- Isolation valves shall be fitted on both steam and water legs, using suitably rated globe valves;
- The isolation valves shall be mounted so that the valve spindles are horizontal;
- The water column drain shall lead to a drain pipe via a valve;
- Any elbows or bends should be kept to a minimum, ideally only one elbow in each leg;
- Steam and water leg piping should be a minimum of 1 inch (25mm) internal diameter;
- The water column should be suspended by a spring mechanism.



Hydrastep installation - Delta Mobrey

3.4.2 Boiler Drum Level Control

Drum level is critical for safety, but controlling and maintaining the correct water level is also important to maximise boiler efficiency. However, there are several factors that make an accurate water level measurement difficult to obtain. For example, the steam drum contains a turbulent mixture of water with entrained steam bubbles and steam. As the demand for steam decreases, the drum pressure will increase and compress the entrained steam bubbles. So even if the amount of water is actually increasing, the drum level will appear to shrink.

Conversely, as steam demand increases, drum pressure decreases and the gas bubbles expand, causing the drum level to appear to swell. To account for shrink and swell, power plant engineers use complex control systems to maintain a constant liquid water level in the steam drum.

In addition to the requirement for a visual indication of drum level, the Pressure Vessel Code and BS EN 12952 stipulate the need for high-integrity solutions such as fail-safe modes, diversity, self-diagnosis and redundancy. The type of level measurement and control technology used for any boiler application is based on a hazard analysis, but codes recommend two local level indicators, combined with two independent level limiters to provide boiler drum level control and indication. Built-in redundancy and the avoidance of common mode failures are essential features, along with the use of diagnostics to determine issues and allow for preventative maintenance.

Based on these requirements and the operational experiences of users, triple redundancy on boilers and feed water systems is becoming an industry standard. Combinations of differential pressure and guided wave radar transmitters can meet this requirement with acceptable combinations being 2 Guided Wave Radar (GWR) + 1 Differential Pressure (DP) or 2 DP + 1 GWR or 3 devices of the same technology.

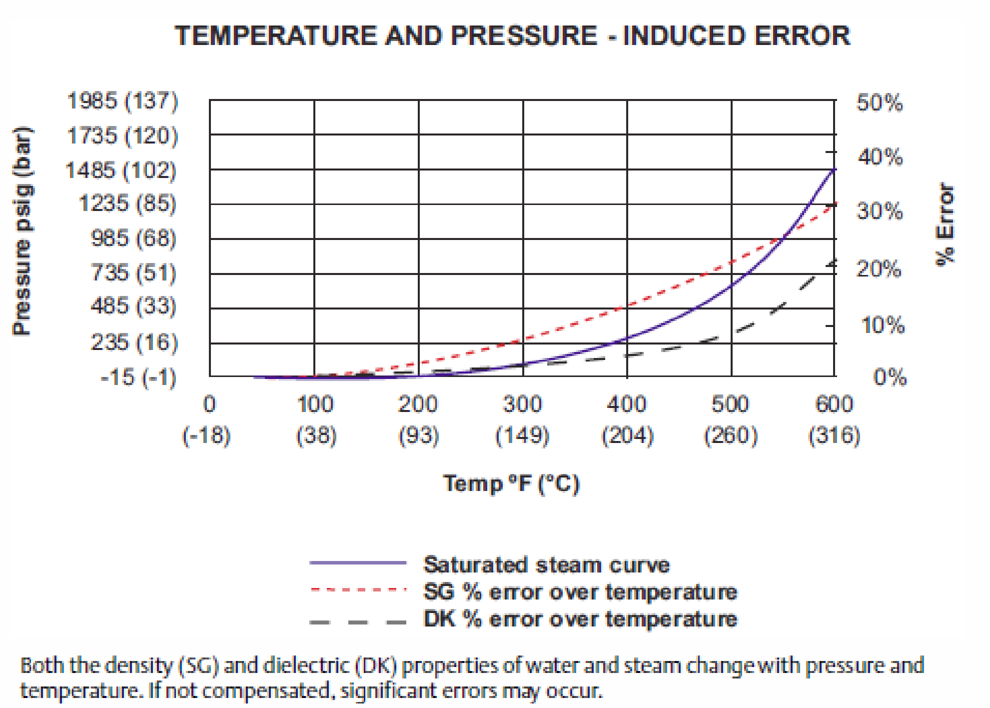
Differential Pressure Transmitters

Differential Pressure (DP) transmitters are widely used for the control of boiler level as they meet the needs of the application for accuracy and reliability. DP transmitters measure both liquid level and static pressure. The high pressure side of the transmitter is measuring liquid head pressure and static pressure, while the low pressure side is measuring the static pressure only. The net result is that the static pressure is automatically compensated out, leaving only the liquid head measurement.

This measurement, combined with the liquid density, provides the level measurement. DP transmitters are calibrated for level based upon a specific liquid density. If that density changes, errors will be introduced into the level measurement. These changes are especially common during start-up, when both the liquid and steam phases of the system will have density changes as the system reaches the operating temperature and pressure. Subsequently, a compensation method based on operating conditions is necessary for the density adjustments of the DP level measurement.

The steam leg to the DP cell has to have the steam condensed back to the liquid phase to make the transmitter work accurately, an important point when calibrating these devices. It is essential to follow the manufacturer’s set-up guidance on all level transmitters.

To provide density compensation for DP level measurements, a pressure measurement is used to determine the appropriate density values based on the operating pressure and the established density values from the saturated steam tables. Where temperature compensation is applied this should be provided from independent instruments to each water level transmitter so that in the event of failure of the temperature compensation equipment all the water level measurements are not compromised.

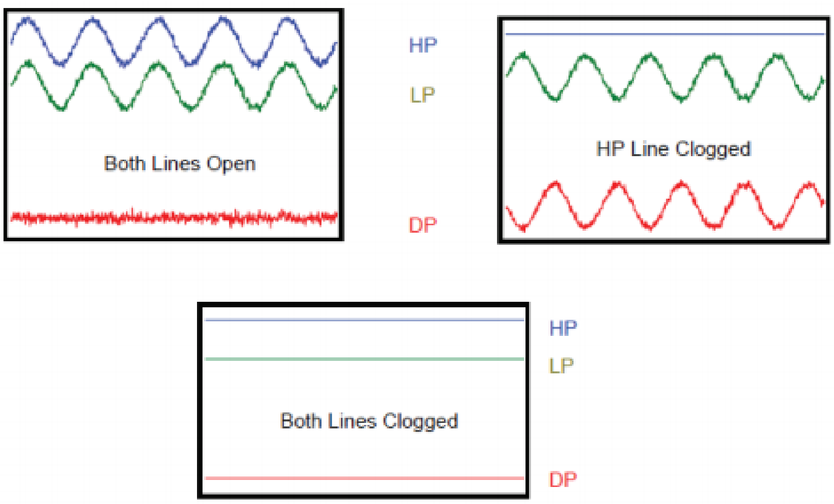


Graph showing how the density and dielectric properties of water and steam change with pressure and temperature – Emerson Process Management

Plugged Impulse Lines

Detection of plugged impulse lines is important for many pressure measurements. Emerson has developed a patented and unique statistical processing technology that can be used to detect plugged impulse lines in a variety of pressure applications. This can provide early warning of process, equipment and installation problems and is accomplished by using statistical techniques to characterize the process signal and noting changes in the process signal characteristics.

In the example below, when both lines are open, the differential pressure sensor subtracts the LP from the HP. When one of the lines are plugged (either LP or HP), the common mode cancellation no longer occurs. Therefore there is an increase in the noise of the DP signal.



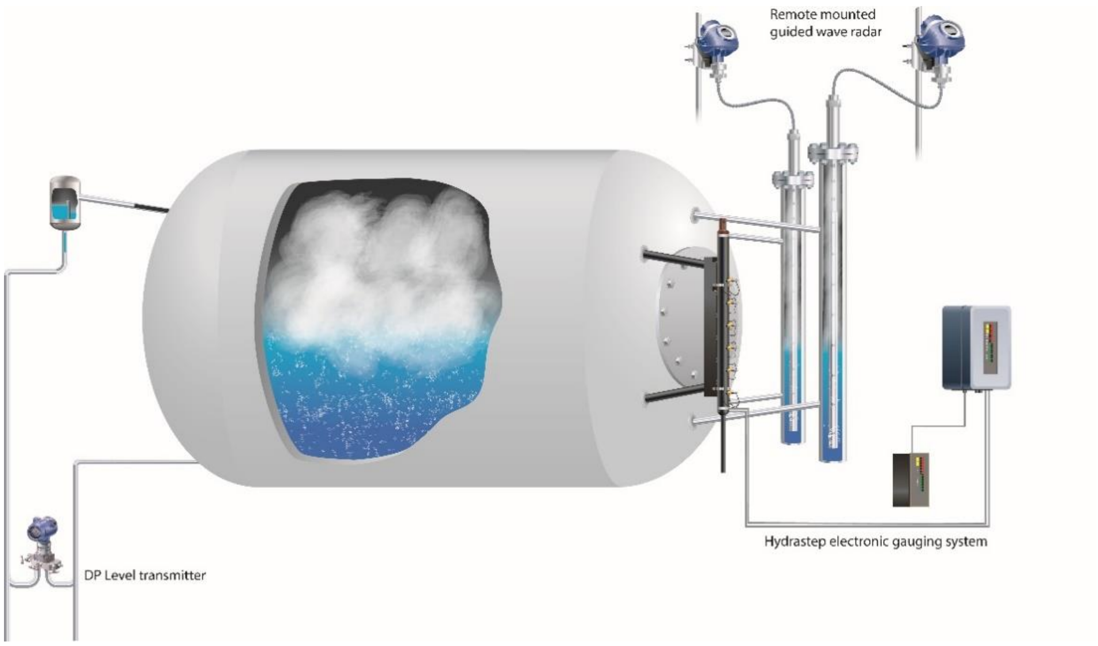
Differential Pressure (DP) Signals Under Different Plugged Conditions – Emerson Process Management

Guided Wave Radar Transmitters

GWR (Guided Wave Radar) transmitters are an alternative choice for steam drum applications as they offer a number of important advantages over DP technology. They provide accurate and reliable measurements even when exposed to mechanical vibration and high turbulence. GWR transmitters have no moving parts, providing the added benefits of low maintenance and high reliability. As experience with GWR has grown, GWR is now considered a reliable, cost effective solution for redundant level measurement in drum level applications.

In a typical installation, the GWR is mounted on top of a chamber with a probe extending to the full depth of the chamber or vessel. A low energy pulse of microwaves is sent down the probe and when the pulse reaches the media surface, a reflection is sent back to the transmitter. The transmitter measures the time taken for the pulse to reach the media surface and be reflected back, and an on-board microprocessor accurately calculates the distance to the media surface using Time Domain Reflectometry principles.

The speed of transmission depends on the dielectric constant of the media. As can be seen from the table below, in the case of water, this changes in both the liquid and steam phases. In high pressure steam applications, the effect is to slow down the speed of propagation and this can result in an error of up to 20% over temperature.



Remote mounted Guided Wave Radar – Emerson Process Management

Temp. (°F/°C)	Pressure psia/bar	DK of liquid	DK of vapor	Error in distance %
100/38	1/0.1	73.95	1.001	0.0
200/93	14/1	57.26	1.005	0.2
300/149	72/5	44.26	1.022	1.1
400/204	247/17	34.00	1.069	3.4
500/260	681/47	25.58	1.180	8.6
600/316	1543/106	18.04	1.461	20.9
618/325	1740/120	16.7	1.55	24.5
649/343	2176/150	14.34	1.8	34.2
676/358	2611/180	11.86	2.19	48
691/366	2900/200	9.92	2.67	63.4
699/370	3046/210	8.9	3.12	76.6
702/372	*3120/215*	*Above critical point, distinct liquid and gas phases do not exist.*		

Table shows the error distance with changing temperature and pressure without any compensation – Emerson Process Management

As the temperature increases, the dielectric of water decreases and the dielectric of the vapour increases. Accurate level measurements can only be obtained if the water dielectric remains sufficiently high to provide a reflection back from the surface. However, there reaches a point between 180 bar and 200 bar when the dielectric difference between steam and water becomes too small to offer reliable level measurement. In this case, level transmitters based on GWR technology are no longer suitable.

Compensating For The Effects Of Changing Dielectric

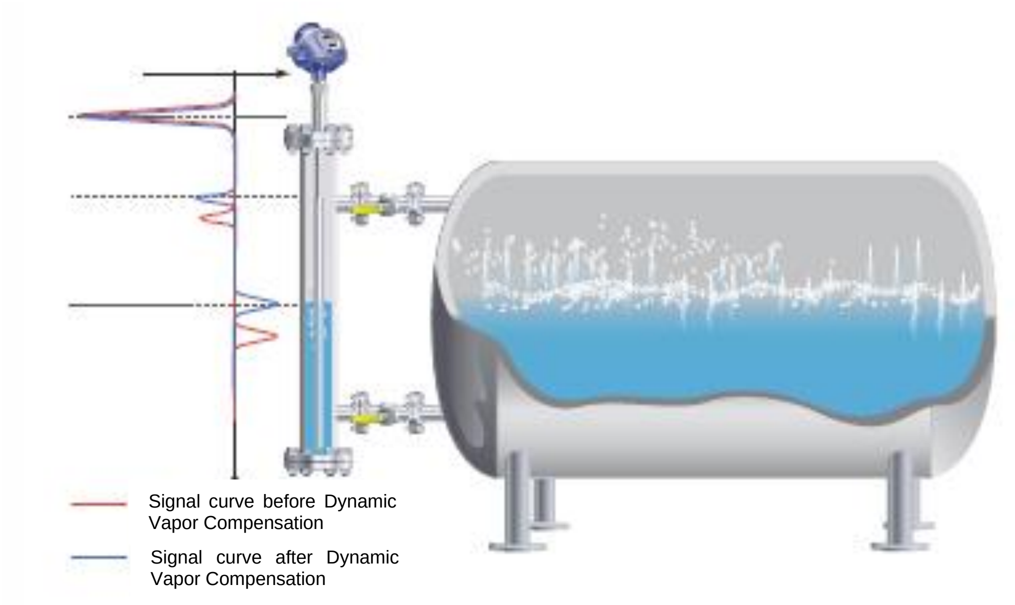
To maintain the accuracy of level measurement it is necessary to apply a compensating factor to the GWR transmitter. If the conditions are stable, the dielectric of the vapour at the expected operating pressure and temperature can be entered manually during the configuration of the transmitter. This allows the unit to compensate for the dielectric at the expected operating conditions.

For higher pressure applications, which may have more variations in the operating conditions or where the users want to be able to verify the unit under near ambient conditions, such as during start-up and shut down, a dynamic form of compensation is required.

Dynamic Vapour Compensation technology can provide highly accurate level measurement across a range of operating conditions. Specified variants of these devices can now be used as a sensor in a limiting device, in accordance with BS EN 12952-11:2007 and EN 12953-9:2007.

Dynamic Vapour Compensation works by using a GWR probe with a target at a fixed distance. The transmitter knows where the pulse reflected from the target should be with no vapour present. When there is vapour in the tank, the electrical distance of the reflector pulse appears beyond the actual physical distance of the reflector point. The distance between the actual reflector point and the apparent reflector point is used to continuously calculate the vapour dielectric. The calculated dielectric is then dynamically used to compensate for vapour dielectric changes, eliminating the need to introduce any compensation in the control system. For applications below 180 bar, GWR with dynamic vapour compensation will provide highly accurate level measurements in saturated steam conditions.

A Dynamic Vapour Compensation integrated still pipe vapour probe with a long reflector is recommended for best practice. Depending on the application, probe type, reflector length and internal as well as external conditions, the accuracy errors can vary; with accuracy errors down to 2% being achieved. Application and installation conditions, such as a lower temperature in the bypass chamber, can cause changes within the measured media. Therefore, the error readings can vary depending on the application conditions and may cause an increase of the measuring error by a factor of 2 to 3.



Signal curve of Guided Wave Radar with Dynamic Vapour Compensation – Emerson Process Management

The figure above illustrates the radar signal curve before and after vapour compensation. Without compensation, the surface pulse appears to be beyond the actual level; after compensation the surface appears at the correct surface level point.

To meet the requirements for indication and redundancy in drum level applications, a recommended combination is a magnetic level gauge with Guided Wave Radar installed in an adjacent chamber. Together these devices provide a low maintenance solution that provides high accuracy and local indication.

Complete level solution combines a GWR and magnetic level indicator in combination for measurement and visual indication of drum level – Emerson Process Management

Three Element Water Level Controls

3 element control (like single element control) includes water level monitoring in the boiler as one element but in addition 2 other elements are monitored:

a) Steam flow;

b) Water flow.

This improves water level control; as the steam demand rises there may be a pressure drop in the boiler resulting in the water level rising due to swelling caused by the increase in steam bubble sizes. In single element control this often means the boiler is starved of water when it is most needed.

Unlike single element control, water level is not the main parameter used to determine whether additional water is required in the boiler.

3.4.3 Combustion Control

Water tube boilers can burn many different fuels, more than any other type of combustion plant – the range includes most gaseous fuels, many liquid fuels, and a wide variety of solid fuels including coal, municipal waste and many forms of biomass. It is not within the scope of this guidance document to discuss all the possible fuel delivery, storage, handling and combustion techniques. However, some general principles and overarching safety and environmental matters are relevant.

In order to improve the general environmental performance of combustion plants and to reduce emissions to air of CO and unburnt substances, Best Available Techniques (BAT) is to ensure optimised combustion and to use an appropriate combination of the techniques below.

- **Fuel blending and mixing**

  Ensure stable combustion conditions and/or reduce the emission of pollutants by mixing different qualities of the same fuel type.

  Regular testing of the fuel is essential. The variability of some solid fuels particularly, and the wide ranges of particle size, may significantly influence the sample results. Infrequent sampling or taking small unmixed samples will not lead to accurate or consistent results.

- **Advanced control system**

  The use of a computer-based automatic system to control the combustion efficiency and support the prevention and/or reduction of emissions. This also includes the use of high-performance monitoring of combustion and emissions.

- **Combustion optimisation**

  Measures taken to maximise the efficiency of energy conversion, e.g. in the furnace/boiler, while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the combustion equipment, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of an advanced control system. The applicability to old combustion plants may be constrained by the need to retrofit the combustion system and/or control command system.

  For solid fuels, ash and slag sampling is a widely used technique, and laboratory examination of well mixed and crushed ash samples can give invaluable information about the combustion performance in the boiler.

- **Good design of the combustion equipment**

  Good design of furnace, combustion chambers, burners and associated devices

  Generally applicable to new combustion plants.

- **Fuel choice**

  Select or switch totally or partially to another fuel with a better environmental profile (e.g. with low sulphur and/or mercury content) amongst the available fuels, including in start-up situations or when back-up fuels are used.

  Applicable within the constraints associated with the availability of suitable types of fuel with a better environmental profile as a whole, which may be impacted by government energy policy, or by the integrated site's fuel balance in the case of combustion of industrial process fuels.

  For existing combustion plants, the type of fuel chosen may be limited by the configuration and the design of the plant.

- **Maintenance of the combustion system**

  Regular planned maintenance according to suppliers' recommendations.

The combustion systems shall incorporate the following (as applicable):

- Ignition flame and main flame detection and safety systems for each burner or firing system;
- Forced draught and induced draught fan proving systems;
- Air and flue damper position proving systems;
- Flame detectors. High-integrity devices are required on all systems where the combustion system does not progress through a restart at least once per day;
- Systems to monitor the correct ratios of fuel and air;
- Separate independent measurements for control and for tripping;
- Interlocks where simultaneous fuel combustion is not permitted.

Having more than one burner firing into a common furnace space can lead to problems with flame detection, purging etc. Burner manufacturers should work closely with boiler makers at the start of the design process to eliminate any burner control system issues.

Where there are multiple burners on a boiler, proof testing by cycling the burners will require a specific procedure to be developed, and might involve the provision of interlocks to allow maintenance staff to temporarily override burner controls or sequencing set points in order to fully test each element of the installation.

Integrated combustion processes ensuring high boiler efficiency and including primary techniques for NOx reduction (e.g. air staging, fuel staging, low-NOX burners (LNB) and/or flue-gas recirculation) are currently regarded as BAT for most combustion systems. The choice and performance of an appropriate combination of primary techniques may be influenced by the boiler design.

In order to reduce dust and particulate-bound metal emissions to air from the combustion of coal and biomass, BAT is to use one or a combination of these techniques:

- Electrostatic precipitator (ESP);
- Bag filter;
- Boiler sorbent injection (in-furnace or in-bed);
- Dry or semi-dry Flue Gas Desulphurisation (FGD) system
- Wet flue-gas desulphurisation (wet FGD)

Similar emissions management techniques will be required for liquid fuels, particularly the ‘heavier’ grades. For gaseous fuels, low NOx burners (with reduction of the combustion air temperature if possible), air/fuel staging and flue gas recirculation are the primary techniques that are currently considered to be BAT.

Air staging involves the creation of several combustion zones in the combustion chamber with different oxygen contents for reducing NOx emissions and ensuring optimised combustion. The technique involves a primary combustion zone with sub-stoichiometric firing (deficiency of air) and a second re-burn combustion zone (running with excess air) to improve combustion. Some old, small boilers may require a capacity reduction to allow the space for air staging.

Fuel staging is based on the reduction of the flame temperature or localised hot spots by the creation of several combustion zones in the combustion chamber with different injection levels of fuel and air. Any retrofit may be less efficient in smaller plants than in larger plants.

Flue gas recirculation cycles part of the flue-gas in the combustion chamber to replace part of the fresh combustion air, with the dual effect of cooling the temperature and limiting the O_2 content for nitrogen oxidation, thus limiting the NO_X generation. It uses the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame. The use of special burners or other provisions is based on the internal recirculation of combustion gases which cool the root of the flames and reduce the oxygen content in the hottest part of the flames.

Sophisticated burner control algorithms are required to enable these and other advanced techniques to work effectively and efficiently.

For SO_X and some dust management, the injection and dispersion of a dry powder sorbent in the flue-gas stream is one recommended technique. The sorbent (e.g. sodium carbonate, sodium bicarbonate, hydrated lime) reacts with acid gases (e.g. the gaseous sulphur species and HCl) to form a solid which is removed with dust abatement techniques (bag filter or electrostatic precipitator). Dry Sorbent Injection (DSI) is mostly used in combination with a bag filter.

An alternative is wet flue-gas desulphurisation (wet FGD). This is a combination of scrubbing techniques by which sulphur oxides are removed from flue-gases through various processes generally involving an alkaline sorbent for capturing gaseous SO_2 and other dusts and transforming them into solids. In the wet scrubbing process, gaseous compounds are dissolved in a suitable liquid (water or alkaline solution). Simultaneous removal of solid and gaseous compounds may be achieved. Downstream of the wet scrubber, the flue-gases are saturated with water and separation of the droplets is required before discharging the flue-gases. The liquid resulting from the wet scrubbing is sent to a wastewater treatment plant and the insoluble matter is collected by sedimentation or filtration.

3.4.4 Pressure and Temperature Devices

Temperature Control, Pressure Control and Pressure Limiters

In general terms, the control and measurement of temperature and pressure characteristics in water tube boilers use tried and tested instruments and devices, modified as necessary for the actual or potential temperature and pressure values likely to be encountered.

Some applications will warrant the use of more specific devices with diagnostic features that assist the operator with their analysis of plant performance.

Where water tube boilers are producing superheated steam, it is normal to have a method of temperature control such as spray or indirect attemperators. It is important that the design temperature of the materials used in the construction of the superheaters and associated pipework and the steam users are not exceeded.

Controls and limiters shall be provided to protect the superheaters, pipework and steam users. The superheat temperature controls are normally independent of the boiler firing controls – at low firing rates the superheat temperature naturally reduces and there is often no need for any attemperation at loads less than, say, 80% MCR. Other factors which influence superheat temperature are the type of superheater (whether it is a radiant or convective type) and the type of fuel.

Superheat temperatures and the amount of attemperation will vary if for example changing from gas firing to oil firing. When considering changing fuel type on a boiler which was not originally designed to burn an alternative fuel it is essential to have the boiler design checked to ensure any necessary modifications to the superheater and attemperation method are included in the scope of changes.

The control system strategy should be designed to deal with the slow response time of superheaters and different heat transfer characteristics of fuels, especially when running a multi-fuel boiler. Design considerations may include “feed forward” strategies instead of relying solely on classical PID feedback controllers.

Heat input must be controlled automatically (for new boilers refer to BS EN 12952) as follows:

- Steam boilers to be controlled by pressure controls (BS EN 12952 Part 8 & 9 - Requirements for firing systems)
- Steam boilers should be protected against excessive pressure (BS EN 12952 Part 10 - Requirements for safeguards against excessive pressure)
- Limiting devices must be fitted to prevent excessive pressure or temperature (BS EN 12952 Part 11 - Requirements for limiting devices)

Users/Owners shall ensure that an adequate test regime for all pressure and temperature limiters is incorporated into the operating procedures for the boilers.

3.4.5 Water Treatment Plant

Water quality in all boilers, and in particular high pressure water tube boilers, is of paramount importance, and particularly where steam turbines are involved.

Compliance with BS EN12952-12:2003 Water-tube boilers and auxiliary installations and BS 2486:1997 (if specified), is essential. Equipment manufacturers and steam boiler water treatment specialists should be consulted at the earliest stages of a project, and throughout the life of the installation to ensure that the right water source is selected, the correct pre-treatment regime is specified, the right water treatment and water testing equipment is installed.

The waterside conditions should continuously remain within the designated parameters if the boilers are under load and when the boilers are idle or on standby.

Any type of deposit in a boiler can rapidly lead to system failure. Silica and other contaminants on a steam turbine, for example, will severely affect performance, increase costs, and risk the integrity of the plant. Apart from personnel safety, which is the top priority, water quality management is one of the most important aspects of water tube boiler design and operation.

