

De-aeration of Boiler Feed Water Guidance for Industrial Installations

Ref: BG06



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Foreword

This comprehensive guide deals with non-chemical aspects of feed water provision for industrial steam boilers and why it is necessary to carefully manage and control the water that is supplied to the boiler. We trust that by studying the contents and following this advice your boiler plant will operate safely and more efficiently, and provide you with a trouble-free system. If in any doubt contact the supplier, the system designer or your boiler water treatment specialist for advice.

This guidance is aimed at the Owner, Operator, Engineer and Manager of the boiler plant to help them understand all aspects that affect the boilers and their water supply arrangements, 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 plant, and who is responsible for managing the safe operation of this type of equipment. Ultimately the responsibility lies with the most senior person on site.

With other HSE guidance being withdrawn, and having taken all factors into consideration, The Combustion Engineering Association (CEA) agreed to write this guide with the help of its members.

Within this guide there are a significant number of legal requirements, regulations and standards highlighted; these regulations and standards are periodically reviewed and they can and do change, but they are as accurate as possible at the time of publication.

CEA cannot accept any liability for the information provided herein; however, be assured that we have consulted widely with our member companies during the compilation of this guide.

Cover image courtesy of Cochran Ltd, (main image) de-aerator and (bottom left image) one example of an installation.

Acknowledgments

A special note of thanks goes to Coal Hill Associates for bringing their extensive technical knowledge to bear in writing the bulk of this document, BG06. Thanks also go to other members and staff of CEA for their contributions.

- Energy and Environmental Solutions
- Deep Water Blue Ltd
- Industrial Boilerhouse Safety
- Bosch Thermotechnology

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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.

Unless otherwise stated, all pressures refer to gauge pressure.

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1 INTRODUCTION

De-aeration of Boiler Feed Water – Guidance for Industrial Installations (Ref: BG06) 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 Competent Persons. It is applicable to both new and existing installations of de-aerators and hot wells and addresses the following issues:

- The safe and correct provision of feed water for steam boilers;
- The safe use and operation of de-aerators and hot wells;
- Proper maintenance and inspection of de-aerators and hot wells.



De-aerator tank installation – Deep Water Blue Ltd

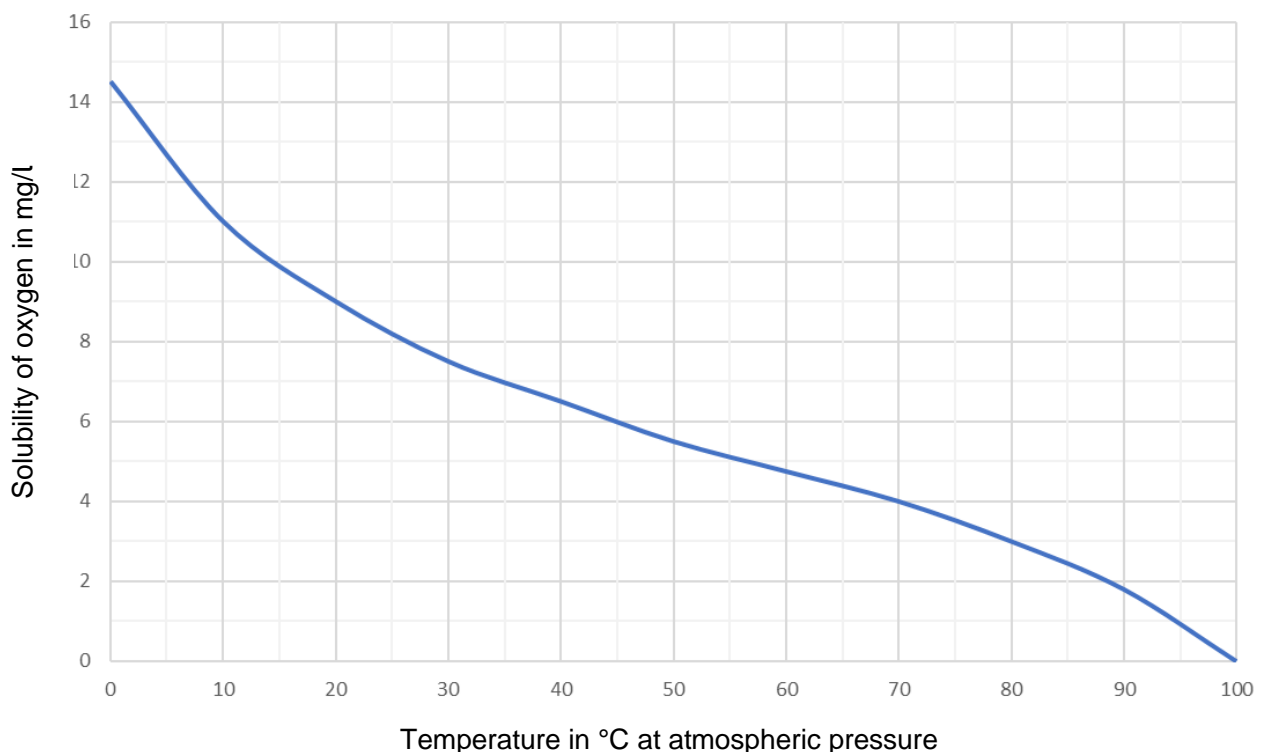
2 SCOPE

This guidance applies to feed water arrangements using de-aeration equipment of various designs for supplying feed water to steam boilers in commercial and industrial installations. The primary purpose of de-aeration (or de-oxygenation) is to manage and reduce the amount of dissolved gases in boiler feed water. Achieving this by thermo-mechanical means before 'fine tuning' with chemical addition to the water will usually represent the most efficient and cost effective solution.

Hot wells have been used in steam boiler houses as a primary means of de-aeration for many years very successfully and are historically the predominant mechanical process for de-aeration in UK steam systems operating at up to around 40 bar steam pressure. Where higher pressures or very high steam volumes are required, the use of thermal or mechanical de-aerators can be of benefit, but they often require greater capital investment and may fall under PED and PSSR, requiring routine inspection by a Competent Person.

The temperature within a pressurised de-aerator can be much higher than in a hot well without any detrimental effect to the feed pumps. The thermal shock as the feed water enters the boiler, is therefore greatly reduced, especially in boilers operating at 15 bar and above. Also, because the de-aerator is operating above 100°C the amount of oxygen scavenger required is greatly reduced which has the added benefit of slightly reducing TDS, hence reducing blow down volumes.

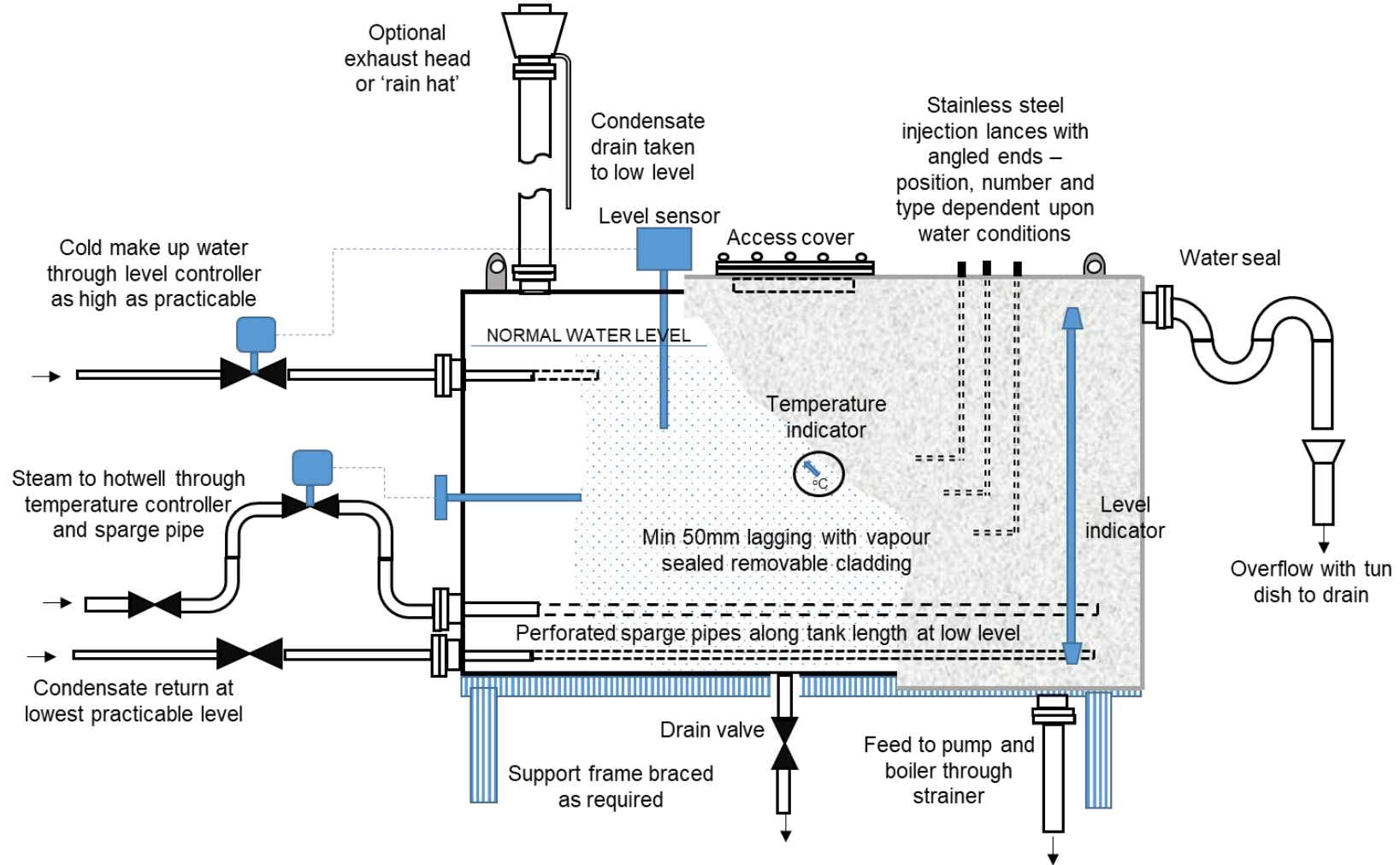
Boiler house owners and designers should evaluate the whole life cost of the installation, its operation and maintenance costs, the cost of chemicals and all the other elements that affect the provision of suitably treated water for the boiler in order to arrive at the most effective choice for their particular requirements.