A few basic rules shall be followed:

- A comprehensive survey of the likely water supplies is essential – water comes from a wide variety of sources which can vary markedly hour on hour whether from a utility or a private water supply; any water treatment plant should be capable of working within a large range of water qualities and should not be designed on the best water analysis but on the worst that is likely to be experienced. It is more and more difficult to say with any certainty that the analysis of water you receive today will be the same next week.
- Untreated potable, or wholesome, water will not be satisfactory for boiler feed. The volumes of high purity make-up water used in all water tube boilers need to be calculated with a large margin of error so that suitable water treatment plant and potentially contingency water storage can be installed.
- There are many ways of treating the incoming water supply to make it high purity and suitable for the installation, but specialist advice will be required as to which is likely to give the best, most cost-effective return on investment and keep the boiler and system safe and clean. Modern pre-treatment technology has substantially reduced chemical handling issues.
- Equally, there are many different ways to store and treat water that is ready to be used in the boiler. High temperature storage (in excess of 80ºC at all times) will help, as will high levels of clean condensate return. “Once through” boilers with no condensate return will require very different plants to traditional steam turbine installations.
- All water circulating in boilers shall be tested regularly by trained and competent staff to ensure specifications are routinely met. Water sampling equipment must be safe to use and samples should be taken at several representative points in the system. Test results should be available promptly so that any adjustments required to the water or any other investigations, such as for leaks, are carried out immediately.

- Continuous monitoring systems for water quality are available but shall be backed up by regular physical monitoring by suitably qualified and trained personnel. Manual intervention will still be required to check automated monitoring and dosing systems are working correctly.

- Many of the issues arising from poor water quality result in the boiler suffering one or more of the many possible failure mechanisms – see Appendix 2 for a full list of failure mechanisms and their common causes.

- Every steam system is bespoke. You should therefore carry out a site and system specific Boiler Water Treatment Risk Assessment and implement from that a suitable and sufficient Boiler Water Treatment Written Control Scheme as described in BG04, which requires a Responsible Person and a Statutory Duty Holder to be appointed for steam system water treatment activities. These documents should consider the steam system as an entity and not just refer to the boiler itself.

  Note – BG04 currently is limited to boilers up to 32 bar and 70 tonnes/h steam output although the management and risk assessment/control principles therein are applicable to all boiler plants, including those described here in BG11.

For a new installation. It is recommended that the system incorporates the following:

- Means for treating incoming water, such as a water softener, reverse osmosis, and final polisher (normally mixed bed ion exchange resin or continuous electro-deionisation) and potentially an oxygen degasser. This will be based on a full analysis of all potential raw water supplies. It will probably be necessary to install duplex systems and sufficient strategic water storage for emergency and shut down reasons.

- Devices to record hot well or de-aerator temperatures and levels, and alarm on deviation.

- Devices for monitoring condensate quality and alarms for potential contamination.

- Means for safely collecting boiler water samples from appropriate locations such as from inside the boiler, from the hot well, in the condensate return line, and from all water treatment plant inlets and outlets and at any other areas within the plant location.

- Means for delivering water treatment chemicals at appropriate points in the system with measurement and control devices to alarm if chemical dosing is low or out of specification, chemical stocks are low, or chemical dosing plant has failed (dosing pump faults, leaks, etc.).

- Equipment for on-site measurement and testing of boiler water parameters.

Lengthening times between boiler house visits will require increased quantity and quality of the monitoring and alarm equipment for feed water and condensate.

Examples of Feedwater Parameters Specified by BS EN 12952-12:2003 & BS 2486:1997

Table 5.1 of typical recommended water quality parameters fired water tube boilers (Abstract from BS EN 12952-12 2003)

Parameter	Unit	Feedwater Containing Dissolved Solids			Feedwater & Attemperator Spray Water Salt Free	Make-up Water For Hot Water Generators
Operating Pressure	bar	> 0.5 to 20	> 20 to 40	> 40 to 100	Total range	Total range
Appearance	-	Clear, free from suspended solids				
Direct Conductivity @ 25°C	µS/cm	Not specified, only guide values for boiler water relevant, see BS EN12952-12 table 5.2			-	See BS EN12952-12 table 5.2
Acid Conductivity @ 25°C (1)	µS/cm	-	-	-	< 0.20	-
pH Value @ 25°C (2)	-	> 9.20 (3)	> 9.20	> 9.20	> 9.20 (4)	> 7.00
Total Hardness (Ca + Mg)	mmol/l	< 0.02 (5)	< 0.01	< 0.005	-	< 0.05
Sodium & Potassium (Na + K)	mg/l	-	-	-	< 0.010	-
Iron (Fe)	mg/l	< 0.050	< 0.030	<0.020	< 0.020	< 0.20
Copper (Cu)	mg/l	< 0.020	< 0.010	< 0.003	< 0.003	< 0.10
Silica (SiO_2)	mg/l	Not specified, only guide values for boiler water relevant, see table 5.2			< 0.20	-
Oxygen (O_2)	mg/l	< 0.020 (6)	< 0.020	< 0.020	< 0.10	-
Oil/grease Concentration	mg/l	< 1.00	< 0.50	< 0.50	< 0.50	< 1.00
Organic Substances (as TOC)	mg/l	See note (8)		< 0.50 (7)	< 0.20	See note (8)

Notes:

1 The influence of organic conditioning agents should be additionally considered.

2 With copper alloys in the system the pH value shall be maintained in the range 8.7 to 9.2

3 With softened water pH value > 7.0 the pH value of the boiler water according to table 5.2 should be considered

4 For injection water only volatile alkalising agents shall be permitted.

5 At operating pressure < 1 bar total hardness max. 0.05 mmol/l shall be acceptable.

6 Instead of observing this value at intermittent operation or operation without de-aerator, film forming agents and/or excess of oxygen scavenger shall be observed.

7 At operating pressure > 60 bar, Total Organic Carbon (TOC) < 0.2 0.2 mg/l is recommended.

8 Organic substances are generally a mixture of several different compounds. The composition of such mixtures and the behaviour of their individual components under the conditions of boiler operation are difficult to predict. Organic substances can decompose to form carbonic acid or other acidic decomposition products which increase the acid conductivity and cause corrosion or deposits. They also can lead to foaming and/or priming which shall be kept as low as possible.

Table of typical recommended water quality parameters fired water tube boilers (Abstract from BS 2486:1997)

Pressure at Boiler Outlet barg	***20 - 40***	***40 - 60***	***60 - 80***	***>80***
Feed Water At Economiser Inlet				
pH	8.5 – 9.5			
Total Hardness	Nil			
Dissolved Oxygen mg/kg (note 3)	0.02	0.01	0.005	0.005
Iron, Copper and Nickel mg/kg (note 4)	0.05	0.03	0.02	0.02
Organic Carbon	Note 6 – shall be minimised			
Boiler Water				
Phosphate mg/kg (note 7)	20 - 50	5 - 15	5 - 10	3 – 6
pH (note 11)	Note 11 – dependent upon type of chemistry used			
Caustic Alkalinity mg/kg CaCO3	<50	<20	nil	Nil
Silica as SiO2 mg/kg (note 8)		5 max	2 max	1 max
Oxygen Scavenger mg/kg	0.1 – 0.5	0.1 – 0.25	0.05 – 0.2	0.05 – 0.1
Chloride mg/kg (note 9) *Non-Volatile Alkalising Treatment* *All volatile treatment*			 <4 <0.2	 <2 <0.2
Conductivity Max µS (note 10)	1500	750	200	50
Dissolved Solids mg/kg	1000	500	150	30

See notes overleaf

Notes

1	Boilers operating at 40 – 60 bar with a local heat flux density of >300kW/m^2 treat as 60 – 80 bar
2	Plant containing copper alloys in the feed or condensate system shall have the pH of the feed water limited to 8.2 – 9.2. If the feed system is completely ferrous the pH shall be limited to 8.5 – 9.2. For plant using the feed water for spray attemperation or de-superheating the pH shall be controlled with volatile alkalis only.
3	The dissolved oxygen target is that which should be aimed for after mechanical deaeration. In addition to this a chemical oxygen scavenger should be used.
4	The weighted mean metal content shall not exceed the figures in the table during the 24 hours following start-up and 1 hour following a >20% load change.
5	The level of blowdown depends on the level of blowdown in the feed water. For spray attemperation or de-superheating the solids shall not exceed 1mg/kg. Modern steam turbines have strict limits on sodium and other alkali metals (<0.005mg/kg Na) which shall be adhered to.
6	Organic material will degrade in the boiler to form acids and carbon dioxide. These have the effect of lowering pH and causing corrosion. The presence of these contaminants **shall** be minimised.
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 that experience phosphate hideout. For co-ordinated and congruent phosphate programmes please refer to specialist advice.
8	Silica limits are based on the avoidance of silicate scale deposition and the limitation of silica solubility in steam. Please refer to specialist advice.
9	Chloride attack in high pressure boilers is a major hazard. The level of chloride tolerated with All Volatile Treatment (AVT) is much lower than that where Non-Volatile Alkalising Treatment (NVAT) is used. The values also vary dependent upon whether the boiler is coal or oil fired.
10	The conductivity and TDS values are when operating with phosphate chemistry. Please seek advice when setting parameters for All Volatile Treatment.
11	The pH is dependent upon the type of chemistry being used. For the pH range for the various phosphate treatments or when using AVT, please seek advice.

3.4.6 Blowdown

Blowdown is required for two main purposes, mainly to control the boiler water quality by maintaining the total dissolve solids (TDS) content below set limits, and secondly ensuring that the boiler water level indicator and limiter impulse lines are clear and the indicators are showing a correct level.

Unlike shell boilers where water treatment regimes differ, there is generally no need for bottom blowdown of sludge/sediment on water tube boilers. An intermittent blowdown valve may be provided to allow the operator to address any issues with high TDS, and for water level control during start-up when the water level tends to rise as the water temperature rises.

A properly designed blowdown system is an integral part of any steam boiler installation. Blowdown Systems, Guidance for Industrial Steam Boilers (Ref: BG03) is a guidance document intended to provide advice to designers, specifiers, manufacturers, installers and those responsible for the management and operation of steam plant as well as CPs.

BG03 is applicable to both new and existing installations of steam boilers and addresses the following issues:

- The safe discharge of blowdown from boilers;
- The safe use and operation of blowdown vessels;
- The safe use and operation of blowdown pits;
- Proper maintenance and inspection of blowdown vessels and pits including requirements for regular inspection.

Advice was previously provided by Health and Safety Executive Guidance Note PM60 Steam boiler blowdown systems 2nd edition 1998 which has been withdrawn. This new, comprehensive guide deals with all aspects of steam boiler blowdown for industrial steam boilers and why it is necessary to carry out the function of "blowing down" the boiler.

It is aimed at the User/Owner, Engineer, Manager and Operator of the boiler plant to help them understand all aspects that affect the boilers and why blowing down is necessary, both from a practical operational performance view and for the legal requirements.

It covers who is responsible for the safe and efficient operation of steam boiler blowdown plant, and who is responsible for managing the safe operation of this type of equipment. Ultimately the responsibility lies with the User/Owner as defined by the PSSR.

On water tube boilers, BS EN 12952 Part 7 says "..*blowdown operation shall be detectable*" for any gauge glass, controllers or limiters.

Then in Part 11, when referring to limiters in external chambers, the following recommendation (if applicable):

> *"blowdown systems should be fitted with a timing element which prevents the blow down period exceeding a predetermined maximum safe time and monitors the complete move next of the relevant valves and the function of the limiter output contact" and "If isolating valves are fitted on the connecting pipes to external chambers, an interlock system shall be installed to shut off the heat supply when valves are not fully open."*

Part 11 does not require external chambers to be blown down if the connecting pipes are designed in accordance with the recommendations of BS EN 12952-11 section 5.2.3.4 – see below. However, where float type water level detectors are used, it is recommended that these are regularly checked as other issues such as sticking floats need to be addressed.

"5.2.3.4 Chambers shall be considered as being an integral part of the boiler and need not be blown down if:

a) connecting pipes are 100 mm minimum clear bore on the water side and 40 mm minimum clear bore on the steam side; and

b) connection pipes are less than one metre long; and

c) there are no isolating valves fitted on the connecting pipes."

Sub optimal continuous blowdown control strategies may cause the blowdown control valve to operate in a very narrow band or only just open, which will potentially cause premature value wear or failure. This suggests that the wrong type or size of valve is installed. Consideration should be given to allowing the conductivity control loop to modulate the blowdown valve over a larger range and to have a minimum opening constraint in place.

It is recommended that any measurement of TDS is taken from the blowdown (drain) line; in-line analysers are often limited with respect to pressure, so a sample needs to be fed to an analyser.

3.5 Water-Side Protection of Idle Boilers

If the boiler is not to be used continuously and might therefore be subjected to significant down time, an early decision on whether to store the boiler 'wet' or 'dry' might affect the provision of treated water and other features of the design of the system. Advice from a boiler water treatment specialist in conjunction with the boiler manufacturer should be obtained.

The neglect of boilers when out of service can lead to serious corrosion in the steam and water spaces. This can then ultimately lead to further corrosion during operational periods. The length of time a boiler may be out of service informs the appropriate choice of lay-up procedure.

Storage Overnight or for a Few Days

The boiler can be left on standby with the water conditions for normal operation, provided these are maintained during the outage. Any feed water added shall be suitably de-aerated. The steam outlet valve, boiler drain, and feed water inlet valve need to be closed. It is essential to ensure waterside tests are carried out to ensure compliance with specifications. If the outage is deemed to be significant then further action may be necessary.

Standby & Load Topping Boilers

Boilers that are lightly steamed or kept up to pressure to act as standby can lose water through sampling and blowdown. The water that replaces this lost water will be deficient in water conditioning chemicals, thereby lowering the reserves, and increasing risk of corrosion. To minimise this risk, it is recommended to increase oxygen scavenger levels to at least three times the maximum values, and the pH should be kept at a minimum of pH10.

Wet Storage

This method should only be used when the boiler is out of service for a short period of time, typically several days, but may be needed at short notice. All parts of the boiler including the economiser and superheaters shall be filled with suitably conditioned water. Where boilers have non drainable superheaters, they should only be filled with condensate quality water and treated with volatile oxygen scavengers and suitable amines such as ammonia derivatives or similar equivalent alternatives. It is most important that no pockets of air are allowed to remain and there is no leakage.

Consideration should be given, where required, for the provision of a nitrogen blanket in the drum and superheater to allow for any decay in the boiler pressure.

When filling the boiler, it is recommended to add sufficient conditioning chemical to ensure the pH is a minimum of pH10 and there is a 10mg/kg reserve of oxygen scavenger. It is extremely important that the distribution of these chemicals is throughout the boiler and that the levels are checked regularly. When returning to service, drain the boiler to normal working levels.

Additionally, for any period of wet storage, both the feedwater system and the steam side of the system should not be neglected, and appropriate actions should be taken to alleviate the risk of offline corrosion or any other mode of failure.

Where possible the boiler lay-up chemistry solution should be periodically circulated and rechecked for validity.

This helps reduce zones of stagnation and also allows the plant chemists to obtain more accurate analyses of the lay-up chemical concentrations. Should these concentrations be found to be outside of the required specifications then appropriate action can be taken by competent staff.

Offline corrosion can be very destructive to a boiler system and so suitable and sufficient lay-up procedures are of vital importance in maintaining the integrity of the steam generating system during outages.

Dry Storage

This is the preferred method of storage when boilers are out of service for extended periods. When taking out of service the boiler shall be emptied completely and dried thoroughly. Where possible, warm dehumidified air should be blown through the boiler to ensure all of the surfaces are dry; it can be considered dry when the relative humidity of the egress air is less than 30%.

Trays of silica gel or quicklime should be placed in the boiler drum or shell and then the drum or shell sealed. Typical quantities are 1.5kg/m^3, and the condition of the desiccant should be checked regularly. An alternative technique is to use chemicals such as vapour inhibitors.

All procedures and specifications for both wet and dry storage should form an integral part of the Boiler Water Treatment Written Control Scheme and Boiler Water Treatment Risk Assessment, in accordance with BG04.

3.6 Chimneys and Flues

The safe handling of the products of combustion from boilers shall be carefully considered. Poor combustion, and poorly constructed chimneys and flues, can give rise to life threatening accumulations of CO and other pollutants, and the emissions to atmosphere from combustion processes must be managed in accordance with environmental legislation such as the Clean Air Act, IED, WID and the Medium Combustion Plant Directive.

All new water tube boiler installations will be notifiable under local planning requirements and larger installations (>1 MWth) will be subject to environmental permitting regulations and require a permit to operate, differing depending on the nett thermal rating of the plant and the fuel to be combusted. Chimneys will need to be designed to cope with the expected products of combustion under normal and abnormal operating conditions.

The materials of construction and corrosion allowance for chimneys and flues need to take into consideration that any resultant combustion gases exiting any economiser or other heat recovery equipment may be close to their dew point with any resulting condensed liquor possibly being acidic and corrosive.

Structural requirements may require the advice of specialists in supporting the loads, providing safe access to work on the chimneys, and providing access platforms for emissions monitoring activities. Lightning protection systems and aircraft warning lights will frequently be required on chimneys for water tube boiler installations, and means for inspecting and testing these will be required.

HSE GS53 – Single flue steel Industrial Chimneys – inspection and maintenance is now out of print but advice can be obtained from the Association of Technical Lightning & Access Specialists (ATLAS).

Where multiple fuels can be burned in a single furnace or multiple flues enter a single chimney there may be a need for interlocked dampers and interlocked fuel supplies to provide for safe operation under all possible combinations of firing. These should be rigorously tested at appropriate intervals.

3.7 Communications and Alarms

The number and type of alarms on the boiler and associated systems will depend on a number of variables, and a review of the design and risk assessments shall be undertaken to validate this decision. Boiler systems shall be designed such that boilers will always remain in a safe condition and will shut themselves down upon critical alarm, without manual intervention.

A lock-out condition requires that the boiler be attended and can only be reset locally.

Risk assessment is likely to indicate that there is benefit in also relaying alarms and providing an emergency shut-down facility at a remote location e.g. for boilers that are left unattended for a defined period of time.

The following should be considered:

- The response time for personnel to investigate and rectify alarm conditions shall be considered as part of the design of the control system; where a competent boiler operator is unable to attend the boiler within a reasonable time, a remote shut-down and lockout facility shall be provided;
- Alarms shall be clearly audible and visible at a permanently manned location where persons who are trained to take the appropriate action can hear or see them;
- It shall be possible to ascertain the current status of the boiler from the remote location;
- The integrity and testing of communication links between the boiler house and control rooms or remote locations, and the action to be taken by the automated system on the loss of that communication shall be considered as part of the design of the control system;
- With the fast development of electronic communications and remote connectivity it is now possible that some alarms and controls can be transmitted wirelessly to a ‘tablet’ or other ‘smart’ device so the trained operator can take appropriate action, subject to validation by risk assessment.

3.8 Gas Detection, Fire Detection and Automatic Fuel Shut-Off Systems

Automatic fire detection and fuel shut-off is required for all oil-fired plant. Burners shall include automatic shut-off valves on all fuel trains, and the control system shall close these valves when a fuel is not in use, and in the event of a fault condition. Dual or multi fuel systems shall include interlocks to prevent simultaneous use if the burner or boiler is not designed for this, and these shall be routinely tested to ensure burner safety.

Solid fuel fired installations will require fire and smoke detection and fuel shut off provision. Fire dampers or fire suppression systems may be required, and the risk of leaving fuel burning on the grate shall be carefully assessed. Running the partly burned fuel off the grate to a safe place may be an option, but in this case other considerations relating to personnel safety and unintended consequences must be addressed.

Waste burning plants can suffer very high levels of gas side corrosion and burst tubes are common; this results in a catastrophic loss of water level. Procedures should be put in place to maintain water flow to the drum to bring the furnace roof temperatures down to safe levels and reduce the chance of boiler collapse. Other procedures will be required to get unburnt waste onto the grate and push the waste towards the ash discharger.

The need for gas detection and automatic gas shut-off systems will be determined during the risk assessment and by following the recommendations of relevant standards; modern gas fired boiler houses are mostly regularly attended and well-ventilated spaces, making it unlikely that an accidental release of natural gas of sufficient volume to create a flammable atmosphere will develop. A manual Emergency Control Valve is needed at the Primary Meter and if the meter is remote from the building (plant room) an Additional ECV also; both must be fireproof and of specified type e.g. gate valve, not butterfly type.

As part of a building fire safety strategy a fire system incorporating an Automatic Isolation Valve (AIV) may be chosen, and is frequently specified in most new installations of a significant size. Further information is available from IGEM/UP/10, IGEM/UP/16 and IGEM/SR/25.

Gas detection systems will be necessary where forced inlet and/or extract ventilation systems are employed, and where the gas is not sufficiently odorised (e.g. producer gas, or bio-gas) as leaks are likely to go unnoticed by boiler attendants. Similarly it may be necessary to consider CO and H_2S detection in certain circumstances (e.g. where CHP engine exhaust ducting passes through a boiler house).

The positioning of gas detection systems is of vital importance to ensuring their correct operation; the use of certain gases such as LPG will require careful consideration. Always consult the equipment manufacturer on the correct placement of sensors.

The provision of emergency stop facilities for solid fuel fired installations will require thorough analysis; issues such as the amount of fuel on the grate, the amount of unburned fuel close to the grate, the ability to run ID and FD fans, and the safety of personnel and local plant items will influence the design of the emergency stop routines. Emergency stop control devices at all key exits shall be clearly labelled with their function, and where placed in groups with other emergency control devices they shall be easily and quickly distinguishable from each other.

It is recommended that emergency push buttons isolate all fuels and power to the burners using the fuel train safety shut-off valves rather that the fitting of an extra automatic isolating valve. In most control systems it is possible to achieve this remotely so causing the system to go to lockout.

Suitable documented procedures should be in place to deal with situations where either a fire or gas leak is detected, and relevant operational and management personnel should be trained in the actions to take in accordance with these procedures in the event of a fire or gas leak.

3.9 Back-Up Power Supplies for Critical Items

Consideration should be given to the possibility of electrical power failure at the site and the effect of this on the boiler and associated plant and systems. For any loss of power, either mains electricity, UPS back up or compressed air system it is essential that all fuel valves fail to the closed position and the boiler safely shuts down. A number of scenarios and solutions are possible.

Control systems should always be supported by uninterruptible power supplies (UPS), certainly for the critical parts of the system that sounds alarms, controls critical functions, or puts equipment sequentially into a safe mode in an emergency, for example. UPS will have a defined power output capability and a limit on the time for which they can provide that output, so they will usually not be suitable for more than reasonably brief interruptions to supplies, and not capable of supporting any significant electrical power loads.

Power outage emergency procedures should identify any critical actions to be taken whilst the UPS support the control systems; routine testing of all emergency scenarios is highly recommended. For more sensitive applications it may be desirable to design a system of standby power supplies or ‘island mode’ operation.

Emergency diesel generators will normally be able to respond to power outages quite quickly, and switching to a generator supply can be achieved in 10 or 15 seconds in many cases, but only if the diesels and switchgear are regularly tested and the electrical load at the site is not greater than the output of the generators. However, 10 seconds is long enough for all the lights to go out, all the electrically operated valves to close (such as the gas supply), and other systems to ‘fail safe’.

It is therefore essential to design and test standby genset applications to ensure that critical plant items such as fuel valves and fan motors can, and actually do, re-start or stay engaged (through a UPS) whilst the gensets are starting. There should also be a controlled application of other services since it is very easy to assume that the power is back on and plant items can be re-started manually when in fact the generator is close to its maximum output and the addition of a large motor or other consumer will cause a trip. Disabling of certain power consumers such as lifts, large battery chargers, and other non-essential loads is essential during a standby power incident.

A common but often more expensive way to avoid this issue is to design the capability to achieve ‘island mode’ operation where the detection of mains electricity instability results in the on-site generation taking over without any appreciable break in supply. This can be achieved with steam turbines and other types of generators, but should be carefully thought through to ensure that the mechanical plant and the steam demand are matched with the electrical supply capability, and any excess steam, for example, can be safely dispersed during the island mode operation. Negotiations with electricity supply companies will be required in order to ensure the provision of all the necessary metering and electrical protection equipment, and their agreement to the island mode activity through a suitable commercial contract.

Many boiler houses use compressed air for valve control, instrumentation and other activities. For emergency situations it is recommended to have a back-up air supply using dedicated compressors in the boiler house, or air receivers with sufficient volume to maintain the plant in a safe state.

4 BOILER OPERATION

This section details the requirements for operating the boiler and the various regular checks and procedures that should be carried out on boiler systems.

Employers must ensure that site-specific risk assessments are carried out for each boiler and site to ensure that all risks remain as low as reasonably practicable, and to determine:

- the appropriate types of controls and limiters, and
- the particular site manning and supervision levels.

All water tube boilers must be examined and tested by the Competent Person (CP) before first use (PSSR Reg 8 (3) c). Boiler inspections and periodicity are an important element of water tube boiler operations; typically they are inspected every 14 to 26 months, but in some instances that periodicity in the Written Scheme of Examination has been extended to 60 months. This needs to be discussed with inspection bodies as appropriate for each installation.

4.1 Boiler Instructions

Boiler instructions shall as a minimum include the following:

- Instructions for the safe operation of steam boiler systems to comply with Regulation 11 of the Pressure Systems Safety Regulations, the relevant parts of BS EN 12952, and the Pressure Equipment (Safety) Regulations;
- The recommended daily checks required including water treatment plant performance and water quality test results;
- How to warm through boiler systems starting from cold in a controlled manner and put the boiler into service. Steam boilers shall be manned throughout the warming period and the water levels corrected to allow for expansion. The controls and limiters shall be tested prior to the boiler entering service;
- Information on the safe systems of work, including appropriate standards of isolation that should be implemented for any work on the boiler systems;
- How to protect off-line boilers against corrosion, freezing and sudden thermal shocks;
- The requirement to notify any significant planned change in boiler operating conditions (e.g. reduction in operating pressure or increase in cyclic operation) to the CP prior to making such change, so that the Written Scheme of Examination can be reviewed and, if necessary, amended to reflect the new operating regime.