2.1 Typical Schematic Arrangements

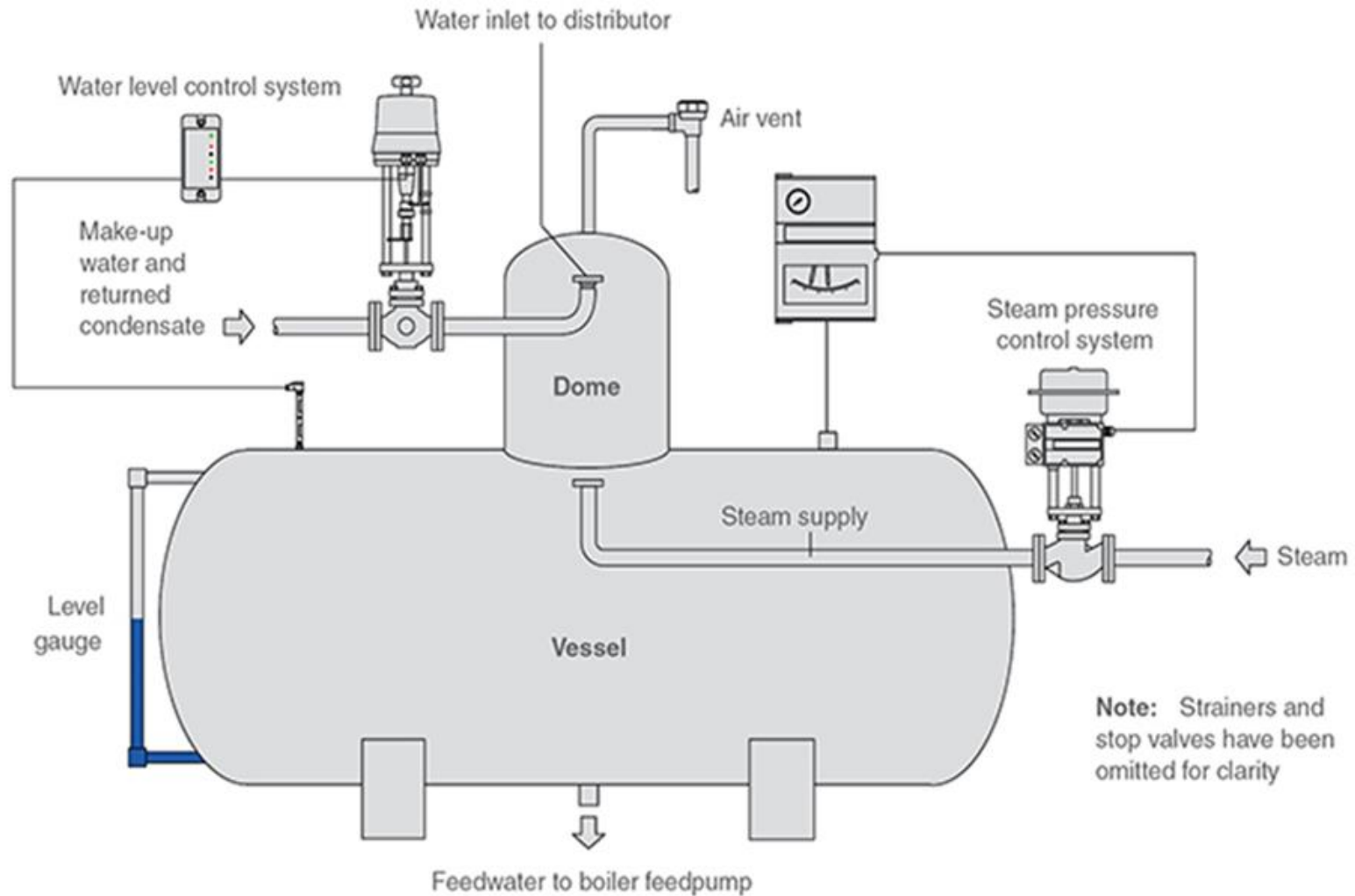
Typical Hot Well Layout – individual requirements may differ

Additional features may be specified on certain installations.



Pressurised De-aerator General Arrangement Result

Additional features may be specified on certain installations.



3 REASONS FOR DE-AERATION

Good quality feed water for shell boilers is an essential part of safe and efficient operation of steam boiler plant. The water that is contained in and supplied from a de-aerator or hot well shall be properly treated and stored under the correct conditions; it is also essential to monitor the condensate returned from the steam system to the tank as this can provide a high percentage of the boiler make-up water in many steam systems.

The temperature of the water being fed to the boiler is of paramount importance. The lower the boiler feed water temperature, the more heat is required in the boiler to produce steam. It is important to maintain the tank temperature as high as reasonably possible to maintain the required boiler output and to reduce the corrosive effects of oxygen in the feed water.

Water which is too cold may cause thermal shock and structural damage to the boiler and will certainly have an adverse effect on the overall energy efficiency of the boiler. If the feed water from the tank is too cold going into the boiler, this can lead to thermal shock and cracking at the intersection of the feed inlet and the boiler shell.

Water which is too hot can cause cavitation of the feed pump resulting in irreparable damage and costly repairs leading to potential loss of production. It is therefore essential to locate the tank as high above the feed pumps as reasonably practicable. This increases the 'head pressure' at the pump suction to help avoid cavitation.

Oxygen is the main cause of corrosion in tanks, feed systems and boilers, therefore every effort should be made to remove it. Elimination of oxygen is normally carried out by a combination of both chemical and physical methods. Water exposed to air is always saturated with oxygen according to the water temperature. At 0°C the oxygen content is 14ppm and this gradually reduces to effectively zero at 100°C. The addition of a sufficient and suitable oxygen scavenger will chemically neutralise the remaining available oxygen and remove its corrosive effect. Physical de-aeration by preheating the feed water followed by chemical neutralisation of residual oxygen is recommended, as this provides for a more successful solution.

The more successful the mechanical de-aeration the less oxygen scavenger is required, the oxygen in the water having been mechanically driven off by the heating of the stored feed water. The most commonly encountered form of de-aeration is a simple steam sparge pipe, typically heating a hot well by injection of live steam to keep the feed water temperature to approximately 85 - 95°C depending on the physical height of the hot well. Anything less than 70°C would be considered to be inefficient, allowing excess oxygen to be present in the feed water and likely to cause other problems in the boiler.

Carbon dioxide is also present in water and in any returning condensate; this will result in a low pH (i.e. the water will tend to be acidic) and the rate of corrosion will be increased due to acid attack. The essential requirement for prevention of this type of corrosion is to keep the pH of the feed water at the correct level. pH correction should be carried out within the water storage tank and be monitored by the pH levels within the boiler. The pH levels in the tank should be approx. 8.5 – 9.5 (except where copper is present) while the pH required in the boiler will vary by type of boiler. Very high levels of boiler pH should be avoided as they lead to foaming and carry-over, and to attack and/or deposition on the gauge glasses and condensate system.

An atmospheric de-aerating head (normally fitted to the top of a hot well) with a recirculation pump is a more advanced form of de-aerator that relies on the feeds to the head itself being capable of carrying out the de-aeration process efficiently. It is strongly advised that if this type of system is to be considered, then a specialist in this area is sought, since incorrect application of these types of units can result in rapid boiler failure.

Whatever form of de-aeration is to be used, chemical treatment is always required, since complete system de-aeration at all times is impossible due to oxygen ingress downstream of the steam header.

Operators should refer to the boiler manufacturer's recommendations and the CEA's guide BG04 Boiler Water Treatment - for further information.

4 HOT WELL AND DE-AERATOR DESIGN

The design of a feed water storage plant is a significant part of the design of the whole boiler house and the way it operates. Careful design of the storage facility and associated plant items can lead to substantial savings in costs of water, energy and water treatment chemicals, and increased reliability of operation.

The main duties of the hot well are:

- To provide a reserve of water to cope with any interruption of make-up water supply or condensate return;
- To provide a reservoir for condensate to be returned to;
- To provide a place for condensate to be mixed with fresh water before pumping treated and de-aerated water into the boiler;
- To be a place where boiler water treatment chemicals can be injected to ensure correct mixing and residency time.

4.1 Tank Construction

A rectangular shape tank is frequently used for hot wells to minimise the floor area for a given volume of water, and most are positioned at high level compared to the location of the boilers. Vertical and horizontal cylindrical tanks are also used, more often for pressurised de-aerators.