System re-starts following lock-out shall only be made by a suitably experienced and competent boiler operator. Repeated attempts to re-start boiler plants shall not be made, except as part of a controlled fault identification process.

It is extremely important to make sure that connections to transmitters and control devices are clear before warming through any boiler - ‘best practice’ is to have a thorough checklist for every plant item that ensures all devices are in the ‘service’ position and providing the expected signals before commencing operation.

Start-Up Routines

It is essential that operators follow the manufacturer's start-up curve for the boiler at every boiler start or re-start. Some installations now have combined safety valves and start-up vents. These specialised valves have three functions;

- As a superheater safety valve being direct mounted on the superheater outlet;
- As a drum safety valve by opening further should the drum pressure continue to rise even after the superheater safety function has operated, and;
- During boiler start-up the superheater start-up vent valve should be opened to ensure there is a steam flow through the superheater tubes.

The steam acts a cooling medium to the superheater tubes thus helping to prevent these tubes from overheating during start-up. Other precautions should also be taken to protect the superheaters during start-up such as limiting the firing rate and /or intermittent firing. The amount of protection required for the superheaters depends on the location of the superheater relative to the evaporative sections of the boiler and whether the superheater is subject to luminous radiant heat transfer or not.

Manufacturers advice/procedures should be sought on the maximum temperatures allowable for each section/bank of superheater tubes and how to start the boiler in such a way to ensure these temperatures are not exceeded.

Emergency Procedures

Suitable documented procedures should be in place to deal with all emergency situations such as where either a fire or gas leak is detected, and relevant operational and management personnel should be trained in the actions to take in accordance with these procedures in the event of an emergency.

With respect to water levels and steam temperature and pressures, safety limiters should be in place to prevent these occurrences, but operators should be trained how to respond in cases where these limiters fail to act.

Water Treatment

The recommendations given in this section reference the relevant sections of BS EN 12952-12:2003 and British Standard 2486:1997. These documents in tandem with BG04 should be used as a standard for the control of water quality, as it reflects good operating practice and design experience from industry and boiler manufacturers. However, each application should be considered on its own merits and where applicable the boiler and steam turbine manufacturers' recommendations should be followed. This is increasingly important when performance guarantees are given.

Water treatment practice is dependent upon the considerations and choice of treatments for the system as a whole. It is therefore especially important that a knowledge of the metallurgy, plant layout and process plant performance is known so that the most appropriate choice of treatment can be made in each separate installation.

The start-up of the boiler and condensate system are potentially the highest risk times for boiler chemistry. When filling a boiler, the water supply should be de-oxygenated feed water or alternatively de-mineralised water with a 5 mg/kg reserve of an appropriate chemical oxygen scavenger - the boiler water pH should be adjusted with either solid alkalising agents such as sodium phosphates or with volatile alkalising agents. Operators shall seek advice from the boiler manufacturer and the water treatment specialist.

Condensate should be dumped until it becomes of an acceptable quality to return to the boiler plant. Samples of condensate should be taken regularly and analysed to determine the water quality.

The method of treatment chosen for the boiler and system depends upon:

- The function of the chemical;
- The quality of the feed water;
- The individual boiler system.

Professional advice from boiler and turbine manufacturers should be obtained, backed up by competent water tube boiler treatment chemists and knowledgeable site staff.

The pumps used for chemical dosing need to be of adequate capacity and manufactured from materials which are unaffected by the chemical. The quality of the water for mixing and dilution should be as recommended by the supplier but no worse than the demineralised make-up.

The chemicals used should be suitable and approved for the process in question; where steam is used directly on a finished product, chemicals may need to be US Food and Drugs Administration (FDA) Approved.

Dosing recommendations:

Oxygen Scavenger

Dose continuously at the feed point selected to give the maximum reaction time. This needs to be either the feed storage section of the de-aerator or in the outlet of the boiler feed tank.

Phosphates

Dosage is usually intermittent although can be continuous. Where economisers or pre-heaters are installed the phosphate should be dosed into the boiler drum at a point below the water line. Be aware of the need for extreme caution and recognition of parameters recommended by the water treatment specialist; these are different to those required in lower pressure fired boilers.

Volatile Amines

Ideally these need to be dosed continuously into the storage section of the de-aerator or into the suction side of the boiler feed pump.

Water Sampling

Sampling and reporting by specialised external steam boiler water treatment chemists is frequently used as the default position on steam boiler plant, but this is not the only or necessarily the best way to ensure the water in the boiler and system is at optimum condition at all times. Staff at the site should be trained to take and analyse samples as part of their daily routines, and these results can be compared with the results obtained by external chemists.

Sampling points should include, as a minimum:

1. Raw water supply;
2. Treated water at plant outlet, and at appropriate points throughout the pre-treatment plant system;
3. Treated water from storage tanks;
4. Condensate at appropriate points;
5. Feedwater after de-aerator;
6. Feedwater at economiser inlet;
7. Top (steam) drum;
8. Bottom (water or mud) drum;
9. Saturated steam;

10. Superheated steam to steam turbine;
11. Low pressure steam to process.

Sampling frequency will be decided as part of the site specific boiler water treatment regime, but in general terms the following routines are recommended:

- Demin water – every shift/twice per day;
- Condensate – every shift/twice per day;
- Boiler feed water at economiser inlet – daily for oxygen scavenger reserve and pH;
- Boiler water – daily;
- Silica in saturated steam – twice weekly.

Instrumentation supporting the water treatment regime and testing may be provided, for example to give conductivity, pH, oxygen, silica and sodium measurements. Instrumentation specialists should be consulted for advice on suitable devices and procedures.

4.2 Recording of Controls, Limiters and Water Quality Tests

Clear, written instructions describing how and when to carry out routine tests shall be kept on-site and be followed by suitably trained and competent boiler operators. In addition, maintaining accurate records of failure events and repairs is essential; without recording this information, vital plant background could be lost with personnel changes and it would be difficult for the CP to make an informed decision on the requirements for safe boiler operations and inspections.

Routine testing of controls, limiters and water quality is essential to ensure continued safe, reliable and efficient operation. It can help prevent the following dangers:

- Low water level which can expose the furnace or fire tubes and lead to metal overheating & catastrophic boiler failure;
- High water level which can lead to priming of the boiler or carry-over of water, causing water-hammer, damage to valves and pipework as well as sudden steam leaks, water in superheaters, scaling, and potentially letting water into downstream processes;
- Scale, excessive sludge deposits and dissolved solids which can quickly build up in a boiler through inadequate blowdown or water treatment regimes. These can cause boiler overheating or water carry-over which can ultimately cause boiler or system failure as they build up over time;
- Faulty combustion controls which can allow the uncontrolled presence of fuel, air and an ignition source, which can result in fires or explosions.

The tests and their frequency shall be based upon:

- Risk assessment of the plant and boiler system
- Water Treatment Risk Assessment in accordance with BG04 and the Boiler Water Written Control Scheme;
- Manufacturers' or modifiers' instructions; and
- The controls and manning levels.

A record of such tests shall be maintained to keep an audit trail of the boiler operation. Examples of daily and weekly boiler log sheet contents are given in Appendix 4.

Examples of the type of records and documents that shall be kept and made available for scrutiny include:

- Risk assessment of the boiler installation;
- Boiler logbook;
- Written Scheme of Examination (WSE);
- Boiler Water Treatment Risk Assessment and Boiler Water Treatment Written Control Scheme;
- Water treatment test records;
- Combustion analysis records;
- Manufacturer's records and instructions;
- Standard Operating Procedures;
- Emergency Procedures;
- Examination reports;
- Record of periodic tests (e.g. Non-Destructive Testing (NDT), Hydraulic test);
- Certificates of thorough examination;
- Records of servicing and modifications;
- Maintenance of controls;
- Evidence of competency, including but not limited to training records for boiler operators, supervisors and managers;
- Audit and system review reports by boiler operators and managers.

The use of loose-leaf logbooks is not recommended. Paper logs shall be securely bound, while electronic logs must comply with the requirements of BS 10008:2014: *Evidential weight and legal admissibility of electronic information. Specification.* Records must be legible, as must the name of the person who made the report and the person who checked or verified it.

Careful consideration of where logbooks are stored is required. While it is useful for information flow between operators to keep the current logbook in the boiler house, there is a risk that the log itself could be lost in the event of a catastrophic incident. For that reason, only the current logs should be stored near the boiler. Verified copies and older logbooks should be stored away from the boiler house.

Logbook entries shall be reviewed regularly by a senior manager within the organisation; this may be a useful time to make appropriate copies for remote storage and prompt a review of the procedures and risk assessment.

4.3 Water Level Controls and Limiters

Reliance on a differential pressure (DP) cell for accurate level indication is not recommended until the boiler is warm and the water level readings from the DP cell have been proven to be stable and correct. For boilers fitted with DP level transmitters in the top drum it is advised to fill the boiler and bring it slowly into service using the gauge glass to monitor the actual water level in the drum. Another important factor in the accuracy of DP cell level transmitters is to ensure both water and steam leg lines have been correctly filled with fluid before starting the boiler.

It is not recommended to use DP cells as the sole means of deriving low and high level alarms/limits. DP cells are known to give spurious readings particularly where each DP cell is not completely independent of each other – for example where a common pressure correction signal is applied to the otherwise independent instruments or where the DP cells are connected to common water and steam stabbings on the steam drum.

Furthermore, DP transmitters commonly give a false and extremely high water level on start up after a shutdown. This is due to the water in the constant head pipework evaporating into the drum while the boiler is cooling. When the variable leg is topped up during the boiler filling process, the resulting differential pressure will frequently be inaccurate and should always be cross checked with another instrument. One method is to rely on the gauge glasses or Hydrastep until the DP cell comes on line, typically at about 25 bar.

The testing regime for water level controls needs to be specific to the type of equipment employed. As a minimum it shall verify the functionality of the water level controls and the associated alarms and limiters. This shall form part of the operating instructions for the boiler system.

The following need to be considered when drawing up instructions:

- The manufacturer's recommended test methods shall be carried out as a minimum;
- Any departure from the test frequencies outlined in the arrangements must be supported by the risk assessment;
- Only a competent operator shall carry out the tests;
- At no time during a test shall the water be lowered to the extent that it disappears from the gauge glass;
- If a boiler fails a functional test of the level limiting devices it shall be shut-down and not brought back into service until such time as the fault has been repaired and the level limiting devices successfully re-tested;
- Test results shall be logged (either electronically or manually) with the operator's name, date of test plus any corrective action taken;
- Corrective action following alarms shall always be taken by the competent boiler operator;
- After tests have been completed, ensure that the water level is restored and that all valves are in the correct operating position. The boiler shall not be left until it is operating correctly.

Further details of tests can be found in BS EN 12952 Part 7 which gives informative guidance on routine testing for un-manned boilers. While the recommended tests are useful for all boilers, the recommended frequency is only appropriate to boilers designed to this standard; risk assessment may demonstrate that some tests should be carried out more frequently.

Testing Low Water Alarms and Limiters

There have been detailed discussions in the boiler industry on the subject of how and when to test low water devices. The most important advice is to follow the instructions of the original equipment manufacturer, as, in the absence of any other advice, the HSE will likely consider this an absolute minimum unless the employer has considered and risk assessed a better way. This will be true for both the methodology for demonstrating the limiter is effective, and for the frequency and timing of the lower water test.

Discussions will usually relate to whether to let the water level drop by evaporation only, or assist the water level to drop with the aid of the blowdown function. Testing of the low water limiter devices has to be agreed with the CP in relation to requirements in PSSR for 'putting into service' testing.

Where the low water limiting device has some form of mechanical linkage or float device that may stick if the position is moved very slowly, then lowering the water by evaporation only is the correct advice as this replicates what the mechanism sees in true operation.

Where the low water limiting device is an electronic signal generated by a change in conductivity, capacitance or radar level and its functionality is not affected by the rate of change in boiler water level, then the use of evaporation assisted by the use of the blowdown valve is likely to be acceptable as long as it is agreed with the CP.

The minimum frequency of testing of limiters is normally documented in the written scheme of examination, but a more widely agreed principle is that the CP should witness the functioning of all limiters as defined in the Written Scheme of Examination and the user should also retest the limiters each time the boiler goes back into service following any shut-down, e.g. for maintenance, where the opportunity for items to become disconnected, stuck, or damaged may occur.

It is essential that either a visual Gauge Glass or Hydrastep (or another legally acceptable alternative water level indicator) is connected to boiler and in working order at all times that the boiler is in operation. Note that a level indication derived from a differential pressure transmitter is not necessarily acceptable. It is strongly recommended that gauge glasses on steam boilers are always left open to the boiler during normal operation and the gauge glass assembly shall be fitted with auto shut-off devices to shut off the steam and water connections for safety of boiler operatives in the event of a broken glass or leak.

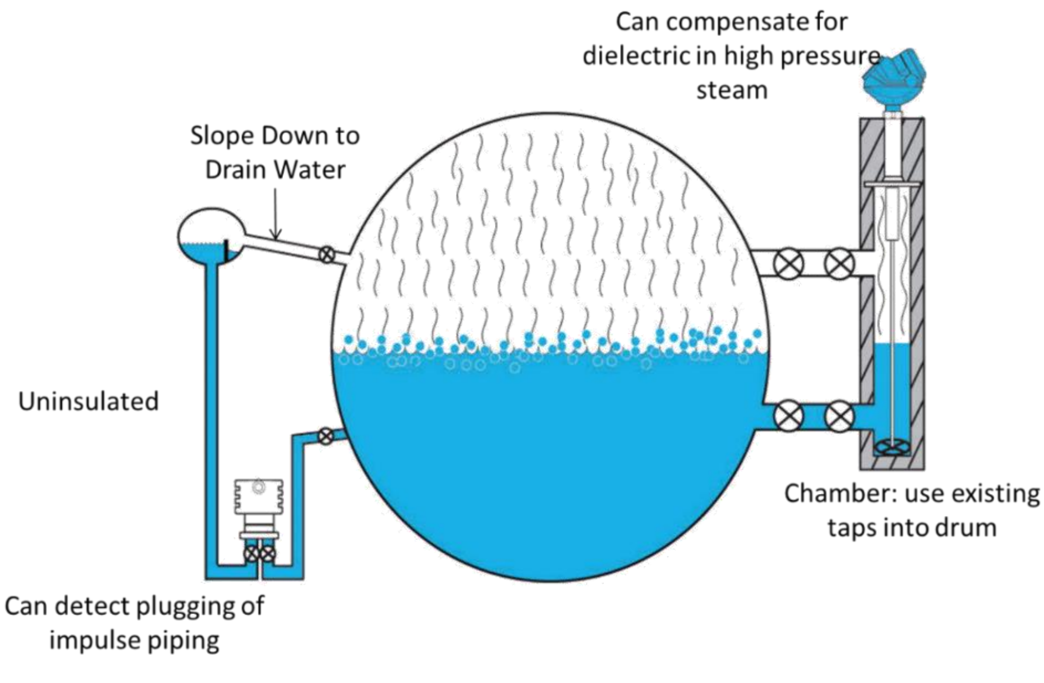
The key safety feature of any system even if it has leaks, is that they should not lose the water level in the drum. A water-steam balance indicator for the operator helps. Also, on start up the water-steam balance indicator needs to be masked to avoid spurious trips and false readings.

Drum Level Compensation

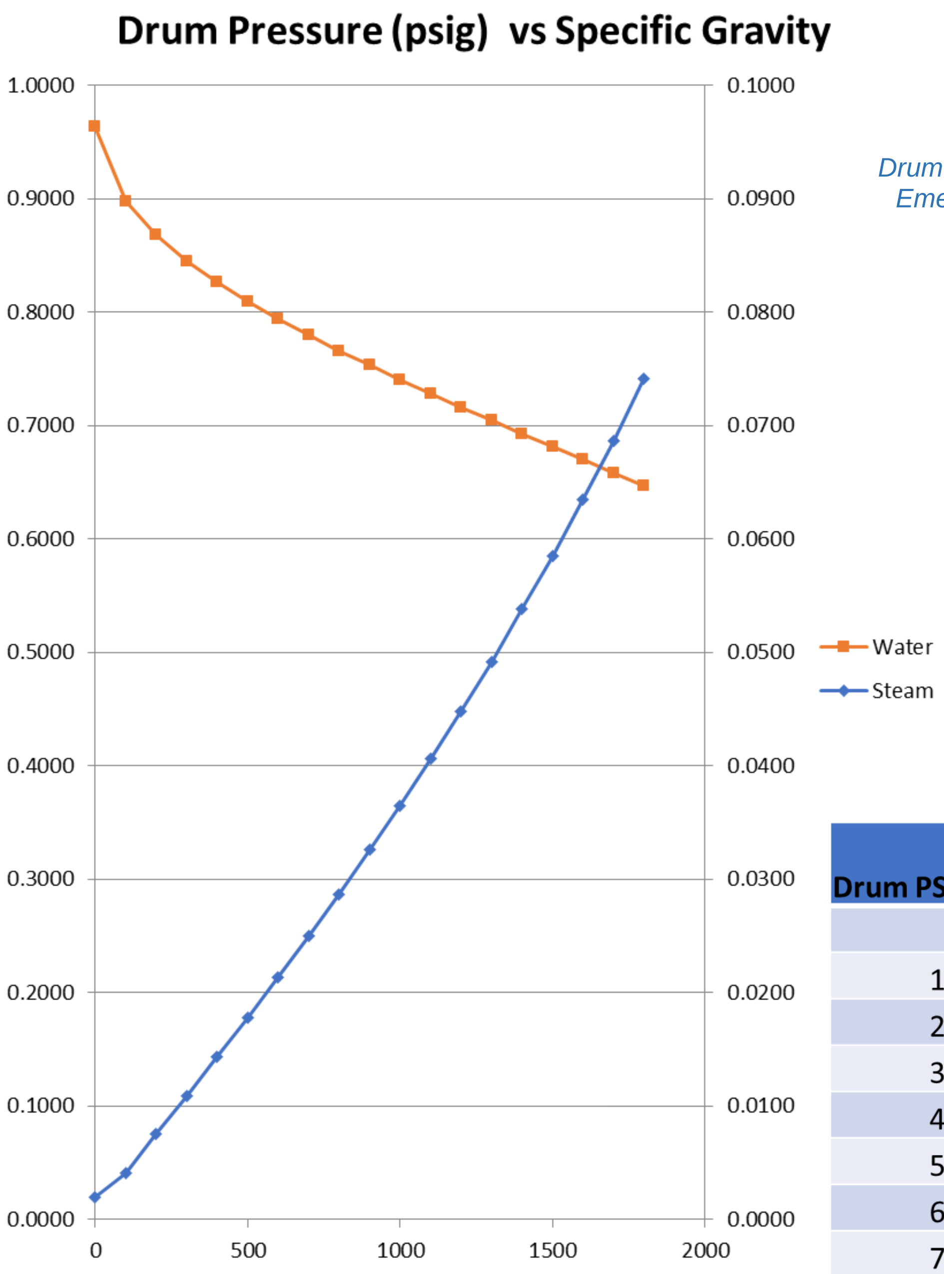
A recommended way to measure boiler drum level is to have a reference leg filled with water at ambient temperature and a seal pot on top to keep the level in the reference leg constant.

If the boiler is started with the reference leg still dry (e.g. after a maintenance outage) then the transmitter would show an extremely high level. It is important to check the upper leg is filled (and uninsulated) as part of the start-up checks. The manifold valves should be fully open (equalised) and the reference leg drained a little.

Commissioning engineers should compensate the measurement based on assuming a reference leg at ambient (say 50ºC) and then perform a dynamic compensation for steam and water SG in the drum, based on drum pressure measurement. This creates a true drum level reading all the way through boiler start-up, making the operator’s job much easier. However this compensation process can make the calibration checks a little more challenging if the effect of applied compensation is not considered.



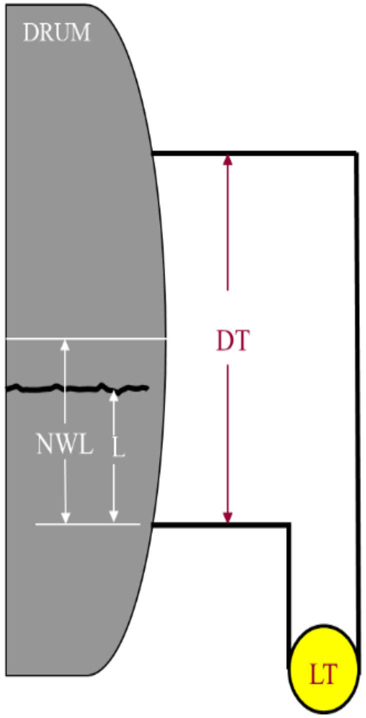
Steam drum level connections - Emerson Process Management



Drum Pressure v Specific Gravity - Emerson Process Management

Drum PSIG	SGs	SGw
0	0.0020	0.9639
100	0.0041	0.8977
200	0.0075	0.8678
300	0.0109	0.8451
400	0.0143	0.8261
500	0.0178	0.8092
600	0.0213	0.7938
700	0.0250	0.7795
800	0.0287	0.7659
900	0.0326	0.7530
1000	0.0365	0.7404
1100	0.0406	0.7282
1200	0.0448	0.7162
1300	0.0492	0.7045
1400	0.0538	0.6929
1500	0.0585	0.6813
1600	0.0635	0.6698
1700	0.0687	0.6583
1800	0.0741	0.6469

Water – Drum Level Compensation



Given the following constants:

NWL = Normal Water Level, inches above bottom tap

DT = Distance between taps

SGw = Specific Gravity Water, based upon drum pressure

SGs = Specific Gravity Steam based upon drum pressure

SGr = Specific Gravity of fluid in the reference leg

And knowing DP (raw reading from transmitter, in pressure units)

Solve for Drum Level (distance from NWL, in length units)

What is pressure at high side of transmitter?

$High = L*SGw + (DT-L)*SGs + K$

What is the pressure at the low side of transmitter?

$Low = DT * SGr + K$

If DP = High side – Low side

$DP = L*SGw + DT*SGs - L*SGs - DT*SGr$

$DP = DT*(SGs - SGr) + L(SGw - SGs)$

Then solve for L in terms of DP:

$$L = \frac{DT*(SGr - SGs) + DP}{(SGw - SGs)}$$

And calculate level around normal:

$Drum\ Level = L - NWL$

Drum Level Compensation example - Emerson Process Management

4.4 Burners and Combustion Tests

Combustion equipment must comply with the relevant standards. Burner commissioning, maintenance and testing by a qualified person in accordance with manufacturer's instructions is essential to ensure safe and efficient operation.

Manufacturer's instructions for the operation of burners shall contain such information as is required for a boiler operator to use and test the equipment supplied.

Access to burner controls and safety related devices which are to be tested by operators shall not be obstructed by fixed panels or otherwise obscured.

Combustion tests shall also be carried out as appropriate to the type of system in operation. Certain tests, such as visual flame examination or furnace inspection may not be possible or practicable on some designs of boiler, so use of an alternative test such as a CO, CO_2 or O_2 check may be appropriate.

All tests shall be recorded on log sheets and emissions limit data must be readily available. Suitably qualified persons shall investigate any problems and take corrective action.

All manufacturers' tests on burners shall be carried out at recommended frequencies with special attention to:

- Testing flame surveillance equipment operation & recording the results. Prove lock-out and manually reset (but see note below). In a process where the burner is firing continuously, a self-checking flame scanner shall be used;
- Testing correct operation of forced ventilation and its interlocks and/or ensure natural ventilation is to design standards and is unobstructed;
- On dual fuel installations, it is recommended that the changeover to the stand-by fuel should be tested monthly or as specified by the burner manufacturer;
- Fuel leak and shut-off checks:
    - Gas - if a significant gas leak is suspected, the gas supply must be shut down immediately and be reported to the Responsible Person. Follow site procedures for any necessary evacuation of personnel and/or activation of audible hazard alarms;
    - Oil - visually inspect pipework, tanks, bunds and supply lines for leakage. Record and immediately report any leaks to maintenance personnel; bund alarms are recommended, particularly where sites are unattended for 72 hours.

Note: Some types of high integrity self-checking photocell need professional adjustment and setting, and the manufacturer's recommendations and timescales shall be followed.

Should the Emission Limit Values of any environmental permit be exceeded, the User/Owner must notify the relevant authorities as soon as possible. If the plant cannot be brought back within limits in a reasonable time, the plant must be taken offline.

Where boilers are fitted with new burners to cope with new or additional fuel types, the design, installation and commissioning of the new equipment must be carried out in accordance with all required legislation and guidance. As one example, if changing a heavy oil fired installation to gas firing, a full check of the ventilation requirements will be required and may involve modifications to the boiler house.

Industrial Emissions Directive (IED)

In most water tube boiler installations the environmental regulations will lead the regulator to require continuous emissions monitoring equipment (CEMS) to be installed. CEMS equipment is expensive to install, operate and maintain, and a significant high level platform on the chimney to allow access for testing personnel will be required.

The specific requirements for the CEMS will be specified in any permit, along with the Emission Limit Values (ELV) for each pollutant, often with hourly, daily and annual peaks and averages, and frequently with improvement conditions that require the Operator of the installation to reduce pollution levels across the installation over time.

The Environment Agency have issued a number of useful guides to Monitoring and Measurement techniques and requirements under the MCERTS scheme (see Appendix 1 Ref: 56).

Emission levels associated with emissions to air refer to concentrations expressed as mass of emitted substance per volume of flue-gas under the following standard conditions:

- Dry gas at a temperature of 273.15 K, and
- A pressure of 101.3 kPa, and
- Expressed in the units mg/Nm^3, μg/Nm^3 or ng I-TEQ/Nm^3.

Reference conditions for oxygen used to express emission limits are given below.

Activity	**Reference Oxygen Level (O_R)**
Combustion of solid fuels	6 vol-%
Combustion of solid fuels in combination with liquid and/or gaseous fuels	
Waste co-incineration	
Combustion of liquid and/or gaseous fuels when not taking place in a gas turbine or an engine	3 vol-%
Combustion of liquid and/or gaseous fuels when taking place in a gas turbine or an engine	15 vol-%
Combustion in Integrated Gasification Combined Cycle plants	

The equation for calculating the emission concentration at the reference oxygen level is:

$$E_R = \frac{21 - O_R}{21 - O_M} \times E_M$$

Where:

E_R: emission concentration at the reference oxygen level O_R;

O_R: reference oxygen level in vol-%;

E_M: measured emission concentration;

O_M: measured oxygen level in vol-%.

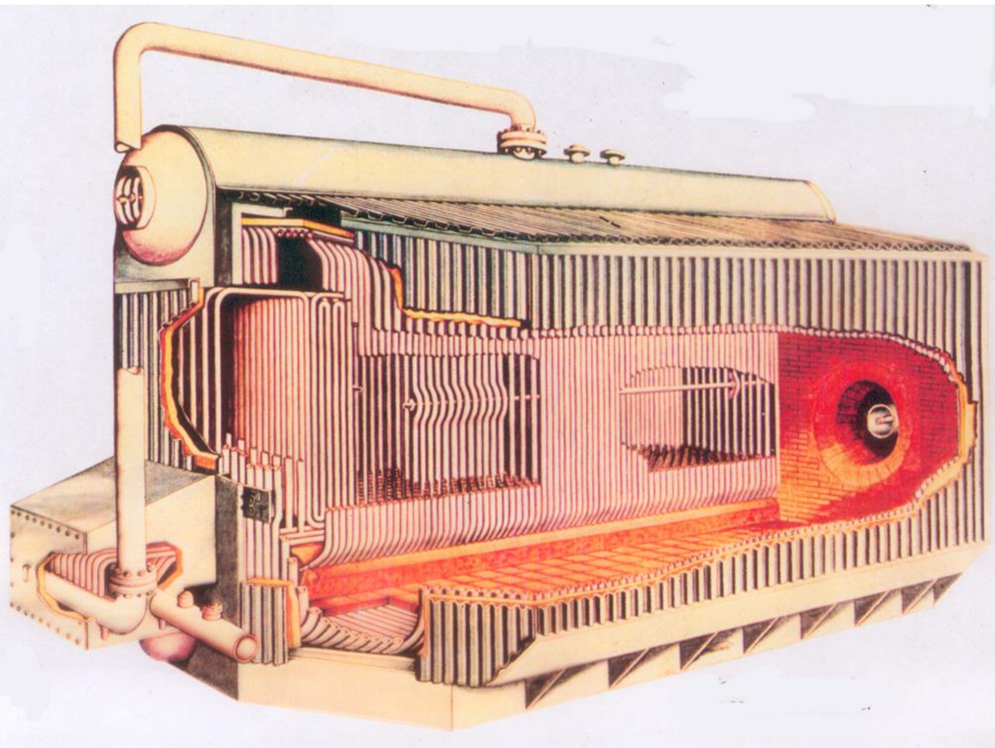
For averaging periods, the following definitions apply:

Averaging period	Definition
Daily average	Average over a period of 24 hours of valid hourly averages obtained by continuous measurements
Yearly average	Average over a period of one year of valid hourly averages obtained by continuous measurements
Average over the sampling period	Average value of three consecutive measurements of at least 30 minutes each
Average of samples obtained during one year	Average of the values obtained during one year of the periodic measurements taken with the monitoring frequency set for each parameter

Source: LCP BREF 2017

Medium Combustion Plant Directive (MCPD)

Relevant systems must comply with the requirements of the MCPD which places limits on emissions of NO_X, SO_X and particulates for all plant with a net rated thermal input of 1 MW to 50 MW. Some plant may need additional abatement systems in order to meet the Emission Limit Values (ELVs) in which case the abatement system shall be maintained in accordance with the manufacturer's instructions.



Gas fired 'shop assembled' water tube boiler – Thermo Technology Ltd

4.5 Solid Fuel and Alternative Sources of Heat

Whilst this guidance is primarily written with oil & gas in mind, much of its contents are relevant for other sources of heat such as biomass and other solid fuels. In this case, references to burners and fuel systems can be taken to mean the heat source and any associated fuel handling equipment.

Where a heat source cannot be completely removed quickly, for example in the case of a solid fuel fired boiler where fuel is already on the grate or in the case of a CHP plant where it is unsafe to regularly and repeatedly trip the engine or turbine, particular consideration shall be given to:

- The residual heat left in a boiler after a shut-down condition. The plant shall be designed so as to be able to accept this heat;
- The margin between normal working pressure and the safety valve pressure;
- The sinking-time of the boiler, i.e. the time during which the water level will sink from the lowest permissible water level to the highest point of the downcomers. This may involve consideration of an automatically closing valve on the steam outlet so as to prevent steam export;
- In some installations, there may be exceptional environmental or operational implications to testing of boiler controls. Testing regimes should be established to ensure that the controls and trips can be proven without tripping the plant except under controlled conditions as justified by a risk assessment.

Stopping solid fuel boilers is difficult because of all the stored fuel. One method which works well is to:

- Stop the primary air;
- Keep the secondary air on (preventing CO forming);
- Control furnace so any smoke goes up the stack and not into the boiler building;
- Slow down any grates;
- Clear all fuel delivery chutes of fuel (possibly run it into the boiler);
- Shut fire gate;
- Burn out the bed; and
- Finally only allow the ID fan to stop many hours (10 maybe) after a boiler stop when O_2 is at least 19.5%. This represents a boiler trip action / emergency shutdown.

In the event of a tube failure this may only be detectable by monitoring water flow, steam flow and blowdown, then comparing the flows or looking at trends for make-up water consumption. In the event of a large tube or header failure it may be that it becomes impossible to feed sufficient water to the boiler to maintain water level. Low water level limiters should protect the boiler from further damage but if the operator sees the water level falling rapidly and there is no obvious explanation, steps should be taken without delay to protect the boiler from overheating, by cutting off the fuel supply to the burners or other means to interrupt the combustion process – thereby minimising heat input into a boiler where the cooling effect of water is no longer present.

Additionally, if the leak is large enough to result in a significant pressure reduction, then steam may no longer be passing through the superheater. Under such a condition it may be necessary to open the superheater vent to promote a flow of steam through the superheaters which will help protect them from potentially overheating.

Tube failures on grate boilers can be extremely dangerous if the pressurised water and steam could cause burning material to be ejected forcefully from the combustion area. This risk must be thoroughly assessed where relevant.

4.6 Feed Water and Boiler Water Checks

A boiler water treatment specialist shall undertake regular checks on the water treatment plant and test the feed water, boiler water and condensate quality. If scale is found in the boiler system, the water treatment programme should be checked for correct operation and appropriate corrective action taken immediately.

In addition, a suitably trained and competent employee or the boiler operator shall make the following checks, usually on a daily basis, unless suitable automatic testing/monitoring is installed and only when a supporting risk assessment is in place, in which case a frequency of up to 72 hours might be acceptable:

- The feed tank (de-aerator) level is adequate and there are no contaminants;
- The feed tank (de-aerator) temperature is above the required level for the chemical water treatment dosing levels specified by the water treatment specialist for complete oxygen scavenging;
- Any chemical dosing metering device is functioning and there are adequate chemical stocks, both in the tanks and elsewhere in the system;
- In-house routine sample results are within their given parameters provided by the water treatment specialist and/or any recognised standard including BS EN 12952-12, BS 2486:1997, or the manufacturer's instructions, and take remedial action when and where necessary.
- In-house routine testing is expected to include at least the following:
    - Oxygen scavenger reserve;
    - Alkalinity tests;
    - pH;
    - Hardness checks of pre-treatment plant, feed tank and boiler, and all other test points deemed necessary by the Boiler Water Treatment Risk Assessment;
    - Total dissolved solids/conductivity level within the boiler and pre-treatment plant;
    - Appropriate tests of the condensate;
    - That the temperature is above the required level for the expected chemical water treatment programme, specified by the water treatment specialist, for complete oxygen scavenging;
    - Other tests as determined by Boiler Water Treatment Risk assessment.

For more detailed and specific guidance please see BS EN 12952-12:2003, BS 2486:1997 or the manufacturer's instructions.

Special consideration shall be given to the water treatment requirements for reserve boilers and boilers that are to be left unused for any period.

4.7 Emissions Control Equipment

The operation of emissions control equipment must always follow the requirements of any environmental permit and the recommendations of the relevant manufacturer. Permits will include detailed emissions limit values (ELV) for the different pollutants, and will have schedules of measurement procedures, approved sampling points, statistical requirements (such as measurement intervals, time periods and confidence intervals), and details of how to report results and deal with non-conformances.

Continuous Emissions Monitoring Equipment (CEMS) will require regular checking, calibration and maintenance, and the performance of the CEMS equipment must be validated by making separate measurements using qualified personnel, calibrated equipment and approved techniques.

The Environment Agency in England has an approved measurement and testing scheme (MCERTS) which covers the verification and validation of many kinds of environmental monitoring, and there are numerous guidance notes available for free download that describe the appropriate equipment, processes, qualifications and techniques. These should be consulted by Operators to ensure that they provide suitable validation facilities, employ qualified personnel, and report emissions data in a way that meets the requirements of their permit.

Soot Cleaning

The removal of excessive gas side deposits remains a requirement in most plant firing solid fuels (fossil and non-fossil) with the objective of maintaining thermal efficiency without the economic penalty of excessive use and potential for damage to heating surfaces.

Soot blowing is often a cause for boiler inefficiency, upset and failure. Basic systems simply blow soot at time intervals and can cause boiler load disturbances; they require contingency to be built into the timing to ensure that excessive deposits are not formed. This method frequently uses more blowing than is required. More accurate methods monitor the boiler performance against benchmark models and perform the soot blowing only when it is deemed necessary.

Means of soot cleaning may include:

- Pneumatically controlled rappers;
- Explosive techniques and acoustic systems;
- Fixed gas cannons;
- Sonic cleaning systems;
- Pressure wave generators;
- Water cannons/shower systems – to create steam in the flue gas and clean the tubes;
- Soot lances;
- Shot cleaning;
- Soot blowers using both steam and compressed air – retractable, rake type and rotary.

When using steam as the cleaning medium, it is important that it is steam and not water (condensate) that is used as water can cause wastage on the heating surface. Where water is used it is ideally atomised to help prevent issues of wastage.

All soot cleaning systems are used to provide additional energy to the soot, grit and dust on the heating surface and keep them in suspension – they are then carried in the gas stream for either removal elsewhere in the emissions treatment equipment or emitted to atmosphere and dispersed. Some systems have hoppers underneath to collect displaced ash material during cleaning with rappers and explosive techniques - often done at reduced loads. It is always preferable to carry out soot cleaning at high loads when the flue gas velocity is greatest.

To determine the frequency of soot cleaning it is recommended the flue gas temperature drop across the relevant heating surface and the differential pressure drop across the gas side are monitored. Using these parameters can help determine the optimum frequency of operation of the soot cleaning equipment.

Some Continuous Emissions Monitors (CEM) using an extractive technique to sample flue gases may need to be turned off when soot blowing or during fuel changeovers to prevent contamination entering the CEM.

Keeping the boiler heating surfaces clean does not always apply to waste burning plants which are sometimes left uncleaned since fuel consumption is not the primary consideration. Whilst maintaining clear gas passes is essential for continued running, it is also necessary to maintain control over gas temperatures through the system as excessive gas temperatures will encourage enhanced fireside corrosion of superheater tubing, the failure of which will cause a plant shutdown and loss of revenue from the primary income stream. Tube cleaning systems are installed but the deciding factors applied for their use is dependent on the furnace pressure. If the furnace pressure moves towards being positive the ash removal systems become more active to reduce the gas path fouling.

After a shut-down in these waste plants there maybe problems operating the emissions control equipment because the boiler is too clean, and the gas outlet temperature from the economisers is too low for efficient operation of the recirculating bi-carb or slaked lime systems. All ash removal systems might be turned off to encourage fouling and enable gas clean-up to work properly.

4.8 Calibration and Testing of Instrumentation

It is recommended to calibrate low-water protection systems, such as those that use differential pressure transmitters to monitor drum level or water flow, at least annually using calibration procedures that are in accordance with manufacturer's instructions. If annual calibration checks show the device has an error of more than 1 inch (25 mm) water level or 5% flow rate, increase calibration frequency until accumulated drift is within these limits.

The current generation of pressure transmitters probably only require a 5-10 year calibration interval to stay within +/- 25 mm H_2O so calibration intervals can be extended if necessary.

Instrument Calibration

Critical interlocks and instrumentation shall be calibrated to ensure correct functionality and to verify tripping levels. Calibration frequency for instruments critical to boiler safety shall be carried out in accordance with manufacturer's recommendations or at least every 6 months. Results will be documented and will be auditable.

The testing and calibration of all other non-critical instrumentation will often be carried out annually and shall be fully documented and will be subject to audit. Calibration and testing shall be planned and any specialist manufacturer's equipment (such as analysers etc.) shall be calibrated against procedures prepared by the specialist manufacturer of the equipment. The specialist manufacturer's procedures should be kept such that they are readily available.

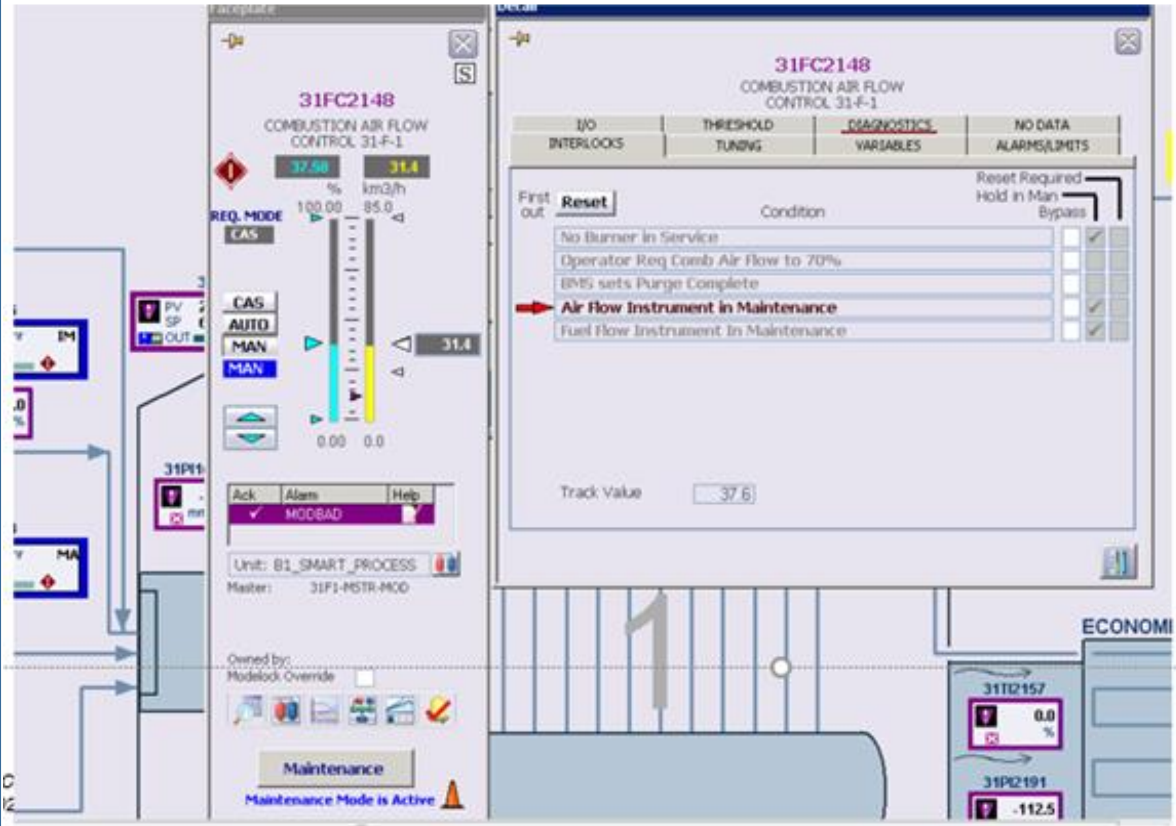
The persons charged with the responsibility for instrument calibration shall be competent for the task and adequately equipped with inspection and test facilities and tools capable of repairing and calibrating the instrumentation to the required accuracy.

If there are no back-up instruments for the control loop using the instrument under calibration, the loop, as a minimum should be placed in manual mode and the effect of any dependant loops should also be considered.

For Steam Flow or Boiler Feed Water flow, drum level three element control should be inhibited. For all trip initiators, overrides need to be in place but only used by authorised staff (usually a Shift Engineer or Team Leader) working to a strict documented procedure.

Key Features - Air Flow Instrument Maintenance

- MUST be selected if any work being undertaken on the measurement device to prevent plant upset
- Air Flow Control is held in manual
- BOTH Fuel Flow Control is held in manual
- Plant Master (31PC0520) WILL react to lead changes from the selected device
- Boiler Firing Modes are not available



Air Flow Instrument Maintenance example – Emerson Process Management

Instrument Testing

All boiler plants shall be provided with safety or critical interlocks of a digital or discrete design, especially on burner management applications. Where critical interlocks or sensors are of the discrete type (pressure switches etc.) their effectiveness cannot be predicted until there is a shutdown demand.

To increase the integrity of these devices they shall be tested on a regular basis. All critical interlocks shall be tested in accordance with manufacturer's recommendations or at least every 6 months. The test shall be designed to establish that the sensor, all interconnections, the logic and final shutdown device operate when there is a process demand.

The test procedure shall be such that the sensor sees true process conditions, e.g. in the case of a pressure switch, the switch shall be triggered by the introduction of the trip pressure into the process connection. The trip pressure shall be recorded and examined for trends. Analogue instruments shall be tested similarly.

Where multiple final device operations would occur as a result it is acceptable to operate the final device once and ensure the sensor, inter-connection and logic operate correctly for the remainder of interlocks (2 out of 3 voting systems). The final devices shall be operated at least once every 6 months, using different primary trips in sequence.

A considerable number of water tube boilers operate continuously between annual or longer outages and it would be difficult or even impossible in some cases to check interlocks without shutdown. Risk assessments shall establish a procedure for testing safety circuits that is commensurate with the operational needs of the installation, and techniques for testing specific items should be developed to reduce downtime whilst effectively testing each circuit and device.

One solution for testing water level limiters on a waste burning plant that has been successfully utilised makes use of a 3-position key switch that can only be used by competent personnel:

i. First position – normal;

ii. Second position, loading crane inhibited, drum level limiters inhibited, ID fan trip inhibited. Used for testing water level alarms; when in position 2 the water level may be raised and /or lowered until the relevant level alarm sounds and the boiler indicates a trip but it does not stop;

iii. Boiler has burst tube, water level lost. Switch enabled allows the ID fan to restart to a pre-set level to suck smoke back into boiler, inhibits combustion and burner fans. Inhibits crane operations on EfW boilers.

5 MAINTENANCE, REPAIR AND MODIFICATION

Many water tube boiler installations are still in perfectly acceptable condition after 20 or more years' service, but this has only happened because they have been well maintained and operated correctly by competent personnel. Some older boilers will not have the same level of control, monitoring and automation that newer boilers have, but this does not mean they cannot be operated safely and efficiently.

Owners of older plant may consider upgrading certain parts of their installation in order to improve efficiency, automate some of the routine operational aspects, replace obsolete components that can no longer be repaired, or upgrade to current standards.

Modifications to water tube boiler installations may not directly affect the pressure envelope but could be just as significant. For example, operators may find that the emissions limits in their environmental permit are quite onerous for certain fuels and a change of fuel is proposed.

Designers and installers of new fuel systems and other modifications for water tube boilers should ensure that all the necessary measures are taken to meet legislation and standards requirements for the new equipment, and that comprehensive testing and commissioning of the installation by competent staff is undertaken and recorded. There is normally no legal requirement to upgrade installations just because they were built to older standards, but some modern practices and materials make upgrading certain items a cost effective and safer proposition.

Modifications to installations will require operators to consider a wide range of issues such as:

- A review and revision of the boiler house technical risk assessment;
- Drafting of revised safe operating procedures;
- Training for operators on new equipment or new procedures;
- Revisions to 'as fitted' drawings and Process Instrumentation Diagrams, operating manuals, DSEAR assessment and other local documents;
- Informing the Competent Person (CP) if any work on the pressure parts has been carried out and the WSE requires review;
- Review of any environmental permits in force in case of revised emissions or new pollutants (change of fuel, or adding abatement for example);
- Review of emergency procedures and emergency action plans;
- Re-commissioning of controls and alarms to ensure safe operation;
- Informing other authorities and agencies (Planning or Fire service perhaps);
- Reviewing insurance risk.

Upgrading control systems to bring the installation into the digital age is often seen as a way to improve information and reporting, and possibly manage manpower requirements, but total reliance on technology will not always give the expected results. What is seen on the screen may not be reality if the sensor lines are blocked or signals have become corrupted for example. It is essential that sufficient competent operators are engaged in routinely inspecting and cross checking data on computer based systems to ensure that an imminent failure has not gone undetected.

5.1 Maintenance

Boiler systems must be properly maintained and in good repair, so as to prevent danger, and must take account of manufacturers' instructions in accordance with PSSR Regulation 12 and PUWER Regulation 5.

All maintenance requirements and activities shall be fully documented, including the frequency that maintenance should take place, and maintenance logs must be kept up to date.

Internal and external inspections of the boiler assembly must take place in line with the examination schedules in the written scheme of examination and will be completed in conjunction with the CP. The CP will be looking for the following indicators (not an exhaustive list):

- The actual colour of surfaces of components in the boiler circuit; brown and rusty probably means poor boiler water chemistry, likely high oxygen levels and the start of corrosion (rust). An internal coating of the steel parts would indicate good boiler water chemistry leading to a build-up of a grey 'magnetite' layer protecting the surface of the steel from corrosion;
- A smooth, black magnetite scale, sometimes decorated with rust spots, coating a dimpled substrate may indicate active flow accelerated corrosion with process safety implications for the integrity of less accessible pressure parts;
- If the internal magnetite layer becomes too thick it could lead to poor heat transfer across the tubes leading to overheating and/or corrosion, so the magnetite thickness needs to be monitored;
- Signs of flame impingement inside the furnace area indicating poor combustion on one or more of the burners;
- Signs of overheating or deformation on any of the internal metal parts, especially where internal cooling of the tubes is at its lest effective, such as in the superheaters;
- Signs of any internal water or steam leaks from tell-tale marks left on the insides of the boiler;
- Signs of erosion caused by water droplets in the steam or other mechanical effects;
- Signs of fire-side corrosion where appropriate from solid or some liquid fuels;
- Tightness and security of any internal removable items such as drum furniture, steam demister trays etc.;
- Missing or broken tube supports, ties and hangers;
- Any other potential water tube boiler failure mechanisms listed in detail in Appendix 2.

Boiler Tube Failures

It is not uncommon for tube failures in boilers to require significant sections of pipework or other components to be replaced. It is important that the possible causes of the failure are thoroughly researched and efforts made to carry out repairs that are effective and long lasting.

Incorrect or inappropriate selection of original materials for specific boiler parts may lead to shortened service life, and when burning more aggressive fuels such as waste or biomass, the pressure parts can have very short life expectancy. Some areas of the boiler may escape the effects of corrosion or excessive gas flow rates and other parts may be less fortunate. Actions to selectively replace a few exposed bends or short lengths of tubing may have to be balanced with more difficult commercial decisions on the suitability of the original design in its entirety.

Investigations into tube failures should always cover a larger area than that of the obviously damaged parts. Damage mechanisms tend to be closely linked to the position of the component in the boiler, and are affected by the temperatures in the boiler (flue gas, steam and water), the metal temperature at the area of damage, the distance of the component from the point of combustion, the heat flux, and the geometry of the boiler itself in terms of tight bends, closely spaced tubes, restrictions in gas passes etc.

Erosion in areas where sootblowers are installed or other local increases in flue gas velocity are encountered will lead to appreciably higher metal loss rates in certain circumstances. As an example, finned tubes on economisers have been replaced by unfinned tubes to try and avoid exceptional gas flow rate increases in these locations when ash accumulation occurs. If flue gas exit temperatures are not well managed then dew point corrosion can be expected to occur quickly thereafter.

Variable fuel composition from day to day, particularly in solid fuels with a high alkali metal chloride content, will likely lead to high wastage rates on the furnace walls and high temperature superheater stages. Fuel additives can help, but there is a cost implication, so a change to the fuel management regime and/or material upgrades may be the best solution.

A targeted approach to repairs on selected bends and components may well be the best option, but the choice between higher specification replacement tube materials and coatings such as weld overlay or thermal spray treatments can be a complex process. A trial of possible candidate materials will help to identify the best way forward.

A good planned maintenance regime and a clear understanding of the issues will help counteract the inevitability, especially in solid fuel plants, of the effects of corrosion and erosion. Weld overlay techniques using IN625 material are a tried and trusted solution but have a limited life. Other cladding alloys have been developed, and the option for thermal spray coatings is one being actively considered on many waste to energy plants.