Hot wells and de-aerators are large and heavy structures, frequently located at height, so the services of a structural engineer may be required for larger tanks to ensure they are properly constructed and supported. It is essential to fit lifting lugs to factory made assemblies to allow safe and easy installation.

The tank should be fully welded and use adequate stiffening especially in rectangular tanks to strengthen the sides and top and to provide adequate support for the base. Failure to do so will result in excessive flexing and premature failure. Tanks can flex and shake when subjected to steam sparging and other events.

All flanged piping connections and other openings should stand-off at least 150 mm to allow for adequate insulation and cladding. All screwed connections should stand-off by at least 20 mm.

Cold make-up water and condensate return lines should be attached securely to the tank. Cold water should be injected at a high level in the tank. However, all sparge pipes shall be installed below the normal water level in the tank. The sparge pipes shall be made from stainless steel and be adequately supported. If steam heating of the tank is specified, the steam line into the tank shall be stainless steel also.

Water authority requirements will usually require a positive air break in the mains cold water supply and if this is not a feature of the whole supply to the site then a separate air break must be provided before the cold make-up water enters the tank.

Access is required for inspection and maintenance and a suitable manway should be provided if the tank can accommodate personnel entry; risk assessments will need to consider the appropriate safety measures for inspection activities, including working at height and the possibility of working in a confined space.

De-aerators and hot wells have many isolating valves, control devices and gauges that need to be accessed, so a system of safe access to high level will be required. A hooped ladder and sufficient railings and toe boards on the top of the tank will be the minimum required for routine maintenance activities. Access should comply with a suitable design standard such as BS EN ISO 14122 which requires the first hoop between 2.2 m and 3 m above ground level.

Adequate insulation is essential, and a minimum of 50 mm rockwool under a vapour barrier and aluminium or stainless steel cladding is recommended. Cladding and lagging may have to be removed for inspections, so due allowance should be made for removal and subsequent replacement.

Tanks are known to leak and overflow occasionally, so it is strongly advised not to position electrical switchgear or electrical/electronic control equipment beneath a hot well or de-aerator.

4.2 Materials

Several options are available:

Cast iron tanks are usually assembled from bolted and gasketed rectangular flanged sections. The joints and flanges can be a source of leaks, and corrosion will be an issue if very careful attention is not paid to the water treatment. They are easier to transport and move to difficult locations compared to single piece tanks.

Carbon steel is occasionally still used for hot wells; it is relatively low cost but extremely susceptible to corrosion. Internal coatings can be applied but they add to the cost considerably and require regular inspection and maintenance. Good management of the water side conditions will help to extend the life of a carbon steel tank. If carbon steel is used then oxygen scavenger injection shall be directly into the hot well to help avoid oxygen attack on the steel.

Austenitic stainless steel grade 304L is now usually selected as the most appropriate material. The enhanced service life of a stainless steel tank will usually justify the higher capital cost. It also allows for the oxygen scavenger to be injected into the feed line using proportional dosing. This greatly reduces chemical usage, which has the 'knock on' effect of reducing TDS.

Plastic is not usually suitable for hot wells, although it may be used for other storage in the boiler house such as water treatment chemicals or cold water storage.

4.3 Tank Capacity and Level Control

Normal practice is to allow sufficient capacity for one hour of steaming at maximum boiler evaporation rates. Where the tank supplies more than one boiler, the stored volume should be sufficient for one hour of steam at maximum system demand.

When calculating the size required for larger installations it may be that a risk assessment determines a smaller volume is appropriate, and this might be linked to the provision of additional cold stored treated water capacity alongside the hot well. Reference should also be made to the maximum flow rate of the incoming water supply to the site and any pre-treatment plant size limitations; expecting a hot well to replenish quickly from a small incoming main or a single softener stream may not provide the flow rate required for maximum steam production.

Conversely, low steam loads and high condensate return rates might lead to very low flows through softeners and other plant and this will result in poor performance of the water treatment plant. A small 'break tank' with level control facilities can help to overcome this problem.

High condensate return rates can occur at start-up when condensate in the plant and pipework is returned to the tank and it may be lost to drain through the overflow. Careful setting of the tank level control system and the appropriate minimum and maximum flow requirements is required at the design and commissioning stages. Water from the tank sent to drain unnecessarily is very wasteful and can be dangerous, and water undertakings usually limit the temperature of water discharged to drain to 43°C according to The Water Industry Act.

A level indicating device visible from outside the tank is required, and additional level sensing and control devices may be specified. A temperature indicator on the tank is required, and other temperature measurement and control devices may be specified.

4.4 Connections To The Tank

All pipework connected to the tank shall be lagged to retain heat and protect personnel.

Make-up Water

An adequately sized line is required with an isolating valve and flanged/screwed connection, utilising a sparge pipe if necessary. The tank will be fitted with a form of level control that maintains the normal water level in the tank as losses occur in the steam system. Level control valves may be electrically or pneumatically actuated and shall fail shut. Valve position switches may be required for fully automated systems.