5.2 WSE and Modifications or Repairs

Prior to any changes or modifications, a risk assessment should be undertaken, and the effects of any modifications, repairs or adjustments to the pressure equipment must be assessed by the CP to determine whether a review of the WSE will be required; this assessment shall take place prior to the work being undertaken. The WSE itself must be reviewed at appropriate intervals (PSSR Reg 8) and it is recommended it is reviewed by the CP at each examination (PSSR ACoP 117).

Modifications and repairs to pressure systems must comply with PSSR Regulation 13. For significant repairs, the following points must be addressed:

- All alterations to the boiler must be documented and reports or records kept for the life of the boiler;
- Repairs and modifications may in and of themselves only address the symptom. The underlying causal factors which necessitated the repairs or modification must themselves also be addressed;
- Design of the repair must make reference to the original design code and other suitable guidance and achieve an equivalent standard;
- Materials must be suitable and closely match the properties of the original equipment and all material certification kept safe for review by the CP;
- Workmanship must be in accordance with suitable standards including the use of correctly coded welders, and suitable non-destructive examination where applicable;
- Significant repairs or modifications to boiler systems, changes in their operating pressure or changes in cyclic operation must be notified to the CP, the WSE reviewed and the system thoroughly examined prior to coming back into use;
- Any alterations to the original specification of either the boiler system or the boiler house will require consideration and approval by the manufacturer and CP/s before instigating;
- Steam and hot water leaks are dangerous and will waste energy. Identified leaks should be cordoned off and repaired as soon as practicable;
- It may be necessary to carry out modifications or repairs to the burner control and alarm systems. Significant modifications and repairs, where they affect integrity and/or safety of the system, its controls & software, shall be properly considered and the CP shall be kept fully informed of proposals.

5.3 Responsibility

The importance of adequate maintenance on the boiler, the control system and the alarm system cannot be over-emphasised. Responsibility can sometimes be divided between those who own and operate the boiler system and those who maintain it. As this can be different in each case it is imperative that the limits of responsibility of each organisation are clearly defined in writing and understood by all parties.

In particular, it is important that the following points are noted:

- The User/Owner is responsible for ensuring that all persons working on or with a boiler are trained to do so, including directly employed staff, agency staff, and sub-contractors;
- Boiler operators shall ensure that they hand over the boiler to maintenance personnel in a safe condition;
- On completion of maintenance, the checking of all controls, limiters and alarms shall be verified by the boiler operator in the presence of the maintenance personnel before the boiler is placed on line;
- If the maintenance is carried out at the same time as the boiler examination, the controls, limiters and alarms will also be verified by the CP.

A typical Boiler Hand Back sheet example is shown in Appendix 4.

6 PERSONNEL AND RESPONSIBILITIES

6.1 User/Owner

The distinction between these terms is important as it will determine the duty holder responsible for ensuring compliance with certain Regulations under PSSR.

In general, the legal responsibilities of the User/Owner cannot be transferred e.g. by an employer to an employee. In situations where more than one employer or self-employed person may have an interest in the operation of a plant, para 46 of the ACoP to the PSSR provides guidance as to who is the User. It may however be prudent to take legal advice on the matter in this type of situation as it must be clear to all parties who is responsible under the Regulations.

6.2 Competent Person (CP)

A CP is defined in Regulation 2, PSSR as "a competent individual person (other than an employee) or a competent body of persons corporate or unincorporate and accordingly any reference in these Regulations to a CP performing a function includes a reference to him performing it through his employees."

From para 10 of the PSSR ACoP this term refers to the organisation employing the person who carries out these duties. Therefore, the legal duty to comply rests with a CP's employer, and not with an individual, unless that person is self-employed.

A CP is required to undertake two distinct functions under PSSR:

- To draw up, certify or review the written scheme of examination; and
- To carry out the examinations in accordance with the scheme and to produce a report after each examination.

These roles may be undertaken by the same or more than one person or organisation. The User/Owner remains responsible for selecting a CP who possesses sufficient expertise in the particular system and is capable of carrying out the duties in a proper manner. A CP is also able to act in an advisory role and advise on other aspects of PSSR such as the scope of the written scheme and establishing the safe operating limits of pressure systems.

In addition to the above legally defined personnel, there are also a number of other personnel involved in the day to day safe operation of boilers. These are discussed below but it should be borne in mind, these may not be terms that have a legal definition.

6.3 Employers

Under the Health & Safety at Work etc Act 1974 (HSWA), employers have general duties, amongst other things, to provide safe places of work and adequate training for staff and safety provisions for others affected by their undertaking. This general duty on employers is also required under other legislation such as such as MHSWR and PUWER.

This legal responsibility cannot be transferred to employees or third parties.

6.4 Employees Managing The Operation Of Boiler Plant

Employers must appoint sufficient suitably trained and competent personnel to be responsible for the safe management and operation of boiler systems. These supervisors or managers must be adequately trained to carry out all the duties they are expected to perform at each specific site. The authority of a person in a management position should be commensurate with the duties and responsibilities of that person.

The duties of boiler house managers may include but are not limited to:

- Ensuring compliance with relevant law (PSSR is specifically noted);
- Risk assessment and risk management;
- Ensuring that manning levels are sufficient;
- Ensuring the plant is operated within safe limits and according to the manufacturers' instructions;
- Ensuring that plant is maintained correctly;
- Oversight on boiler operators;
- Oversight on sub-contractors;
- Defining and maintaining competencies;
- Management of personnel;
- Record keeping.

6.5 Competent Boiler Operator

It is a legal requirement for the User/Owner to appoint sufficient numbers of trained persons to be responsible for the safe operation of the boiler system. These boiler operators must be adequately trained to carry out all the duties they are expected to perform at their specific place of work. The training should enable the operators to recognise when the limits of their own expertise are reached and when to call for assistance.

Owners of boiler systems and employers of boiler operators and boiler house managers are free to select and train staff in the way they see fit for the proposed activities. However, HSE INDG 436 says:

- *The training boiler operators receive must be appropriate for the equipment they will operate.*
- *The level of competence and training required must be reviewed when a system is modified or changed, e.g. increased automation or remote supervision.*
- *Have you a process for ensuring the competence of all personnel, both in-house and contractors?*

Formal training courses and documented personnel assessments are an essential part of the process of ensuring the safety of the plant and the persons affected by its operation. Training for water tube boiler operators frequently takes many months, often carried out on new installations as the plant is being installed and commissioned, and, on existing installations, as a structured process involving theoretical training as well as working alongside manufacturer representatives and current experienced staff.

The duties of the boiler operator should be determined as a logical outcome of a site specific risk assessment. These may include, but are not limited to:

- Shutdown of a boiler in an emergency or if it is unsafe;
- Implementing the boiler manufacturer's instructions, especially with regard to attendance when starting up from cold, and for all the other aspects of boiler operation, use, maintenance and cleaning etc;
- Carrying out all functional tests of limiters and controls where required, at all specified frequencies and in the specified manner. Records of all these tests must be maintained;
- Carrying out the recommended water quality tests, routine water treatment, recording the results and making adjustments where necessary in accordance with established standards and guidance (BS 2486:1997, BS EN 12952-12, BG04 or the manufacturer's instructions). This should be **in addition to** any testing contracted out to a water treatment specialist; note that the User/Owner remains responsible and the water treatment specialist contractor shall have specific and demonstrated expertise in the treatment of water for these high pressure systems;
- Tests on ancillary equipment;
- Checking the burners and associated equipment;
- Responding to alarms and taking appropriate action;
- Identification of maintenance requirements and faults;
- Investigation of abnormal operating conditions;
- Appropriate supervision of contractors;
- Recording the results of checks and tests and boiler house visits.

6.6 Personnel Monitoring Boiler Alarms

Persons whose function is to monitor alarms shall ensure that the boiler is safe in response to an alarm condition, or shut it down from a location deemed appropriate by a risk assessment in response to a site emergency.

Persons whose only function is to monitor alarms shall not enter a boiler house during an emergency unless there is a system or procedure in place to ensure that access is safe. Only trained persons should enter during an emergency and this entry process should be in accordance with tried and tested procedures and include a dynamic risk assessment to ensure their personal safety.

Untrained persons, and persons whose only function is to monitor alarms shall not reset a boiler or any associated part of the system following a lock out.

6.7 Maintenance Personnel

All maintenance personnel, whether employees or contractors, must possess sufficient knowledge and training to be able to carry out their expected duties. Maintenance personnel must only carry out the maintenance work for which they have been trained and are deemed competent. Suitable training courses for maintenance personnel can usually be provided or recommended by manufacturers of boilers, burners, fittings or control equipment.

Maintenance activities should be controlled by a permit to work system or other safe system of work. Permit issuers and authorisers should be competent for the role for which they are appointed.

6.8 Sub-Contractors

Sub-contractors are employed on many sites to perform specific specialist tasks or in some cases to manage the entire day-to-day operation of the boiler plant.

The contracting out party (normally the User/Owner) shall ensure that the chosen sub-contractor is competent to perform the required tasks. Suitable and sufficient oversight should be exercised on sub-contractors to ensure that:

- Legal requirements and legally imposed duties are met;
- Works are undertaken in a safe manner;
- Plant is left in a safe condition (whether usable or otherwise) during and after works;
- Relevant tests and checks are performed on the plant before it is returned to service.

6.9 Manning and Supervision of Boiler Houses

Manning and supervision levels in boiler houses shall be established as a result of a detailed boiler house technical risk assessment, firstly at the design stage (as part of the HAZOP) and then revised later as the operation of the boiler house evolves. In simple terms, the more automation, measurement and control that is installed the lower the manning requirements might be, BUT this has to be taken in context with other issues such as the location of the boilers, the likelihood of water quality issues, the possibility of contaminated condensate, and risks associated with a loss of steam or hot water to process as just a few examples.

Furthermore, different operating scenarios may dictate different supervision levels for the same level of automation. A boiler needs to be fully manned whenever it is in a vulnerable state, such as during start up, but it may be assessed as safe for less frequent visits or lower levels of manning during other periods, for example.

A detailed Risk Assessment is the only way to establish the manning requirements for your plant.

Boilers shall not be warmed through from cold, put on the range, or reset after a lockout without the competent boiler operator present at all times to observe all limiters and alarms, and take the necessary actions whilst following the prescribed start-up procedure issued by the boiler manufacturer, including following the start-up pressure and temperature curves. Water Tube boilers often have a complex start-up process, so the strict adherence to prescribed procedures will help to ensure the safety of the installation and its operators as well as the long life of the plant as a whole.

Boiler plants which incorporate systems which significantly exceed the minimum requirements of the law and include the highest level of automation and monitoring may still need to be fully manned, and this may be for reasons of steam security to process or other considerations.

Local Control and Alarms

The relative size and complexity of water tube boiler installations makes it unusual for them to be left unattended for any significant period of time, if at all. Water tube boilers may only be left unattended for a pre-determined period where a risk assessment allows.

Where the risk assessment determines that the boilers cannot ever be left alone, a competent boiler operator shall be in the immediate vicinity of the boiler controls and alarms at all times whilst the boilers are operating.

This type of supervision is required as a default position when the boiler controls are extremely basic or the boiler is in a vulnerable state, e.g. on start-up or after an unexpected alarm. It is also commonly used when firing solid fuels or unusual liquid fuels, or if there is an unacceptably high risk with the location of the boilers or the complexity of their operation.

If the boilers can, and actually do, automatically shut down safely as a result of any malfunction or incident, a competent boiler operator should be on site at all times whilst the boilers are operating and be able to attend the boiler house or be at the boiler control position within a short period of time. They should be within earshot and sight of alarms at all times. Electronic or radio call devices may be used if accepted by risk assessment.

The boiler operators may have other duties at the site, but they will be present for warming through, starting and stopping the boiler, and shall have specific boiler operational duties such as operational routine checks and, where part of their responsibility, water quality tests. The boilers shall be their first priority.

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7 TRAINING

Employers must ensure that all personnel possess sufficient knowledge of the boiler systems on which they work to perform their duties properly. Every employer shall ensure that any of his employees who supervises or manages the use of work equipment has received adequate training for purposes of health and safety (PUWER Reg 9).

Any training shall form part of a structured scheme taking into account the particular types of boiler on site and the full range of tasks required for safe operation and maintenance of those boilers. All training (including that for boiler systems) should be a structured on-going process which is updated to keep pace with developing technology, equipment and legislation. The level of competence required (and the corresponding training requirements) shall be reviewed when a system is modified, e.g. increased automation or new plant items.

The training shall be delivered by personnel possessing the appropriate practical experience, assessment skills, and knowledge of the working environment.

The employer shall ensure that all managers and operators and other relevant personnel are regularly assessed through work audits. Training shall also be reassessed periodically. All training shall be validated by assessment (written and/or oral) and the results of the assessment recorded.

The Boiler Operation Accreditation Scheme (BOAS) is recognised by the Health and Safety Executive, the UK insurance industry, the Safety Assessment Federation (SAFed) and industry members through the Combustion Engineering Association. Training providers accredited under the BOAS Scheme are accredited to industry standards. BOAS® is a Registered Mark of the CEA.

7.1 Training Courses

There are a number of courses available at various levels. It is recommended that operators and managers achieve the national industry standards for:

- Certified Industrial Boiler Operator (CertIBO) for operators; or
- Diploma in Boiler Plant Operation Management (DipBOM) for managers.

These qualifications form part of the BOAS Scheme which covers various types of boiler plant including water tube boilers.

The level of training for operatives and managers should be tailored to the equipment an individual is expected to operate and the duties that are expected to be performed while operating that equipment, either normally or under emergency or exceptional circumstances.

Generic boiler system training courses can be used to provide basic information at varying levels. All training courses should involve site-specific elements. Courses should include the following topics:

- Boiler operation including start-up and shut-down;
- Boiler and burner controls and failure modes, taking account of fuels used;
- Mechanistic understanding and diagnosis of metallurgical failure modes affecting pressure parts, including boiler tubing, and implementation of appropriate inspection and corrective measures;
- Feed water/boiler water analysis;
- Condensate drainage and steam/water-hammer;
- Actions to be taken in an emergency, and the consequences of inappropriate action;
- Responsibilities of all parties involved and legal aspects;
- Site specific training plus documented written and oral examination on completion of the course.

For water tube boiler systems Operators and Managers, Category 3 BOAS courses cover the following in more detail:

- Basic heat & heat transfer concepts
- Draught & combustion
- Feed water & boiler water analysis
- Control & instrumentation
- Safety & legal requirements
- Energy efficiency
- Environment
- Boilers & auxiliaries
- Operation
- Fuel concepts

BOAS courses cover these basic requirements for boiler operators and managers in general terms, but further training for specific activities is highly recommended. In particular, boiler house operators and managers should be encouraged to undertake enhanced training in boiler water testing, industrial gas operations (I-GAS®), manufacturer specific training for burners and combustion systems, and bespoke training for the operation and daily maintenance of any other plant items provided in their boiler house.

7.2 Training Records

Employers must ensure that all relevant training and assessment records are maintained and kept securely, including details of content and results of assessments. Appropriate audit records must be maintained and kept securely. Such evidence of training may be required to be viewed by enforcing authorities.

8 PERIODIC EXAMINATION OF BOILERS

The boiler must be examined in accordance with a WSE which will specify the parts to be examined, the types of examination required and the intervals between them. Depending on the circumstances and degree of expertise available the WSE may be:

- Written and certified by an independent Competent Person (CP); or
- Written and certified by the in-house CP (so long as they are sufficiently independent from the operating function); or
- Written in-house by staff with sufficient technical capability or staff in consultation with a technical support provider, but certified by an independent CP.

Boiler inspections and periodicity are an important element of boiler operations; currently water tube boilers are typically inspected either every 14 or 26 months, but in some instances that periodicity has been extended to 60 months once some good operating history data has been gathered. This needs to be discussed with inspection bodies as appropriate for each installation.

The overall examination consists of two parts, firstly with the boiler and its fittings stripped down ("out of service") and then after it has been returned to operation ("in service" examination). The second part of the examination includes verifying the protective devices are functioning correctly and it must be performed as soon as reasonably practicable after the out of service examination. In any event, pre-checks on the functionality of controls and protective devices should have already been performed by the User/Owner as soon as the boiler was returned to operation.

The protective devices that must be checked and/or tested include:

- Pressure gauge;
- Safety relief valve; followed by
  - Pressure limit switch;
- Water level controls/limiters;
- Flame detection device.

The User/Owner must ensure that any necessary preparatory work is completed so that the CP can carry out the examination safely. After the examination, the CP will issue a report of examination and all recommendations contained in the report shall be implemented.

Other devices or controls not classed as protective devices in PSSR but should still be checked and tested include:

- Fuel interruption lockout;
- Fuel proving systems;
- Control system power failure;
- Mains power failure;
- Critical alarms (including temperature alarms where fitted);
- TDS alarm.

SAFed Guidance PSG06: Examination of Pressure Systems in Accordance with Written Scheme of Examination, and PSG 07: Guidelines – on the PSSR SI 2000 No. 128 – Working examination requirements in WSE's provide further information.

8.1 Failure Mechanisms

A detailed explanation of failure mechanisms in water tube boilers is given Appendix 2. Any one of a number of design, installation, operational or local environmental issues might initiate a failure of the boiler or its components. Some of the many common failure mechanisms observed by Engineer Surveyors are as follows:

Corrosion

Corrosion is the chemical interaction of a material with the local environment and whilst almost invariably an operational issue, it can arise during shutdowns and occur prior to plant commissioning. Typically the most visible damage mechanism, it can affect the internal and external surfaces of components.

- **Corrosion under Insulation (CUI);** Largely confined to boiler plant under cyclic operating regimes or protracted shutdowns, the damage affects surfaces exposed to a sustained damp environment for extended periods due to water retention by insulation and/or refractory.
- **High Temperature Fireside Corrosion**; Confined to gas pass tubing operating at temperatures above the melting point of fuel specific, ash derived species. Almost exclusively confined to steam tubing.
- **Dew Point Corrosion**; Attack by acidic species, generally sulphurous, condensed from the flue gases where the metal temperature falls below the dew point temperature, a function of flue gas moisture content and active species concentration. Most prevalent in the cooler sections of the boiler, such as economisers.
- **On Load Corrosion**; A family of waterside corrosion mechanisms active where steam is generated and associated with the local concentration of acidic or caustic solutions significantly removed from optimal boiler water chemistries. Damage can be confined to excessive waterside wastage leading to thin-edged ruptures or mid-wall fissuring, resulting in thick-edged failures.
- **Pitting Corrosion**; Localised corrosion where the metal surface is in contact with oxygenated pools of water to allow electrochemical cells to be developed at discontinuities such as oxide fissures. The internal surfaces of horizontally inclined steam tubing being most vulnerable during extended shutdowns.
- **Flow Accelerated Corrosion**; Confined to carbon steel components operating within a critical temperature range and under adverse boiler water chemistries. Characterised by a polished black magnetite scale coating a dimpled substrate, the damage is associated with dissolution of a nominally protective oxide at positions of turbulence.
- **Stress Corrosion Cracking (SCC)**; Responsible for the sudden failure of a nominally ductile metal under tensile stress in a corrosive environment. Where these three criteria are met, the damage can develop from the internal or external surface of a component. In circumstances where exposure to aqueous media is sustained, the intensity is exacerbated by increases in component temperature.
- **Crevice Corrosion**; Localised attack at positions where access to the working fluid by the environment is limited.
- **Galvanic corrosion**; Localised attack where an electrochemical cell develops under an aqueous environment between two connected but different metals to promote a galvanic reaction.

Fatigue

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.

- **Thermo-mechanical**; The result of cyclic mechanical loading at positions of restraint, such as stub welds and attachments, and is almost invariably a consequence of thermally induced system stresses during start-up and shutdowns. The damage is often categorised as 'high cycle' or 'low cycle', the differentiation of which is dependent on the number of cycles experienced over the operational life of a particular component.

- **Thermal fatigue**; The result of rapid cyclic variations in temperature generating tensile stresses above yield at the component surface due to constraints caused by differential expansion with the component mid-wall. Sometimes referred to as thermal shock.

- **Corrosion fatigue**; Largely confined to water tubing, the presence of a 'corrosive' aqueous environment accelerates the initiation and propagation of the fatigue cracking under cyclic loading. Operation at low pH levels or with excessive levels of dissolved oxygen may induce pitting which can act as an initiation for corrosion fatigue. Header stub welds, non-draining lines and, due to the cyclic operational nature of vessels, de-aerators, are prone to this damage mechanism.

- **Fretting**; The result of repeated metal-to-metal contact refers to wear and sometimes corrosion damage at the asperities of contact surfaces. This damage is induced under load and in the presence of repeated relative surface motion, as induced by vibration, for example.

Creep

- **Creep**; The progressive plastic deformation of a solid material as a consequence of long-term exposure to levels of stress below the yield strength. Degradation develops as a 'time-temperature' dependent relationship. The rate of damage can be accelerated through tube bank misalignment or gas path short circuiting if this compromises steam flow through the tube path, notwithstanding any potential detrimental impact on the thermal efficiency.

Defects

- **Reheat cracking**; Degradation which develops in low alloy steel welds as a consequence of stress relief annealing. These cracks do not exist prior to heat treatment and cannot be detected even by means of non-destructive inspection.

9 LEGISLATION

Legislation discussed in this section relates to Acts and Regulations relevant to the UK. Legislation in other jurisdictions may differ, and some parts of the UK may have implemented some legislation, particularly environmental legislation, in slightly different ways, so always refer to the latest appropriate guidance, usually available from gov.uk, hse.gov.uk, CEA.org.uk, safed.co.uk and other reliable sources.

Boiler systems in the UK are required to comply with significant portions of detailed legislation, including a number of health and safety and environmental regulations, which are aimed at ensuring that existing and new boiler systems are continually designed, installed, operated and maintained in a safe manner.

The principal sets of **health and safety legislation** that support the Health and Safety at Work etc. Act 1974 and apply to the use of boiler systems covered by this guidance are:

- The Management of Health & Safety at Work Regulations (MHSWR);
- The Pressure Equipment (Safety) Regulations (PER);
- The Pressure Systems Safety Regulations (PSSR);
- The Provision and Use of Work Equipment Regulations (PUWER); and
- The Dangerous Substances and Explosive Atmospheres Regulations (DSEAR).

With the exception of MHSWR and PER, the regulations listed above are supported by Approved Codes of Practice (ACoP) and Guidance produced by the Health and Safety Executive (HSE), and available as free downloads from www.hse.gov.uk.

There are numerous sets of **environmental legislation** that may be applicable to water tube boilers, including:

- The Clean Air Act;
- The Industrial Emissions Directive;
- The Waste Incineration Directive (for waste as a fuel); and
- The Environmental Permitting Regulations (including the Medium Combustion Plant Directive).

Relevant legislation is addressed in the following text.

Refer to Appendix 1 for a list of currently applicable legislation. It is the reader's responsibility to ensure that they refer to the latest available version of any legislation or guidance. All legislation and guidance can be downloaded or obtained from gov.uk or web sites such as cea.org.uk, safed.co.uk and igem.org.uk.

9.1 The Management of Health and Safety at Work Regulations (MHSWR)

The Management of Health and Safety at Work Approved Code of Practice (ACoP – L21) has been withdrawn and is no longer available. For those looking for information on how to manage risks in their business, HSE has a suite of guidance that will be able to help. Each level of guidance on HSE's website offers appropriately targeted information, focussed on making compliance as straightforward as possible.

If you need basic information or are getting started in managing for health and safety, then the best place to look is *Health and safety made simple: The basics for your business* (INDG449). You should also consult: *Safe management of industrial steam and hot water boilers. A guide for Owners, managers and supervisors of boilers, boiler houses and boiler plant* (INDG436) in which it states *"As the manager of a workplace, you have a duty to manage the risks associated with that workplace. If there is a boiler installation on your premises, you must ensure it remains safe."*

MHSWR apply to every employer and self-employed person who carries out any work activity whether or not they own or use a pressure system (all future references to employers in this guidance should be read to include self-employed persons).

They impose a duty to manage all risks from any work activity, not only within the workplace itself, but also any risks to all persons (including any non-employees) who may be affected by the activity in question.

Regulation 3 requires the completion of a suitable and sufficient risk assessment of the work activity in order to properly identify and adequately manage any risks. This is of central importance. The risk assessment must identify sensible measures to control identified risks that may otherwise result in injury or danger.

Risk assessments for boiler systems are covered in more detail in the following sections.

9.2 The Pressure Equipment (Safety) Regulations (PER)

PER applies to the design, manufacture and conformity assessment of pressure equipment and assemblies of pressure equipment with a maximum allowable pressure >0.5 bar.

All items of new and substantially modified pressure equipment (including steam raising plant) comes within the scope of PER and they must comply with its requirements before they may be supplied for use in the UK.

The Directive on Pressure Equipment (PED - 2014/68/EU) was adopted on 15 May 2014 and all of its provisions entered into force on 19 July 2016, replacing the previous Directive 97/23/EC. The Directive was implemented into UK law by The Pressure Equipment (Safety) Regulations 2016 (SI 2016 No.1105) replacing the previous Regulations SI 1999 no. 2001.

The Regulations apply to pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 bar, although there are a number of exclusions which are set out in Regulation 4 and Schedule 1 to the Regulations. "Pressure equipment" means vessels, piping, safety accessories and pressure accessories. "Assembly" means several pieces of pressure equipment assembled to form an integrated, functional whole. These Regulations do not apply to pressure equipment placed on the market before 8 December 2016.

Schedule 2 of PER details the essential safety requirements (ESR) that qualifying vessels must satisfy. Additionally, there are details of how the different products are classified, the technical requirements that must be satisfied, and the conformity assessment procedures that must be followed.

To comply with the ESRs the manufacturer must either produce a technical file that addresses each ESR in turn, or manufacture the equipment using standards that have been listed in the EU's Official Journal which give a 'presumption of conformity' to specific ESRs.

The Department for Business, Energy and Industrial Strategy has produced a guide to the Pressure Equipment (Safety) Regulations 2016 and this can be downloaded from gov.uk.

9.3 Pressure Systems Safety Regulations (PSSR)

PSSR set out the main legislative requirements to ensure the continued safety of the pressure systems in use (which includes steam and some hot water boilers). PSSR applies to two clearly defined categories of people (**duty holders**). These are the

- '**Owner'** – an employer or self-employed person who owns a pressure system. Where the employer who owns the system does not have a place of business in Great Britain, or an agent in Great Britain who would take responsibility, then the User (see below) will be responsible; and the
- '**User'** – the employer or self-employed person who has control of the operation of the pressure system.

The distinction between '**Owner'** and '**User'** can be important in certain circumstances in determining the duty holder responsible for ensuring compliance with certain regulations under PSSR. However, in general, Owners carry more responsibility in relation to mobile systems, while Users have responsibilities in relation to installed systems. Water tube boilers are considered to be 'installed systems' for the purposes of the regulations if they contain steam at any pressure or hot water at above approximately 110^{o}C (a "relevant fluid").

It is usually the case that water tube boilers and their associated systems would be defined as a Major Pressure System within PSSR, with the associated requirements as defined in PSSR for technical competence, CP competence and hierarchy etc. Major systems (L122 para 98(c)) are those which because of their size, complexity or hazardous contents require the highest level of expertise in determining their condition. They include steam-generating systems where the individual capacities of the steam generators are more than 10 MW.

ACoP L122 Para 99 (c) gives details of the staff, specialist services and organisation necessary for competent persons who draw up or certify such schemes of examination. Accreditation to BS EN ISO/IEC17020:2012 is recommended for bodies acting as CPs engaged to draw up or certify a written scheme of examination or conduct examinations for major systems (L122 para 36).

The User/Owner of the boiler is responsible for complying with the following requirements of PSSR:

- Safe Operating Limits (SOL) have been set and are not adjusted without informing and gaining the agreement of the CP and the manufacturer where appropriate;
- The system is never operated unless a current Written Scheme of Examination (WSE) is in place. Any requirements of this scheme e.g. a report of the last examination, must also be satisfied (Regulations 8 & 9);
- The items identified in the WSE must be examined by a CP in accordance with the requirements of the scheme;
- The results of all tests and examinations must be recorded by the CP (Reg 9) and retained by the User/Owner for a suitable period. A period of at least two years is recommended for retention of records of routine tests;
- All repairs and modifications shall be carried out by people suitably competent in such work (Regulation 13, PSSR, ACoP Para 176). You must discuss and agree any changes with the CP and include any changes within your written scheme of examination (WSE) (ACoP Para 89). The details of such work shall be retained for the life of the plant;
- The statutory technical documentation and other records must be kept and where required, be made available for examination.

All records may be kept on-site or at a designated central location but wherever they are kept, they must be secure and easily accessible, and records must be transferred when the Ownership of a system changes (Regulation14, PSSR).

The User must give operational employees adequate instruction so that the boiler can be operated safely (Reg 11 and para 145 ACoP). For a steam or relevant hot water boiler these should include (paras 151 & 152) instructions covering:

- Pre-firing and start-up instructions;
- Feed water treatment (see BS 2486);
- Safe blowdown of the boiler (see BG03);
- Precautions to be taken when emptying the boiler;
- Precautions to ensure positive isolation and depressurisation of one boiler from a common header and blowdown system if internal access is required;
- Precautions to be taken before carrying out maintenance operations;
- Procedures to be followed in the event of a shortage of water, bursting of tubes or other event requiring the boiler to be shut down.

9.4 Provision and Use of Work Equipment Regulations (PUWER)

Any employer who either provides equipment for use at work (including boiler systems) or has control over the way and manner in which equipment is used at work has a legal responsibility to comply with the relevant provisions of this Regulation. An important, often overlooked, requirement under PUWER is that a maintenance logbook, when provided, must be kept up to date.

Under PUWER, all employees required to use equipment at work must be trained to do so (Reg 9). This will therefore extend to the competence assessment and training of operators and managers of boilers, all ancillary plant, and any feed water treatment plant used for the boilers.

Other parts of PUWER of relevance to boiler systems cover such topics as equipment suitability, maintenance, inspection, information and instructions, and control systems.

This is not an exhaustive list.

9.5 The Construction (Design and Management) Regulations (CDM)

Installing, replacing or even repairing a water tube boiler will probably be a large enough project on its own to be notifiable under CDM; the Regulations will apply in full and must be considered at every stage of the project.

Clients must appoint a Principal Designer and a Principal Contractor to ensure that the CDM Regulations are properly followed. It is incumbent upon designers of new installations to ‘design out’ risks to personnel and plant at the earliest stages of a project, and to keep these principles in mind for the whole life cycle of the installation including commissioning, operation, maintenance, and eventual decommissioning of the plant.

9.6 The Dangerous Substances & Explosive Atmospheres Regulations (DSEAR)

A risk assessment under DSEAR must be undertaken. DSEAR applies to all fuels (not just natural gas) and is very likely to apply to all boilers as any leak from the fuel supply, fuel storage, or fuel handling plant could lead to an uncontrolled release of a gas, vapour, mist or dust; if an ignition source is found then uncontrolled combustion could spread to the entire unburned mixture.

The Owner of the system may assist the manufacturer by providing information from an assessment of the probability of the presence and the likely persistence of a potentially explosive atmosphere in the proposed working environment.

Equipment supplied for use in a potentially explosive atmosphere must also satisfy the relevant requirements of the *Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations*.

9.7 The Control of Substances Hazardous to Health Regulations (COSHH)

COSHH is the law that requires employers to control substances that are hazardous to health. Employers must prevent or reduce workers exposure to hazardous substances in the workplace.

Substances can take many forms and include chemicals and products containing chemicals, fumes dusts and vapours, mists gases and asphyxiating gases, and biological agents (germs) including germs that cause diseases. If the packaging has any of the hazard symbols then it is classed as a hazardous substance.

There are many substances in the boiler house that might cause health issues for employees. The most common problems arise from handling water treatment chemicals; every substance must have a Safety Data Sheet describing the properties and dangers of that substance, and all substances are listed in EH40/2005 ‘Workplace Exposure Limits’ where further information can be found.

Recent work on analysing yellow coloured deposits from combustion processes has identified the presence of Hexavalent Chromium; it arises as a product of the materials used in refractory and the chromium present in stainless steel where significant heat is applied, and has appeared in hot gas passes of turbines, combustion case bolting, and the lagging of steam pipework.

Hexavalent chromium is harmful to the eyes, skin, and respiratory system and is considered to be toxic and an occupational carcinogen; workers may be harmed from exposure to hexavalent chromium and the level of exposure depends upon the dose, duration, and work being done.

9.8 The Industrial Emissions Directive and the Environmental Permitting Regulations

All combustion plants with a nett rated thermal input 50 MW and above will be required to follow the Industrial Emissions Directive (IED) which necessitates the issue of a permit for all the activities associated with the combustion of fuels in these installations, as well as for other activities such as potential water pollution and managing waste arising.

Early discussion with the Regulator is essential as the application for a permit can be a lengthy and detailed process. The permit will contain specific operating conditions for the operator to follow which might influence aspects of the design, including, in many cases, some improvement conditions, and will require regular surveillance visits to ensure the conditions are being followed.

All combustion plants rated between 1 MW and 50 MW nett rated thermal input will be required to comply at the due dates with the Medium Combustion Plant (MCP) Directive which has been transposed into UK legislation through changes to *The Environmental Permitting (England and Wales) (Amendment) Regulations, The Pollution Prevention and Control (Scotland Amendment Regulations*, and *The Pollution Prevention and Control (Industrial Emissions) (Amendment) Regulations (Northern Ireland)*.

This legislation requires the registration of all new combustion plants put into first use after 19 December 2018 and the registration of existing combustion plant before 01/01/2024 for plants individually 5 MW and above, and before 01/01/2029 for plants rated from 1 MW to <5 MW. Where more than one new plant is on a site the new plants will be aggregated to a single MCP.

From the date of first use (in the case of new plants after 20/12/2018) and from 01/01/2025 (for existing 5-50 MW plants) and 01/01/2030 (for existing 1-5 MW plants) the emissions from those combustion plants must not exceed specified emission limit values (ELV) for NOx, SOx and dust (total particulates), and these will be measured at specified intervals along with carbon monoxide (CO) (no limits currently set for CO). Plants rated 20 MW and above will be measured annually, and plants below 20 MW will be measured every 3 years.

The Environment Agency (EA) in England and their equivalents in the devolved UK administrations will administer the legislation and will consult with Local Authorities where there may be a combustion plant in or close to a Local Air Quality Management zone. This may mean tighter ELVs will be applied. Sites that currently have environmental permits for other activities will have any MCPs added to their permits at the due date.

The EA have produced detailed guidance on how these Regulations will be applied, and similar guidance exists for the devolved nations of the UK.

9.9 The Waste Incineration Directive

Where waste is used as a fuel, the Waste Incineration Directive (WID) will usually apply in addition to other environmental legislation. Different waste incinerator, co-incinerator or small waste incineration plants have to meet different requirements. Which chapters of the Industrial Emissions Directive apply to a plant will depend on certain criteria.

Operators and regulators must follow the Environmental Permitting Regulations (England and Wales) 2010, as amended. These set out how the EU directive 2010/75/EU (the Industrial Emissions Directive) applies to England and Wales.

Chapter 2 applies to a waste incineration or waste co-incineration plant if it has a capacity of:

- More than 10 tonnes per day of hazardous waste;
- More than 10 tonnes per day of animal carcasses;
- More than 3 tonnes per hour of non-hazardous waste.

The Environmental Permitting Regulations define small waste incineration plants (SWIPs) as all waste incineration or waste co-incineration plants with a capacity less than the limits specified in chapter 2 of the Industrial Emissions Directive above.

Typical fluidised bed boiler – Thermo Technology Ltd

10 LEGAL RESPONSIBILITIES

10.1 Risk Assessments – For Existing and New Sites

Regulation 3 of MHSWR requires that a 'suitable and sufficient' risk assessment be carried out before the work activity commences. Its purpose is to determine whether any risks are present and, if they are not already adequately managed, what further control measures are required. The significant findings of the risk assessment must be recorded where there are 5 or more employees.

The control measures must have the primary aim of eliminating risks. Where elimination is not possible, the control measures must aim to reduce the risks to a level as low as is reasonably practicable (ALARP). Regulation 4 and Schedule 1 of MHSWR sets out the principles of prevention.

The responsibility for the risk assessment lies with the employer although they may do this using input or assistance from various sources such as boiler manufacturers and control system experts, or have the entire risk assessment carried out on their behalf by someone competent to do so.

Traditionally for large new schemes a study of hazard identification and system operability (HAZOP) will be undertaken to carefully inspect each component and each integrated system of the proposed installation to establish how the individual components of the system will work and, more importantly, how they work with other parts of the system to ensure overall safety of the final solution. Many techniques are in common use to enable a HAZOP process to be undertaken.

For existing schemes, a boiler house technical risk assessment should already have been undertaken, and this must be reviewed at intervals as defined in the assessment, or when plant and personnel change, or when there is an incident that requires investigation.

For a boiler, the risk assessment should consider issues such as:

- The likelihood and severity of injuries from:
    - Burns from hot water, steam, burners and flues;
    - Electric shock;
    - Fuel escape, or fuel incidents;
    - Fire;
    - Asphyxiation, and toxic effects from combustion products;
    - Falls from height (still a very common industrial injury);
    - Impact by a moving vehicle (particularly on sites using solid or liquid fuels);
- The location of the boiler with respect to:
    - Numbers of persons likely to be affected;
    - Proximity to industrial premises/workers;
    - Proximity to the public especially vulnerable populations - such as nurseries, schools, hospitals, care homes etc.;
    - The potential impact on neighbouring sites due to an incident;
- Capability and reliability of safety-related systems;
- Level of operational supervision;
- The positioning and calibration of alarms and the associated response times;
- The provision of emergency procedures;
- The presence of other dangerous materials;

- The adequacy of boiler house ventilation and flue integrity;
- Environmental effects, e.g. noise, pollution, waste arising;
- Effect of chemicals on workers, the environment and others, e.g. water treatment chemicals;
- Operational risks:
  - Leaks of steam or water, the effect of high operating temperatures on materials, and other mechanical issues;
  - Mechanical or water damage to plant or equipment;
  - Water-side explosion due to catastrophic failure of the pressure envelope;
  - Combustion explosion, caused for example by unspent fuel;
  - Failure of the water treatment equipment to deliver properly treated water to the boiler;
  - Speed of response to loss of steam or hot water to process.

Since risk assessments must assess the existing control measures, they should also consider information regarding:

- Manning and supervision;
- Type and reliability of controls and the integrity of safety-related systems.

Risk assessments must be reviewed periodically, or after any accident or incident, or when there is a significant change e.g. a system variation, change in operating parameters or manning levels etc. The outcome of any reviews must be recorded.

As an example, an Owner moving to a lower level of supervision of the boiler shall, as a first step, review the boiler design and the current risk assessment to take account of the planned change in manning levels. The results of the risk assessment will be used to determine any measures necessary to ensure that the boiler remains safe to use and to operate. Such measures may include:

- The proper formulation and correct application of all modifications and installations to ensure they have sufficient safety integrity to adequately mitigate the risk of a dangerous occurrence;
- Amendment of procedures where appropriate to ensure the plant continues to be operated safely;
- Ensuring all personnel on-site and off-site and in surrounding property remain safe.

10.2 Written Scheme Of Examination (WSE)

The requirement for a WSE is set out in Regulation 8 of PSSR. The User/Owner is ultimately responsible for ensuring that the scope of the WSE covers all relevant parts of the boiler system, and they should select an organisation with sufficient knowledge and expertise on the systems in question to carry out the Competent Person (CP) duties on that system.

The CP role and responsibilities are covered in the PSSR ACoP. A brief summary is provided below.

The WSE must include the name of the CP who certified the scheme as suitable, the date of the certification, and the following information:

- All parts which require examination by the CP;
- Justification for excluding items from examination;
- All protective devices;
- The nature and frequency of the examinations required;
- Details of any preparatory work required by the User/Owner in order for the examinations to be completed;
- Details of any requirements for the initial examination;
- Details of any repairs and modifications where the CP needs to be involved.

Where there is more than one WSE for a single pressure system, (e.g. one for the boiler house and another covering the site) or there are hired boilers brought to site, the respective responsibilities for each part of the pressure system must be clearly identified. The boundaries of each WSE must be adjacent to each other with no physical gaps.

10.3 Examinations in Accordance with The WSE (Thorough Examinations)

Regulation 9 of PSSR requires that all pressure systems be periodically examined by a CP in accordance with a WSE, itself being drawn up by a CP.

The User/Owner is responsible for ensuring their boilers meet this requirement. Where the WSE specifies any preparatory work, they are also responsible for ensuring that this is completed before the examination.

WSEs for water tube boilers frequently require that, as part of a formal “out of service” examination, an Authoritative Technical Review is presented at a pre-outage meeting by a Technical Services Provider for debate and agreement between the CP and the User / Owner. This Technical Review should consider known failure mechanisms, historical issues and plant operation, and tailor the scope of examination to address those issues. Following the outage, a formal post-outage meeting between interested parties will review the outcomes of those examinations and set goals for future examinations.

As soon as possible following examination, the CP will prepare a report of examination for the User/Owner. The report will also include, amongst other information, the following:

- Whether any repairs are required and the date by which they must be completed;
- The latest date by which the next examination must be carried out;
- Whether any modifications are required to the WSE.

Note that the CP may also specify the manner and procedures which these modifications should take. The CP may also specify the nature of the required modifications to the scheme.

If any of these issues are raised in the report of examination, the User/Owner must:

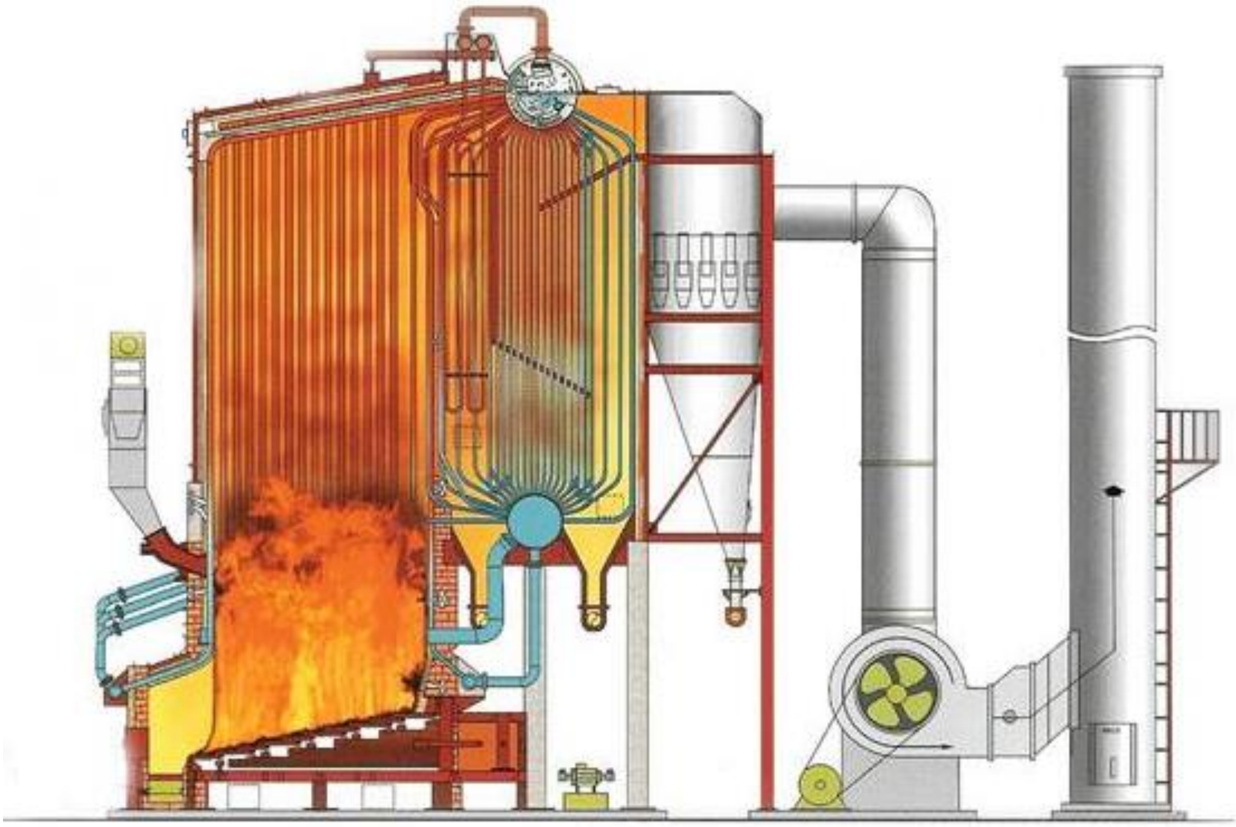
- Ensure that the boiler is not used or supplied if the date set for any repairs or examinations passes without these being completed;
- Make the required modifications to the WSE and have it re-certified by a CP;
- Ensure the boiler is not used or supplied if the date set for the modifications to the WSE passes without these being implemented and certified by a CP.

10.4 Summary of Responsibilities

The User/Owner of a boiler system is ultimately responsible for ensuring the system complies with all the relevant Health & Safety legislation (not just those responsibilities mentioned above).

While third parties, e.g. engineering consultants or maintenance contractors, can be used to assist in achieving compliance with these legal obligations, the overall and legal responsibility remains with the User/Owner and cannot be contracted out, although there is scope for certain duties to be transferred (as set out in a written agreement) between the Owner and User.

Useful help and advice on ensuring boiler systems remain safe to operate can be obtained from a number of sources, such as the CP carrying out the periodic examination of the boiler, or from the equipment manufacturer.



Reciprocating Grate Boiler - Thermo Technology Ltd

11 ENERGY AND ENVIRONMENT

11.1 Energy Management

Energy management of boilers is sensible to minimise operating costs and emissions, to facilitate safe operation, and to prolong plant life. Expert advice should be sought before any change in the operating parameters of a boiler which may affect the safety, environmental impact and efficient operation. This may include the following:

- Metering to monitor boiler efficiency;
- Water treatment monitoring and reporting;
- Combustion analysis and burner adjustment to reduce energy wastage and emissions;
- Energy improvement devices such as economisers, variable speed drives, flue gas dampers, auto TDS control, combustion control etc.;
- Plant scheduling and boiler optimisation to maximise plant efficiency.

The ability to carry out measurement is recommended to demonstrate efficient operation and compliant emissions.

A comprehensive Energy Management System ensures plant energy usage is not only monitored and reported but can also be used to help predict energy usage as well as helping plants achieve ever reducing emissions targets. A good indicator of a plant implementing best practices in Energy Management is the attainment of ISO 50001 certification.

It should be noted that reducing steam pressure inside the boiler may lower the saturation temperature of the boiler water allowing for a lower stack temperature and higher efficiency, but this is not always the case and local modelling should be done to identify the optimum boiler pressure.

11.2 Environmental Issues

All combustion plant has an impact on the environment through a combination of emissions to air, land and water. Legislation and guidance can be downloaded from gov.uk, hse.gov.uk, or the CEA and other web sites.

Emissions To Air

Larger installations will already be covered by a permit issued by the Environment Agency, NRW, SEPA or NIEA. New installations that have boilers with a nett rated thermal input 50 MW and above will need to apply for a new permit under IED/EPR. Waste burning boilers will need to follow the requirements of the Waste Incineration Directive.

Individual combustion plants with a nett rated thermal input of between 1 MW and 50 MW will eventually all be covered by a permit issued under the Medium Combustion Plant Directive. This permit will detail the boiler’s effect on the environment and list the permit conditions applied to the operator. It is against the law to operate the plant without a permit and outside these conditions, and all new medium combustion plants first fired after 19/12/2018 require a permit.

Local Authorities are principally concerned with the issues of nuisance, such as smoke and dust emissions, which will be regulated. However, operators still have a requirement to ensure that all products of combustion are adequately dispersed.

Solid and Liquid Waste

All solid and liquid waste products produced by a combustion plant must be removed by a licensed waste carrier.

Water discharged to drains must comply with water utility restrictions, and a discharge temperature to public sewer of greater than 43ºC is not allowed under the terms of the Water industry Act 1991; other local plant specific limits might also apply.

In order to reduce water usage and the volume of contaminated waste water discharged, BAT is to use one or both of the techniques given below.

- Water recycling -
  - Residual aqueous streams, including run-off water, from the plant shall be reused for other purposes. The degree of recycling is limited by the quality requirements of the recipient water stream and the water balance of the plant.
  - Not applicable to waste water from cooling systems when water treatment chemicals and/or high concentrations of salts from seawater are present.
- Dry bottom ash handling in plants combusting solid fuels -
  - Dry, hot bottom ash falls from the furnace onto a mechanical conveyor system and is cooled down by ambient air. No water is used in the process.

Noise

Noise levels can be reduced by increasing the distance between the emitter and the receiver and by using buildings as noise screens. Operational measures include:

- Improved inspection and maintenance of equipment;
- Closing of doors and windows of enclosed areas, if possible;
- Equipment operated by experienced staff;
- Avoidance of noisy activities at night, if possible;
- Provisions for noise control during maintenance activities.

APPENDIX 1 - REFERENCES

The following is a list of applicable documents current at the time of preparation of this publication. The following should be noted:

- This is an indicative, not comprehensive list. Users should ensure they are working with the latest information available.
- Free copies of all legislation are available from gov.uk.
- Legislation marked with an asterisk is supported by Approved Codes of Practice and Guidance (ACoP) published by the HSE.
- Legislation marked with a double asterisk is supported by more than a single ACoP.
- The Electricity at Work Regulations (EAW) 1989 are supported by a Memorandum of guidance published by the HSE.

1. Health and Safety at Work etc Act 1974.
2. Management of Health and Safety at Work Regulations (MHSWR) 1998 SI 1999/3242.
3. Provision and Use of Work Equipment Regulations (PUWER) 1998* SI 1998/2306.
4. Electricity At Work Regulations 1989 - SI 1989/635.
5. Confined Spaces Regulations 1997* - SI 1997/1713.
6. Control of Substances Hazardous to Health Regulations (COSHH) 2002* SI 2002/2667.
7. Dangerous Substances and Explosive Atmosphere Regulations (DSEAR)** SI 2002/2776.
8. Control of Noise at Work Regulations 2005 - SI 2005/1643.
9. Construction Design and Management Regulations (CDM) 2015* - SI 2015/51.
10. Supply of Machinery (Safety) Regulations (SMSR) 2008 - SI 2008/1597.
11. Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 - SI 2016/1107.
12. Pressure Equipment (Safety) Regulations (PER) SI 2016/1105.
13. Pressure System Safety Regulations (PSSR) 2000* - SI 2000/128.
14. Work at Height Regulations 2005 SI 2005/735.
15. The Regulatory Reform (Fire Safety) Order 2005 – SI 2005/1541.
16. The Gas Safety (Installation and Use) (Amendment) Regulations (GSIUR) 2018 * SI 1998/2451.
17. The Environmental Permitting (England and Wales)(Amendment) Regulations 2018 SI2018/110 (MCPD).
18. L5 The Control of Substances Hazardous to Health Regulations 2002. Approved Code of Practice and guidance.
19. L22 Safe use of work equipment Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance.
20. L101 Safe work in confined spaces. Confined Spaces Regulations 1997. Approved Code of Practice, Regulations and guidance.