The size of the make-up line shall be calculated with reference to the potential flow rate from the incoming water supply and any pre-treatment plant. A meter is frequently fitted to assist with steam plant monitoring, and may be connected to a boiler house computerised management system. This make-up water meter is the only accurate method of calculating condensate return.

Condensate Return

The returning condensate should be the main source of hot water added to the tank which is then topped up by the steam sparge. An adequately sized line with isolating valve and flange connection to a perforated sparge pipe shall be provided. Optional additional items may include a condensate monitoring system and a water meter to measure the amount of condensate returned. Advanced systems will have readings from meters and turbidity/conductivity alarms fed back to boiler control systems. All potential contaminants that can get into condensate should be identified and the risk to the boiler of each contaminant should be assessed.

Steam Sparging For Heating

An adequately sized line with isolating valve and flanged or screwed connection to a sparge pipe shall be provided. This will be fitted with a control valve that maintains the target operating temperature in the tank. Control valves may be electrically or pneumatically actuated, or self-acting, and should fail shut. Valve position switches may be required for fully automated systems.

Perforated sparge pipes shall extend across the whole length of the tank; short sparge pipes can cause significant turbulence issues and cold spots affecting the chemical dosing of the system and entraining more oxygen into the tank. Sparge pipes shall have nozzles that are designed to prevent the undesirable consequences of steam contacting cold water.

Steam injection systems should include an anti-vacuum valve installed at high level to prevent the contents of the tank being drawn into the steam pipe. Consideration shall be made to the placement of sparge connections to ensure adequate mixing; multiple sparges at different heights and orientations may therefore be required on larger tanks. **Sparging systems that agitate the water such that oxygen might be introduced shall be avoided completely.**

Steam pipework and control valves may be included in the Written Scheme of Examination for the boiler house under PSSR.

Atmospheric De-aerator Head

This is usually fitted as a domed extension to the top of the tank to include manifolds for the make-up water and condensate return connections plus any heat recovery connections from flash steam. They require a small automatic vent connection at the top of the immersion tube, and pipework for a small-bore recirculating system from the base of the tank. A small recirculating pump connected to a pipe-mounted temperature sensor is provided for circulating feed water. It is strongly advised that if this type of system is to be considered then a specialist in this area is sought, since incorrect application of these types of units can result in very rapid boiler failure.

Temperature Measurement and Control

The minimum requirement is a dial thermometer, mounted around the mid-level of the water in the tank, to read the temperature of the water. Where steam injection is provided for temperature management of the feed water, a control probe is fitted around the mid-level of the tank that operates the automatic valve in the steam sparge line. More advanced control systems may require additional temperature signals to be relayed to central control systems.

Very large hot well tanks may require a pumped circulation system to be supplied which circulates the water in the tank for optimal temperature and chemical treatment distribution. Water shall not be circulated or agitated in such a way that oxygen can become entrained.

Level Measurement and Control

The minimum requirement is a level indicating device mounted on the side of the tank to directly indicate the contents, such as a valved sight gauge complete with protector. The normal minimum and maximum water levels should be clearly indicated on the gauge. Where automatic level control by adding make-up water is provided, one or more sensors are mounted in the tank to control a valve in the make-up water line.

Consideration should always be given to the volume of make-up water and its quality at any given time as a proportion of the total tank volume. This can have significant effects on system waterside balance and control.

Overflow

A generously sized outlet pipe shall be located high on one face of the tank, normally on the opposite side to the supply connections. The tank should overflow to a tun dish or other visual indicating device which shall be fitted to alert operators to overflow conditions. A 'U' tube water seal may also be required to prevent flash steam loss, but there should be no overflow of tank contents in normal operation.

Outlet To Pump and Boiler

A connection at the base of the tank to connect directly to the boiler feed pump(s) through generously sized pipework shall be provided. The outlet shall be placed sufficiently far away from the make-up and condensate input connections and any chemical injection points to prevent stratification and short circuiting of the water in the tank – a fully mixed and representative feed water supply is essential. The top of the outlet pipe connection shall protrude at least 50 mm upwards into the base of the tank to avoid drawing away any sludges or sediment from the bottom of the tank.

Careful consideration of the size of the water pipework shall be made to minimise friction losses and the resultant risk of pump cavitation, and to avoid “preferential flow” or uneven temperature and/or chemical distribution where a tank serves multiple boilers.

Vent Pipe

A generously sized vent pipe shall be provided that allows the tank to be ventilated to atmosphere. The vent outlet and pipework shall be routed away from personnel and taken to a location outside the building. A maximum of two 90 degree bends or equivalent shall be installed in the vent line, and the size of the line shall take account of the distance from the tank to atmosphere. Bird screens and 'rain hats' may be required.