21. L108 Controlling noise at work The Control of Noise at Work Regulations 2005 Guidance on Regulations.
22. L122 Safety of pressure systems. Pressure Systems Safety Regulations 2000. Approved Code of Practice.
23. L138 Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance.
24. L153 Managing health and safety in construction. Construction (Design and Management) Regulations 2015. Guidance on Regulations.
25. HSG253: The safe isolation of plant and equipment.
26. Permit-to-work systems HSE INDG98 ISBN 0 7176 1331 3.
27. HSE Pressure Systems website http://www.hse.gov.uk/pressure-systems/index.htm
28. BEIS Pressure Equipment (Safety) Regulations 2016: Guidance
29. HSE INDG436: Safe management of industrial steam and hot water boilers.
30. BG01 Guidance on Safe Operation of Steam Boilers. (CEA)
31. BG02 Guidance on Safe Operation of Hot Water Boilers. (CEA)
32. BG03 Guidance on Steam Boiler Blowdown Systems. (CEA)
33. BG04 Guidance on Boiler Water Treatment. (CEA)
34. BG05 Guidance on Design and Operation of Biomass Systems. (CEA)
35. BG06 De-aerators and Hot Wells - Guidance for Industrial Installations. (CEA)
36. BG08 Guidance on Temporary Steam and Hot Water Boiler Plant. (CEA)
37. BS 799: Part 4:1991 Specifications for atomising burners (other than monobloc type) together with associated equipment for single burner & multiburner installations.
38. BS 2486:1997 - Recommendations for treatment of water for steam boilers and water heaters
39. BS 5410-2:2013 Code of practice for oil firing - Part 2: Installations over 45 kW output capacity for space heating, hot water and steam supply services.
40. BS 5925:1991 Code of practice for Ventilation principles and designing for natural ventilation.
41. BS 6068-6.7:1994. Water quality. Sampling. Guidance on sampling of water and steam in boiler plants.
42. BS 6644:2008 Specification for Installation of gas-fired hot water boilers of rated inputs between 70 kW (net) and 1.8 MW (net) (2nd and 3rd family gases).
43. BS 7671 Requirements for electrical installations. IET Wiring Regulations.
44. BS EN 298:1994 Automatic Gas burners Control systems for gas burners and gas burning appliances with or without fans.
45. BS EN 676:1997 Automatic Forced Draught Burners for Gaseous Fuels.
46. BS EN 746:1997 Part 2 safety requirements for Combustion and Fuel Handling Systems.
47. BS EN 12952 Water Tube Boilers.
48. IEC 61508 Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems.

49. Institution of Gas Engineers and Managers Utilisation Procedure IGE/UP/1A - Strength/tightness testing and direct purging (Small I&C) and IGEM/UP/1C - Strength/tightness testing and direct purging (Meters).

50. Institution of Gas Engineers and Managers Utilisation Procedure IGEM/UP/2 - Installation pipework.

51. Institution of Gas Engineers and Managers Utilisation Procedure IGEM/UP/10 Installation of gas appliances in industrial and commercial premises.

52. Institution of Gas Engineers and Managers IGEM/UP/12 Application of burners and controls to gas fired process plant.

53. Institution of Gas Engineers and Managers IGEM/UP/16 Design for Natural Gas installations on industrial and commercial premises with respect to hazardous area classification and preparation of risk assessments.

54. Institution of Gas Engineers and Managers IGEM/SR/25 - Hazardous area classification of Natural Gas installations.

55. MCERTS documents from EA – a selection taken from Monitoring emissions to air, land and water (MCERTS) on gov.uk.

    a) M1 sampling requirements for stack emission monitoring.

    b) M3 how to assess monitoring arrangements for emissions to air in permit applications.

    c) M5 Monitoring of stack gas emissions from medium combustion plants and specified generators.

    d) M20 quality assurance of continuous emission monitoring systems.

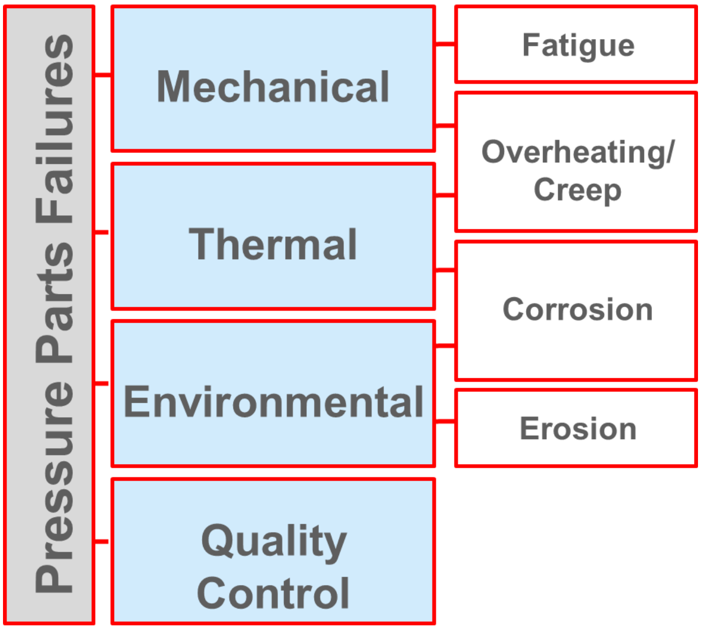
    e) M22 measuring stack gas emissions using FTIR instruments.

56. Client Guide for the Inspection of Steel Chimneys ASG:003 July 2017 - Association of Technical Lightning & Access Specialists (ATLAS).

APPENDIX 2 - WATER TUBE BOILER - FAILURE MECHANISMS

Premature in-service degradation and ultimate failure of pressure parts in water tube boilers derives from the complex interaction between the thermal, mechanical and chemical environments to which the components are exposed, particularly within the gas pass. Whilst sometimes designated simply as stress or wastage failures, deeper analysis shows that more than a dozen different damage mechanisms can be responsible for pressure parts failures, either independently or synergistically.

Diagnosing the active damage mechanism responsible for failure is critical to root cause determination and implementing short and long-term inspection and maintenance strategies appropriate to the failure theat. The following represents a glossary of key terms and descriptions of the key failure mechanisms responsible for pressure parts failures in water tube boilers.



Mechanical

- **Thermo-mechanical fatigue**. Almost invariably the product of thermally induced system stresses developed during each start-up and/or shut-down cycle, the resultant leak paths are discrete and often transverse in orientation. The cyclic loading is typically below the material yield stress limit but always above a nominal threshold stress (the Endurance Limit) which is material specific. The fatigue cracks develop with each cycle above the Endurance Limit, generally initiating at the component outer diameter at positions of restraint including wall attachments, hanger supports, header stub welds, geometric changes, and junctions in tube finning. The damage is often categorised as ‘high cycle’ or ‘low cycle’, this relating to the number of cycles experienced prior to failure. High cycle fatigue is commonly associated with poorly supported piping systems or excessive operational vibrations from, for example, rotating plant. Low cycle fatigue is more commonly associated with components subject to the normal operational cycling of boiler systems. Significantly, boiler structural components such as buckstays can sustain fatigue damage and should be considered in any inspection regime.

- **Thermal Fatigue**. Damage arises from the development of through wall temperature gradients during rapid heating and cooling (thermal shock), conditions under which a hot surface contacted by a colder medium (gas or fluid) experiences tensile stresses as its contraction is restrained by the hotter bulk component. The damage shows as multiple transverse cracks on the exposed surface. The quenching of hot tubes by condensate formed in soot blower lines, attemperator over-spray, spray water leakage/mal-operation, or from condensate management issues such as reflux in drain systems, represent known sources for this damage.

- **Corrosion Fatigue**. Largely meeting the same pre-requisites as for thermo-mechanical fatigue, the damage mechanism is confined almost exclusively to water containing pressure parts, including vessels (e.g. de-aerators), pipework, headers and tubing, and inlet sections of the primary superheater. The damage shows as multiple transverse cracks on the water exposed surfaces and, due to the presence of a 'corrosive' environment, can develop at stresses below the Endurance Limit. Often initiating at design features, such as header stub welds and internal swages, manufacturing defects and off-load corrosion pitting can provide alternative and less predictable initiation sites. This includes non-draining lines where remnant condensate can promote internal pitting from which corrosion fatigue cracking may initiate. Empirical data has established that off-load thermal stratification renders the water walls of natural circulation boilers significantly more vulnerable to this damage mechanism than the corresponding circuit in assisted circulation plant. Aside from the background presence of an oxidising environment, other factors influencing corrosion fatigue include pH levels and dissolved oxygen in the boiler water.
- **Fretting**. This is the result of repeated metal-to-metal contact between neighbouring components such as tubes and structural supports, with excessive wastage arising from direct metal loss or through the repeated removal of nominally protective scales. Relative movement between the components can derive from in-service resonance in the gas flow, differential thermal expansion or regular soot cleaning activities. Wastage rates may accelerate with operation as the components gain more freedom to move.

Thermal

- **Short-Term Overheating**; Coolant starvation or impaired heat transfer, whether associated with excessive internal scaling or oil contamination, can precipitate rapid thermal degradation of previously integral tubing and lead to violent failures. This derives from a marked yield strength reduction with temperatures from approximately 150°C above design values such that tensile overload becomes the dominant failure mode when the hoop stress from the internal pressure exceeds the yield stress at the given temperature. The root cause can be operational (e.g. low-drum level), mechanical (e.g. foreign debris) or hydrodynamic (e.g. leak earlier in tube path).
- **Creep**; This is the long-term exposure of pressure parts to a constant stress below the yield point at an elevated temperature, typically above 40% of the material absolute melting point (Kelvin), resulting in progressive component deformation. The thermally driven process creates atomic level voids (vacancies) within individual grains which progressively migrate and coalesce at grain boundaries leading to the development of microstructural grain boundary cavities. Eventual cavity link-up creates intergranular fissures until the residual section can no longer sustain the load leading to final ductile, thick-edged failures. The rate of degradation is time and temperature dependent and can be moderated through alloying with strong carbide formers, such as molybdenum and vanadium. Whilst anticipated at the design stage, premature failure can occur when sub-specification material has been installed or operating temperatures exceed design values.
- **Graphitisation**; A mechanism only active at temperatures between 420°C and 520°C and limited to carbon steel and 15Mo3/16Mo3 low alloy components. The mechanism is associated with the thermal decomposition of pearlitic carbides to the true stable equilibrium structure of ferrite and graphite after operation at elevated temperatures for extended periods of time (>100,000 hours). This microstructural degradation can cause the violent, premature rupture of tubing and pipework without offering any prior indications of distress.

Environmental

- **Fireside**
  - **Furnace Wall Fireside Corrosion**. Water wall fireside corrosion is associated with exposure to a persistently low O_2 gaseous environment, almost invariably the result of flame impingement in plant with burners. The wastage rate is influenced by fuel chemistry (chlorine and sulphur) and the incident heat flux.
  - **High Temperature Fireside Corrosion**. Generally confined to steam tubing, wastage derives from the dissolution of 'protective' scale by the presence of fuel specific molten species within the ash layer, such as sulphatic species and vanadyl vanadates in coal and oil-fired plant respectively. The thermal threshold above which attack develops is determined by the melting point of these corrosive phases. Wastage rates under these molten layers can be furthered by the preferential release of chloride and/or sulphur species to directly attack the tube substrate. In addition to the fuel chemistry, the rate of attack is again influenced by the incident heat flux such that the most exposed tubing within a bundle will experience the most intense wastage.
  - **Erosion (including abrasion)**. Constituting the mechanical removal of material from a component, the damage can arise from interaction with sootblower jets, impinging fly-ash or sliding contact with loose ash debris on inclined heating surfaces. However, it is not exclusively a fireside issue, spalled steam side scales having been responsible for internal erosive wear to drain-line bends and valve components. Whilst the rate of metal loss is a function of substrate and erodent hardness and angle of impact, it is primarily determined by the interaction velocity, the rate increasing as the third power of velocity.
  - **Erosion-Corrosion**. Essentially combining elements of fireside corrosion and erosion, any mechanical disturbance, such as soot cleaning operations or enhanced gas flows, has the potential to disrupt and cause the loss of the semi-protective corrosion scale/deposits and expose the underlying tube to fresh fireside corrosion. When repeated many times, this ultimately results in a greatly enhanced rate of metal loss when compared to that which would occur if exposed to only fireside corrosion or erosive wear in the given environment.
- **Waterside/Steamside**
  - **On-load corrosion**. This is a generic term given to a family of waterside corrosion mechanisms active where steam is being generated and associated with the local formation of concentrated acidic or alkaline (caustic) solutions. The mechanism requires a significant departure from ideal water chemistry on a local or a general scale, the latter being extremely rare. Whilst such events can arise through gross plant chemistry upsets, the local concentration of aggressive species mostly develops through the discrete generation of steam pockets, the contaminants having a much lower solubility in steam than water. The damage is invariably confined to the heat-facing crown of evaporator tubing. The likelihood of damage developing is increased by excessive internal scaling (i.e. 'wick-boiling'), local tube geometry (e.g. over-penetrated welds) or gas-by-passing, the latter being specific to tubing adjacent to side walls in HRSG modules.
    - **Acid-Chloride Attack**; In boilers nominally operating above approximately 60 bar, failures take the form of thick-edged leak paths, often associated with heavy scaling or scabbing of the tube waterside. The migration into the tube wall of hydrogen generated by the corrosion process results in a reaction with microstructural carbides, evolving methane molecules (CH_4). These molecules migrate to grain boundaries to create fissures which link-up to produce a thick-edged failure with a shear lip at the outer edge. At lower operating pressures, damage is exclusively by internal wastage leading to thin-edged ruptures, the waterside condition remaining as described. Wastage rates of up to 10 mm per year have been reported;

however, the more rapid development of sub-surface intergranular fissures responsible for the thick-edged fractures in high pressure boilers almost invariably results in earlier failures than would be expected from wastage alone.

- **Caustic Gouging**; Always associated with significant waterside wastage, the damage appears as a series of elongated pits or gouges along the tube radiant crown. The locally concentrated caustic solution reacts with and dissolves the nominally protective oxide scale on the tube bore, the subsequent precipitation of a non-protective corrosion product giving the waterside scale a sparkling appearance. Wastage rates up to approximately 2 mm per year have been reported.

- **Acid Phosphate Attack**; Sharing many characteristics of those exhibited by caustic gouging, the damage is confined to plant operating phosphate based cycle chemistries and can be differentiated from the more established mechanism by the absence of 'sparkling' crystals from the heavy waterside scaling.

- **Off-load Pitting**; The localised corrosion of a metal surface, confined to a point or small area, pitting damage arises during boiler shut-down and after 'breaking-vacuum' when pools of oxygenated condensate can form within horizontally inclined pressure parts. This provides an environment for creating electrochemical cells with localised attack developing at anodic sites where breaks in the surface oxide, or other discontinuities, exist. Such damage can alone perforate thin-walled tubing to cause pinhole leaks shortly after the return to service or can become aligned to encourage corrosion fatigue cracking in water tubing. The presence of contaminants, such as chlorides or sulphur species, can intensify the attach severity by promoting electrochemical activity.

- **Flow Accelerated Corrosion (FAC)**; This damage mechanism involves dissolution of the normally protective magnetite (Fe_3O_4) layer formed on carbon steel in a stream of flowing water (single-phase) or a water-steam (two-phase) mixture. This process causes the oxide layer to become thinner and less protective, with the wastage rate ultimately being determined by the steady state condition where the growth of the oxide and the iron oxide dissolution rates balance, but can be up to 3.0mm per year. In extremes, the oxide scale is reduced sufficiently as to allow rusting on exposure to a damp off-load environment, but is usually characterised by a shiny, black appearance and pitting of the substrate, often with a horseshoe profile. The wastage rate is a function of:

  - Dissolved oxygen (<1ppb);
  - pH levels (<8);
  - Steel composition (chromium content is advantageous);
  - Fluid hydrodynamics (turbulence); and,
  - Temperature (120-280°C).

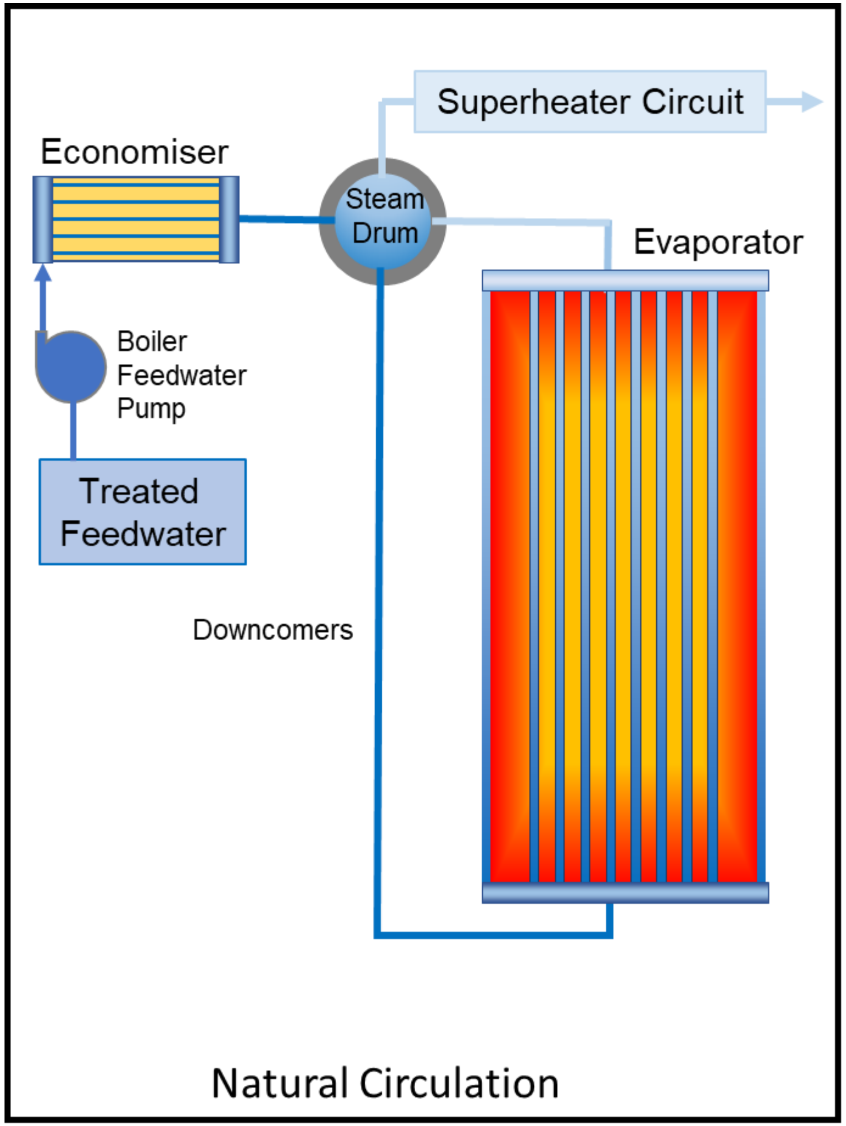
  Within the power industry, FAC has been found in boiler feed systems and the LP circuits on gas-fired plant. However, recent evidence suggests that HP systems may become vulnerable to FAC under certain load conditions when pressure reductions expose components to fluids within the FAC susceptible temperature range.

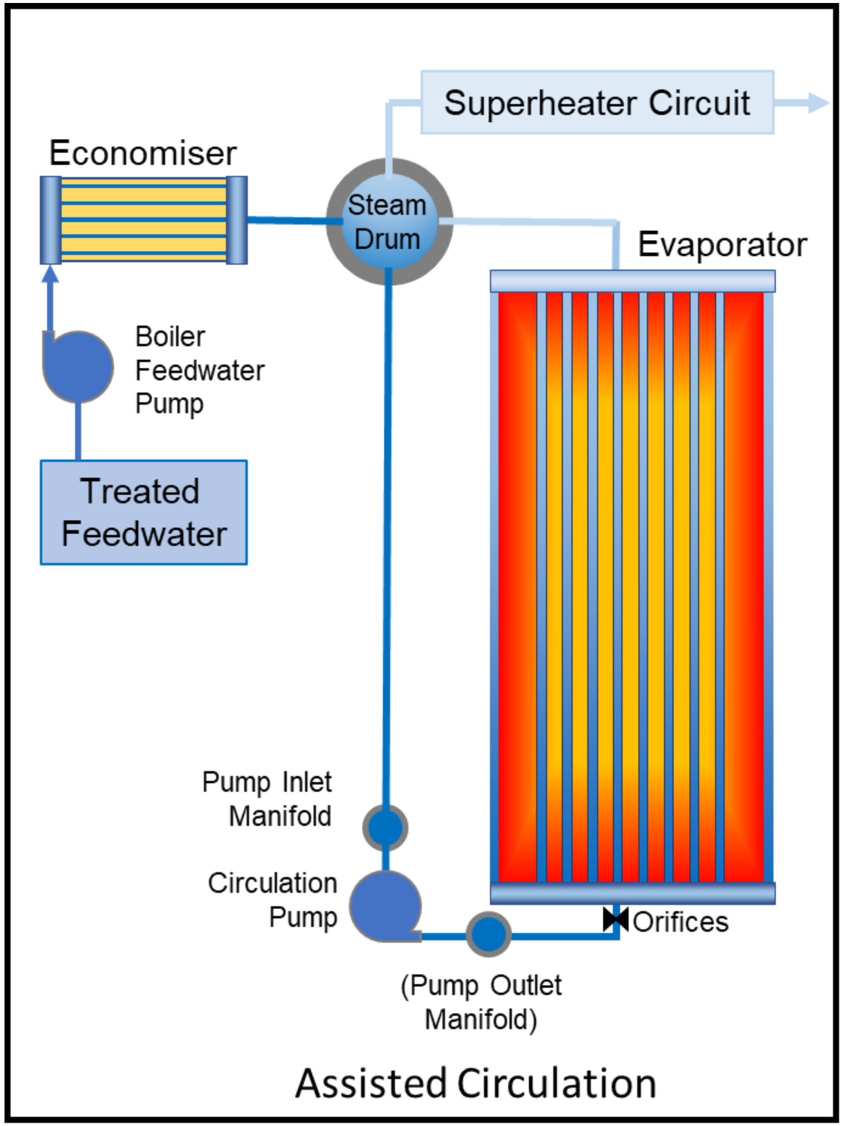
- **Other mechanisms**
    - **Stress Corrosion Cracking (SCC)**; A damage mechanism that can be responsible for the rapid failure of a sensitive material exposed to an aqueous environment while under an applied or residual loading. Significantly, the affected component may appear bright and shiny, despite containing multiple microscopic cracks. The damage can initiate externally or internally with the vulnerability of a steel grade often being specific to a given chemical environment and the intensity of attack generally increasing with temperature, subject to remaining exposed to an aqueous media. Although often associated with stainless steels in a sensitised condition after extended service at elevated temperatures, ferritic grades are not immune, particularly where fabrication has taken the material hardness above a nominal 200HV threshold.
    - **Corrosion Under Insulation (CUI)**; Lagged components can sustain significant external wastage where breaks in the insulation allow water ingress to expose the pressure part to a sustained damp environment. Corrosion can be further exacerbated by the presence of ash derived species, eg sulphates, chlorides. On boiler plant, the cold sides of lower water wall tubes are particularly vulnerable, notably where boiler washing is routinely performed with degraded tubes having the potential to develop violent axial ruptures along the tube non-radiant crown. In pipework, bends at the bottom of vertical runs and system low-points are most vulnerable. It is also found to be more prevalent in boilers that are not base loading.
    - **Dew Point Corrosion**; Dew Point Corrosion occurs when flue gases condense to form sulphurous and sulphuric acids. The exact dew point depends on the flue gas chemistry, but it is usually between 70°C and 150°C. Surfaces cooler than this temperature are likely locations for dew-point corrosion. Any point along the flue-gas path, from combustion in the furnace to the top of the chimney, is a possible site, however it is most prevalent in economisers. Significantly, a transition to low load operation has seen the emergence of this problem on plant previously unaffected.
- **Crevice Corrosion**; Occurs in spaces to which the access of the working fluid from the environment is limited. These spaces are generally called crevices. One metal part plus two connected environments.
- **Galvanic Corrosion**; Localised attack where an electrochemical cell develops under an aqueous environment between two connected, but different, metals to promote a galvanic reaction.