The vent pipe shall be sufficiently sized so as to prevent pressurisation of an atmospheric tank under the most adverse conditions. A sufficiently large vent connection with the connected vent pipe leading into the open air ensures that the pressure does not build up to an unsafe level in the feed water tank.

A condensate drain shall be provided at the base of the vent head to drain any water away to a safe place at low level.

Access For Inspection

An inspection hatch shall be provided for smaller tanks, and a full-size manway with removable lid shall be provided on larger units. The access lid shall be fully insulated, bolted and gasketed to a suitable flange on the tank, and may require handles or lifting eyes depending on the weight of the lid. Heavy lids will require local lifting points for block and tackle.

Chemical Dosing and Sampling

Where water treatment chemicals are to be dosed into the tank the boiler water treatment specialist shall specify the ideal location for safe and consistent dosing points. Screwed socket connections shall be provided. Dip pipes and dosing quills shall be of an appropriate material for the chemical being dosed. Tanks shall include a suitable and safe test point for gathering a representative sample of the tank contents along with a suitable sample cooler for testing the feed water.

Dosing shall not be carried out into colder areas of the tank or close to the feed water inlet. In every case the recommendations of CEA document BG04 and the advice of the boiler water treatment specialist shall be followed.



Above: Scale formation inside a boiler

Drain

A drain connection shall be fitted to the bottom of the tank to facilitate its emptying for inspection.

Insulation

The tank and all its pipework and relevant fittings and mountings shall be adequately insulated to protect personnel and to reduce heat loss.

Access Requirements

If access is routinely required to the top of the tank an appropriate ladder and railings must be provided as a minimum. Toe boards must be utilised on any platform. For dedicated access, refer to BS EN ISO 14122 or an equivalent standard. In the case of combined access platforms where the tank is accessed from a mezzanine for example, The Construction Products Regulations 2013 will apply, requiring the structure to be marked with an appropriate Certification Mark.

Support and Platform Assembly

An adequately sized support structure shall be provided to take the weight of the completed tank and all its fittings and pipework plus the weight of water inside and the weight of two men with tools and spares. An adequate safety margin shall be specified by a structural engineer.

The design shall consider vibration of the tank resulting from steam sparging and flash steam in the condensate return – this can be quite severe at times.

4.5 De-aerators

Two main types are normally found, atmospheric or pressurised de-aerator.

Atmospheric De-aerators

The traditional atmospheric hot well can be fitted with a de-aerator head and a steam injection system. The de-aerator head accepts cold make-up water, which usually has a high oxygen content, and mixes it with flash steam from the condensate and the blowdown heat recovery system. Oxygen and other gases are released from the cold water and automatically removed through a vent before the water enters the main feed tank through an internal tube.

A recirculation pipe with a small pump is fitted between the bottom of the hot well and the top of the de-aerator head to promote circulation and avoid stratification. It is strongly advised that if this type of system is to be considered then a specialist in this area is sought, since incorrect application of these types of units can result in very rapid boiler failure.

Pressurised De-aerators

In certain boiler plants, pressurised de-aerators are sometimes installed and live steam is used to bring the feed water up to approximately 105°C to drive off the oxygen. A pressurised de-aerator comprises a pressurised tank fitted with a de-aerating head and various control systems. Pressurised de-aerators are thermally efficient and will reduce dissolved oxygen to very low levels, minimising the need for oxygen scavenging treatment chemicals, although they do require regular inspections under a Written Scheme of Examination.

They can also serve as a surge collection tank for process condensate return and typically hold about 15 minutes' worth of treated hot water in reserve storage to meet process load changes. Normally a pressurised de-aerator needs to be operated in conjunction with a feed tank that provides additional storage capacity.

The head section of a de-aerator breaks the water into as many small drops as possible and surrounds these with steam. The result is a large surface area of water exposed to steam to allow rapid heat transfer from the steam to the water, which quickly attains steam saturation temperature. This releases the dissolved gases, which are then carried with the excess steam to be vented to atmosphere. The de-aerated water then falls to the storage section of the vessel.

A blanket of steam is maintained above the stored water to ensure that gases are not re-absorbed. A modulating control valve is used to maintain the water level in the storage section of the pressurised de-aerator vessel. Modulating control provides stable operating conditions, avoiding an in-rush of relatively cool water that an 'on-off' control system would generate, severely affecting the ability of the de-aerator to respond quickly to sudden demand changes.

A modulating control valve is also needed to regulate the steam supply to maintain the pressure within the vessel. Accurate pressure control using a fast acting, pneumatically actuated control valve is vital to control the temperature in the de-aerator. A pilot operated pressure control valve may be used on smaller applications, and a self-acting control valve may be used when the load is guaranteed to be constant.