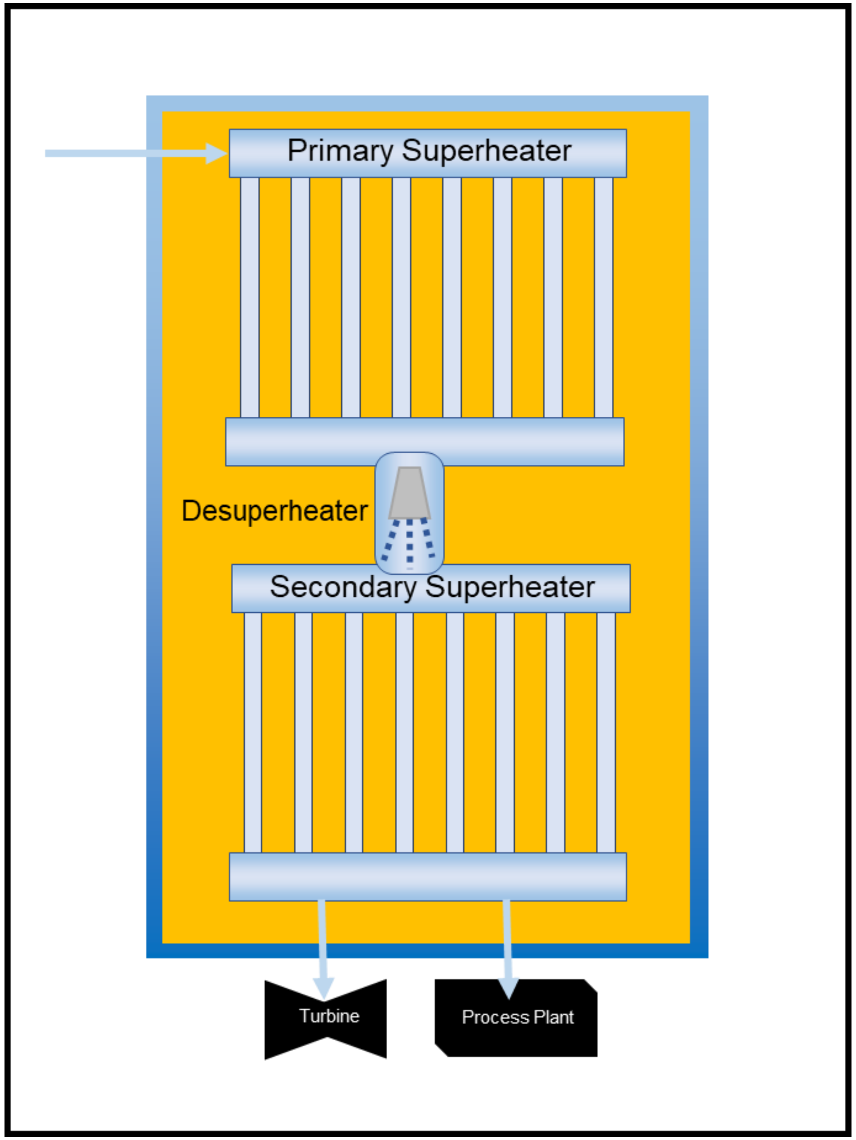
Quality Control

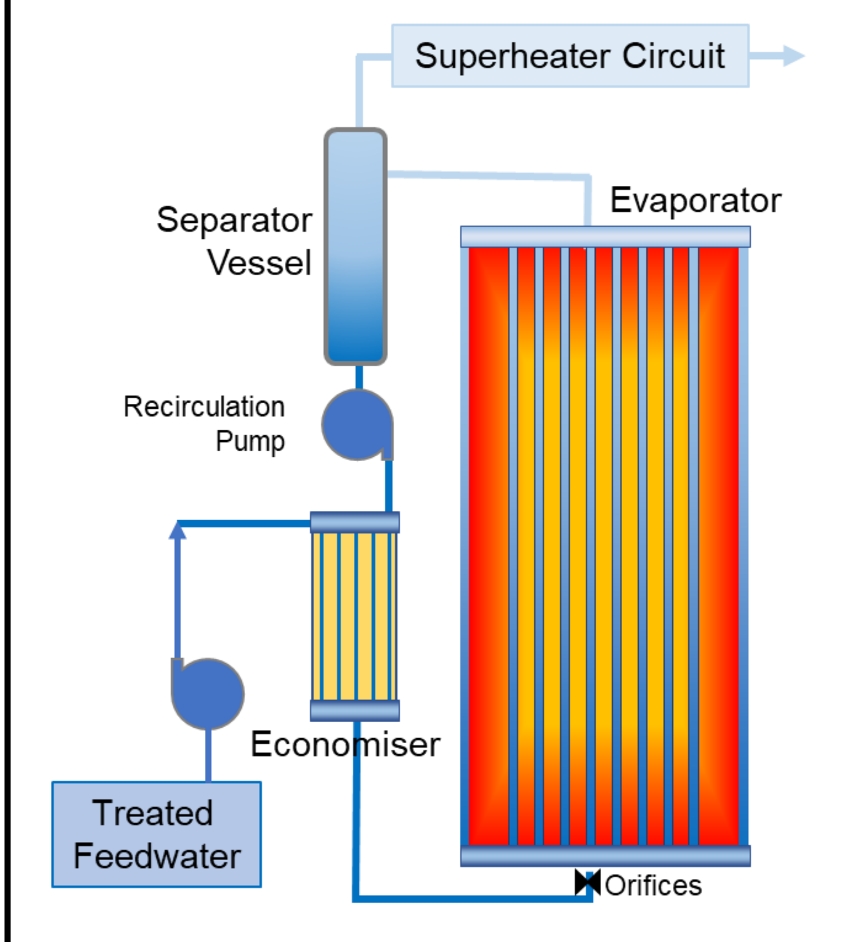
- **Component Manufacture**; Internal laps, mid-wall defects and other manufacturing defects can be responsible for component failures during pre-commissioning hydrostatic testing and the early operation of plant. However, such features can be directly or indirectly responsible for crack initiation and growth by a secondary damage mechanism causing a loss of pressure containment after prolonged periods of operation (typically >100,000hrs).
- **Welding**; Non-compliance with approved welding procedures and/or poor consumable management can introduce a host of defects at any stage of weld manufacture. Such defects include lack of fusion, lack of penetration, porosity, slag inclusions, hydrogen cracking (cold/delayed cracking), solidification cracking (hot cracking), lamellar tearing and reheat cracking. Such defects can be difficult to detect by non-destructive techniques and may result in early pinhole or circumferential leaks or alternatively provide a preferential site for a secondary damage mechanism to initiate and develop through to component failure.

APPENDIX 3 - DIAGRAMS OF TYPICAL BOILER ARRANGEMENTS









Once-Through (Supercritical)

APPENDIX 4 - TYPICAL LOG SHEET EXAMPLES

The boiler logs possess two functions:

- They should be formulated as the logical outcome of a risk assessment and as such the checks contained within constitute a risk assessment checklist;
- They are also a record of the activities that occur within a boiler house and as such all visits, work, actions and interventions which may affect the operation of the boiler should be recorded in as much detail as necessary for safe and efficient operation.

The examples that follow are suggestions for the types of records that need to be kept for typical boiler houses – **every boiler house is different and will need its own log sheet.**

Examples are provided for:

Shift log sheet - a log for shift records by the operators during operation. The computer based control system also logs every operator action to the boiler such as mode changes, setpoint changes, alarm generation and acceptance as well as recording plant data in a activity history log; when incidents are reported in the paper log sheet operators can look back at the history to get a more accurate view of the chain of events. Paper logs also require operators to walk the plant and observe/record operation which is essential for good operating practice.

Maintenance check list and commissioning check sheets performed by the maintenance teams before hand back – cover sheet and first checklist only provided.

Boiler hand back check – used by operators checking the boiler is ready to return to service following a maintenance or operational outage.

Schedules courtesy of Emerson Process Management

BOILER LOG SHEET

DATE/TIME	
SHIFT LEADER NAME	
SHIFT OPERATOR NAME	

PAGE 1 OF 2

Water / steam system	No 1 Boiler		No 2 Boiler	
Boiler control mode				
Feed water inlet flow		T/hr		T/hr
Steam flow		T/hr		T/hr
Steam / water differential		T/hr		T/hr
Feed water inlet temp		ºC		ºC
Combustion Air inlet temp		ºC		ºC
Final steam outlet temp		ºC		ºC
Combustion chamber pressure		mbar		mbar
Trip bypasses active	YES / NO		YES / NO	
O2 control air heater / stack %		%		%
COG / SCOG System				
No of COG Pilots in service				
R/H COG Flow		m^3/hr		m^3/hr
L/H COG Flow		m^3/hr		m^3/hr
(Approx 70/100 m^3/hr per burner)				
BFG System				
No of BFG Burners in service				
R/H BFG Flow		m^3/hr		m^3/hr
R/H BFG Setpoint		m^3/hr		m^3/hr
L/H BFG Flow		m^3/hr		m^3/hr
L/H BFG Setpoint		m^3/hr		m^3/hr
Checks for leaks / flames escaping				

BOILER LOG SHEET

DATE/TIME	
SHIFT LEADER NAME	
SHIFT OPERATOR NAME	

PAGE 2 OF 2

BFG "U" Seal Pots				
On-line seal pots full	YES / NO		YES / NO	
Off-line seal pots overflowing	YES / NO		YES / NO	
Air Heater				
Air heater in service	YES / NO		YES / NO	
Air heater sump oil level				
Air heater gearbox oil level				
Controller on auto	AUTO/MANUAL		AUTO/MANUAL	
Fuel Oil System Checks				
No of Fuel oil burners available				
Atomising steam Pressure		barg		barg
Fuel oil temperature @ boiler		ºC		ºC
Fuel oil pressure @ boiler		barg		barg
R/H Fuel oil flow		T/hr		T/hr
L/H Fuel oil flow		T/hr		T/hr
Smoke density % (max 10%)		%		%
Boiler Fan Checks				
FD Fan Bearing DE Temp/ Noise		ºC		ºC
FD Fan Bearing NDE Temp/Noise		ºC		ºC
ID Fan Bearing DE Temp/ Noise		ºC		ºC
ID Fan Bearing NDE Temp/Noise		ºC		ºC
Correct control mode	LOCAL/CASCADE		LOCAL/CASCADE	

BOILER MAINTENANCE CHECK SHEET – RETURN TO SERVICE

Technicians

Name:		Date	
Signed			
Name:		Date	
Signed			
Start Time			
Completion Time			

Countdown checks to be started after all boiler work is complete, all personnel off the boiler, all boiler permits signed off, but boiler keys still in "Lock Off Box".

Countdown checks to be completed by TWO personnel - 1 person operating the relevant equipment as per the attached sheets and the other walking round, visually checking the equipment.

Before proceeding, obtain “live testing danger” board from Instrument workshop and attach to the relevant Lock Off Box.

Complete the following check sheets completely.

If any of the checks fail, inform the relevant people so that repairs can be carried out.

Boiler NOT to be handed back to operations until all problems rectified, or covered by a relevant Management of Change.

List of sheets attached:

1. Header & Information (2 pages)
2. Countdown Procedure (2 pages)
3. General Instrumentation Checks (3 pages)
4. LHS Gas Burner Checks
5. RHS Gas Burner Checks
6. LHS Oil Burner Checks
7. RHS Oil Burner Checks
8. Common Oil Burner Checks
9. Control Valve Checks
10. Fan Interlock Checks
11. Limiter Checks

Countdown Procedure			
		Complete	Comments
1	Ensure all instrumentation shutdown work, and all instrumentation rebuild work is complete, as per "Boiler 6 Rebuild Check" sheet.		
2	Confirm with all work parties that all work on the boiler is completed, and all permits are cancelled.		
3	In conjunction with mechanical section, and operations, cancel procedure A21.		
4	Ensure boiler is filled to working level.		
5	Reconnect all disconnected terminal links in the burner management panel, on terminal rails B6IC01 to B6IC13.		
6	Confirm / ensure all fuel isolation valves are shut		
7	Remove all compressed air isolations (reverse A21) and turn air valves on.		
	Ensure no air leaks. Repair as required.		
	If regulators not set up, set to required pressures.		
8	De-isolate 110Vac MCBs (as listed in "Boiler 6 110Vac Isolations")….EXCEPT igniter isolators.		
	Ensure original D4 locks are fitted to distribution board door.		
9	Complete general instrumentation checks, as per "Boiler 6 General Instrumentation Checks", sheets 1 to 3.		
10	Complete gas burner valve checks, as per: "Boiler 6 LHS Gas Burner Checks" sheet and "Boiler 6 RHS Gas Burner Checks" sheet.		
11	Complete oil burner valve checks, as per: "Boiler 6 LHS Oil Burner Checks" sheet and "Boiler 6 RHS Oil Burner Checks" sheet and "Boiler 6 Common Oil Burner Checks" sheet.		
12	Complete control valve checks, as per "Boiler 6 Control Valve Checks" sheet.		
13	Arrange for operations to complete "Fan Interlock Checks".		
14	Remove and test operation of pilot flame detectors		
	(Use lighter to test through lens. Check signal on DeltaV).		
	Left Back		
	Left Front		
	Left Top		
	Right Back		
	Right Front		
	Right Top		
	Check air is turned onto the scanner tube(draft only), and then refit detectors		

		Complete	Comments
15	De-isolate 110Vac MCBs for igniters (as listed in "Boiler 6 110Vac Isolations").		
	Ensure original D4 locks are refitted to distribution board door.		
	Test pilot igniters from local J/B relay. If OK, install igniters and connect ready for use		
	Left Back		
	Left Front		
	Left Top		
	Right Back		
	Right Front		
	Right Top		
16	Lift Mobrey switch pack off mount, and ensure alarm operates on DeltaV. Refit.		
17	Check operation of Emergency Shutdown pushbuttons:		
	New Control Room		
	Old Control Room		
	Boiler Charms Panel		
	Once countdown is completed (including any remedial work and re-testing), inform operations that the boiler is now available for operations to prepare the boiler for returning to service.		
	Accepted by Operations: ________________________________	Date:	

BOILER HAND BACK SHEET EXAMPLE

Work Area	Job Status			Comments
	Complete	Part Complete But not affecting start up	Not Complete	Page 1 of 3
Steam Drum Area	☐	☐	☐	
Safety valves refitted & Drains				
S/Valve Gags removed handle refitted				
Explosion Doors refitted				
Dosing / Blow down v/v refitted correctly				
Drum Doors and lagging refitted				
Air Cocks refitted				
All Scaffold removed				
All Good Housekeeping Completed				
Openings re-instated & temp barriers removed				
Water Drum Area				
Mobrey refitted				
Mobrey Valves refitted correctly				
Drum Doors and lagging refitted				
Cleargauge Re-fitted				
Cleargauge Valves Re-fitted Correctly				
Level Transmitter valve refitted				
Chemical dosing v/v's refitted correctly				
Hydrastep v/v's Fitted correctly				
Crown valve and lagging refitted				
Non-Return and lagging Refitted				
Soot Blower Isolation v/v repacked				

	Complete	Part Complete But not affecting start up	Not Complete	Page 2 of 3
Instrument Work Completed				
Final Steam depressurisation valve and blank fitted				
Pressure Gauge Isolation v/v's Refitted				
Good Housekeeping completed				
Scaffold removed				
Openings re-instated & temp barriers removed				
De-super heater Air Cock Level				
Feed Water Control v/v refitted				
Air Cocks Refitted				
Header Caps and lagging refitted				
Instrument Work Completed				
Drum Sludge v/vs. fitted correctly				
Final steam Pressure transmitter Isolation v/v				
Openings re-instated & temp barriers removed				
Butterfly valves re packed				
De-super Heater Areas				
De-super Heater Drains & Isolation v/vs.				
Drum Isolation v/vs. fitted correctly				
Recirculation v/v refitted				
Copes Feed valve & Guards refitted				
Header Caps and lagging refitted				
Explosion Doors Refitted and Stoppers in				
Super heater Drain & Isolation valve refitted				

	Complete	Part Complete But not affecting start up	Not Complete	Page 3 of 3
Good Housekeeping completed				
Scaffold removed				
Instrument Work Completed				
Openings re-instated & temp barriers removed				
Basement				
ID Fan Work Completed				
FD Fan Work Completed				
Safety Cages Rebuilt				
Scaffold removed				
Instrument Work Completed				
Air Heater Completed				

Sign, date and time below

Team Leader	Sign	Date/Time
Boiler Engineer	Sign	Date/Time
Instruments	Sign	Date/Time
Electrical	Sign	Date/Time

Recommended checks and tests schedule for Water Tube Boilers.

(C) Observation of abnormal noises, smells or other noticeable factors.

(T) Checking and/or testing the functional behaviour of equipment parts, including observation.

Checks And Testing	Daily	Weekly	1 Month	6 Months	12 Months	24 Months	Remarks
Safeguards against excessive pressure (safety valves)	C				T	T	See NOTES a) and b) below
Water level indication comparing gauge glass with transmitters	T						Compared with transmitters, limiters and controls – visual check for consistency
manually blowing down gauge glasses			T				
Drain and blow-down devices	C						
Valves	C			T			As per manufacturer's instruction manual
Feed water control	C			T			
Feed water and steam flow meter			C		T		Calibration
Low water protection	C			T			A physical check by lowering the water level as described in section 8.3 Water level controls and limiters - testing low water alarms & trips
Steam pressure and temperature indication	C						Compared with limiters and controls
Pressure limiter	C			T			
Temperature limiter	C			T			
Flame Scanners	C			T			
Devices water & steam quality measurement	C	T (1)		T (2)			(1) Comparison of the measured values with the reliable samples (2) Performed by a suitably qualified and competent person
Other protective systems	C			T (3)			(3) Electrical and mechanical testing performed by a suitably qualified and competent person
Pressure parts (pipes, inspection openings, flanges, gaskets, joints…)	C						
Pressure controller and temperature controller	C			T			
Feed water supply	C		T (4)				(4) checking standby pumps and feed water filter differential pressure
Water quality	T						See BS EN 12952-12 and BS2486:1997
Heat supply (burners)	C			T (5)			(5) Performed by a suitably qualified and competent person as per manufacturer's instruction manual but not less than once a year
Sliding Feet/ Sprung loaded Supports			C				check & lubricate sliding feet, and check the 'hot' position on sprung loaded supports

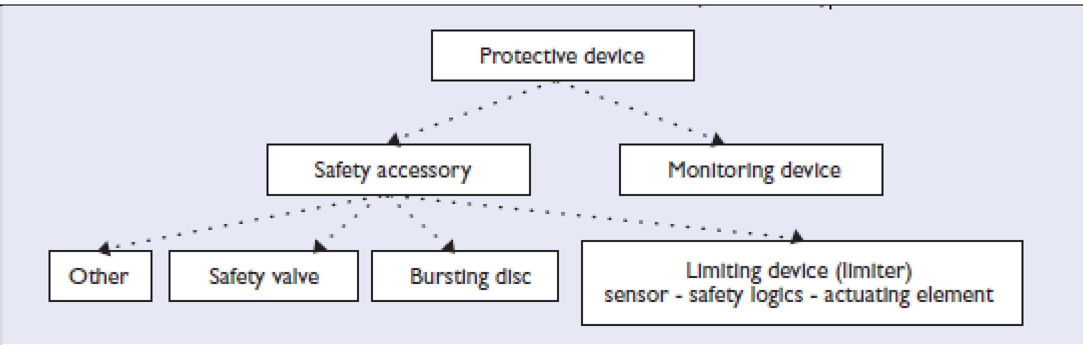
NOTE a) Additional function tests and observation can be required either by National Rules, third parties or the manufacturer.

NOTE b) Deviations of periods or tests are possible with agreement of third parties if safety level will not be reduced.

NOTE c) Other devices or controls not classed as protective devices in PSSR but should still be checked and tested are listed in Section 10 Period Examination

APPENDIX 5 - DEFINITIONS

Boiler system	Boilers, ancillaries and all related items including pipework. Additionally may include: fuel supply, water treatment, feedtank, flue, ventilation, blow down equipment, vents, monitoring, limiters and control equipment etc.
Boiler operator	Someone who has attended a training course with assessment, is familiar with the boiler system on-site and has sufficient knowledge & experience to operate the boiler system safely.
Cold boiler or steam system	At atmospheric pressure and a temperature low enough to prevent harm to persons working on the equipment.
Competent Person (CP)	Competent Person as defined in The Pressure Systems Safety Regulations 2000 (PSSR). The individual or organisation that certifies the written scheme of examination and/or carries out the required examinations in accordance with the WSE.
Control	Devices used for maintaining the variable to be controlled (e.g. pressure, temperature, water level) at a specific value (set point).
Controlled blow down	Manually lowering the water level within the boiler in order to perform tests of level controls, having due regard to any discharge constraints. Discharge temperature to public drains should not exceed the permissible limit of 43ºC.
Cut-out	A monitoring device, which on reaching a fixed value (e.g. pressure, temperature, flow, water level) is used to interrupt the energy supply and does not require manual reset when conditions return to normal.
Diversity	The provision of more than one different means of performing the required function, e.g. other physical principles, or other ways of solving the same problem.
Downcomers	Large diameter tubes to feed water from the steam drum into the lower drum/headers – designed to maintain natural circulation (circulation rate typically minimum 10 x water to steam production)
Economiser	Tubular heat exchangers fitted between the boiler outlet and the stack inlet which extract low grade, downstream waste heat to take boiler feed water close to boiling before transferring it to the boiler drum. Helps improve boiler efficiency by preheating the boiler feed water closer to the saturation temperature in the drum.
Fail-safe	A limiter or control device is fail-safe if it possesses the capability of defaulting to remain in a safe condition or transferring immediately to another safe condition in the event of certain faults occurring, e.g. loss of power supply.
High-integrity	Refers to a control, limiter or cut-out system where a fault condition does not lead to loss of safety function (fail-safe). Components are high-integrity when they are of fail-safe design so that a single fault in any related part does not lead to loss of safety function. This may be achieved by fault avoidance techniques, self-monitoring, redundancy, diversity or a combination of these methods.
Limiter	A device that, on reaching a fixed value, e.g. pressure, temperature, flow, water level, is used to interrupt and lock-out the supply, for example the energy supply and/or FD/ID fans. Note: A limiting device comprises: • A measuring or detection function; and • An activation function for correction, or shutdown, or shutdown and lock-out, and which is used to carry out safety related functions as defined in the PED, on its own or as part of a safety (protective) system (e.g. sensors, limiters). If this is achieved by multi-channel systems, then all items or limiters for safety purposes are included within the safety (protective) system. • Protective devices and safety accessories according to Directive 2014/68/EU (PED/PER) and (from PSSR) devices designed to protect the pressure system against system failure and devices designed to give warning that system failure might occur, including bursting discs.



Lock-out	A safety shut-down condition of the limiter, such that a restart can only be accomplished by a manual reset of the limiter or by a manual reset of the safety logic and by no other means. This will be achieved by a competent operator taking account of the physical situation.
Maintenance personnel	Suitably trained persons who are responsible for undertaking maintenance on the plant.
Manned	A boiler operator is on-site during hours of boiler operation.
MAP	Maximum allowable pressure
On-site	Physical presence on-site, not necessarily in the boiler house.
Owner	'Owner' in relation to a pressure system, means the employer or self-employed person that owns the pressure system or: if he does not have a place of business I n Great Britain, his agent or: if there is no such agent; the User (Regulation 2, PSSR).
Redundancy	The provision of more than one device or system which, in the event of a fault, will still provide the necessary facilities.
Risers/Evaporators	Walls or banks of relatively small diameter tubing in which water passing from the lower drum/headers to the steam drum is converted to steam (evaporation) through the extraction of heat from combustion gases. The steam bubbles generated inside the tubes are less dense than the surrounding water and therefore 'rise' to the steam drum, hence the name 'riser tubes'
Self-monitoring	Regular and automatic determination that all chosen components of a safety system are capable of functioning as required.
Superheater	Series of tubes used to heat the saturated steam produced in the boiler to a higher temperature than saturation temperature
Water tube boiler	A water tube boiler is one where the heat source is external to the tubes and water/steam is contained inside the tubes
SOL	Safe operating limit.
Steam generator	Steam is made in a coiled tube surrounded by products of combustion. No perceptible water level in the tube.
User	The User of a pressure system - the employer or self-employed person who has control of the operation of the pressure system
Water-hammer (steam hammer)	Dynamic shock loading resulting from the accumulation of condensate in steam pipework.
WSE	Written Scheme of Examination.

APPENDIX 6 - ACRONYMS

For the purposes of this document the following acronyms apply:

ACoP	Approved Codes of Practice
AIV	Automatic Isolation Valve
ALARP	as low as is reasonably practicable
ASME	American Society of Mechanical Engineers
BAT	Best Available Techniques
BOAS®	Boiler Operation Accreditation Scheme
BPVC	Boiler and Pressure Vessel Code
BS	British Standards
CAA	Clean Air Act
CDM	The Construction (Design and Management) Regulations
CEA	Combustion Engineering Association
CEMS	continuous emissions monitoring system
CertIBO	Certified Industrial Boiler Operator
CFBC	Circulating Fluid Bed Combustion
CO	carbon monoxide
CP	Competent Person (usually in terms of PSSR)
DipBOM	Diploma in Boiler Plant Operation Management
DP	Differential Pressure
DNB	Departure from Nucleate Boiling
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
DSI	Dry sorbent injection
DVC	Dynamic Vapour Compensation
EA	Environment Agency
ECV	Emergency Control Valve
ELV	emission limit values
EN	European Standards - Euro Norm
EPR	Environmental Permitting Regulations
ESP	Electrostatic Precipitator
ESR	essential safety requirements (of PED)
FD	Forced draught (fan)
FDA	US Food and Drugs Administration
FGD	Flue-gas desulphurisation system
GWR	Guided Wave Radar
HAZOP	hazard identification and system operability study
HP	High Pressure
HRSG	Heat Recovery Steam Generator
HSE	Health and Safety Executive
HSWA	Health & Safety at Work etc Act 1974

ID	Induced Draught (fan)
IED	Industrial Emissions Directive
I-GAS®	Industrial Gas Accreditation Scheme
IGCC	Integrated gasification combined cycle
IGEM	Institute of Gas Engineers and Managers
LP	Low Pressure
MAP	Maximum Allowable Pressure
MCERTS	Monitoring Certification Scheme (of EA)
MCPD	Medium Combustion Plant Directive
MHSWR	Management of Health & Safety at Work Regulations
NIEA	Northern Ireland Environment Agency
NOx	Oxides of Nitrogen - The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2
NRW	Natural Resources Wales
Owner	an employer or self-employed person who owns a pressure system
PED	Directive on Pressure Equipment of the European Union
PER	Pressure Equipment (Safety) Regulations
PID	Proportional Integral Derivative
PRDS	Pressure reducing and de-superheating stations
PSSR	Pressure Systems Safety Regulations
PUWER	Provision and Use of Work Equipment Regulations
SCR	Selective catalytic reduction
SEPA	Scottish Environmental Protection Agency
SG	Specific Gravity
SIL	Safety Integrity Level
SNCR	Selective Non Catalytic Reduction
SOL	Safe Operating Limits
SOx	Sulphur dioxide - The sum of sulphur dioxide (SO_2) and sulphur trioxide (SO_3), expressed as SO_2
SWIP	small waste incineration plant
TDS	Total Dissolved Solids
UPS	Uninterruptible Power Supply
User	the employer or self-employed person who has control of the operation of the pressure system
WID	Waste Incineration Directive
WSE	Written Scheme of Examination (as in PSSR)

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Ref: BG11 Edition 1 - February 2021 – **£95**