Principal reasons for selecting a pressurised de-aerator (operating under water conditions outlined in BS EN 12953) are:

- To reduce oxygen levels to a minimum (<20 parts per billion) without the use of water treatment chemicals. This will help to eliminate corrosion in the boiler feed system;
- To save water treatment chemical costs;
- To prevent contamination where the steam is in direct contact with the product, for example in foodstuffs or for sterilisation.

4.6 Types of De-aerator

Different manufacturers offer a wide range of different types of equipment for different applications. The advice of the manufacturer should be sought and followed. Some of the more common arrangements are:

Thermal Feed Water Partial De-aeration Plant

These work on the thermal principle which heats the feed water up to 85-90°C so that after additional chemical treatment the feed water is suitable for the operation of steam boilers. The water to be de-aerated (fresh make-up water and unpressurised condensate containing oxygen) is supplied to the feed water tank through separate connectors.

Optimum distribution of the condensate in the feed water container saves sparged steam and fuel. The steam required to heat up the feed water is supplied through a nozzle pipe, and because complete thermal de-aeration does not take place, any remaining oxygen and carbon dioxide residues shall be removed using chemicals.



Thermal Feed Water Full De-aeration Plant With Trickle De-aeration Device

The system works on the thermal principle that heats the feed water up to 102-105°C so that after additional chemical treatment the feed water is suitable for the operation of steam boilers.

The surface area of the water in the tank is enlarged by means of cascade plates so that inert gases (oxygen, carbon dioxide and nitrogen) leave the water spontaneously. At the same time, the water trickling downwards through the cascade is heated up by the steam flowing upwards, so that almost all the oxygen and carbon dioxide is removed.

The steam necessary to heat up the feed water is blown in through a sparge pipe so that the water in the tank is subsequently de-aerated at the same time. Any remaining oxygen and carbon dioxide residues, e.g. caused by load fluctuations, start-up processes, etc., should be chemically separated.

To avoid under-pressure situations, e.g. if the tank cools down or if unacceptably large volumes of make-up water are added, or if the condensate pump is insufficiently throttled, the system is fitted with a negative pressure safeguard device.

Thermal Feed Water Full De-aeration Plant With Spray De-aeration Device

The system works on the thermal principle in the same way as the trickle de-aeration device above but in this case the surface area of the water is enlarged by spray nozzles, and through the surrounding cushion of steam, the finely sprayed water droplets are heated up by the steam so that almost all the oxygen and carbon dioxide is removed.



4.7 Dealing With Condensate

As steam is generated, the water within the boiler evaporates and it is replaced by pumping new feed water into the boiler. As the steam passes around the system to the various items of steam-using plant, it changes state back to condensate which is virtually pure water.

Unless some contamination is likely (from the process or from the materials of construction in the steam system), this condensate is ideal boiler feed water. The return of condensate represents huge potential for water and energy savings in the boiler house; condensate has a high heat content and approximately 1% less fuel is required for every 6°C temperature rise in the tank. Recovering condensate will also reduce the cost of treating boiler water, and reduces the losses associated with blowdown.

100% condensate return is not feasible as there will always be system losses through traps, drains and blowdown, but many steam systems will have very high levels of condensate return. Some steam may be lost as it is injected directly into a process for applications such as humidification and food production, and there will be water losses from the boiler itself such as continuous TDS and bottom blowdown, gauge glass routines and taking water samples. Make-up water will have to be introduced to the tank to maintain the correct working levels.

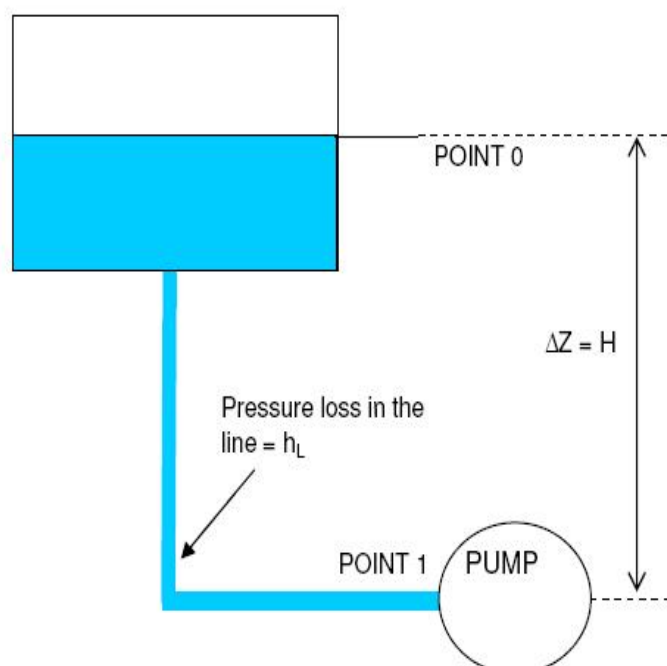
If pressurised condensate is being returned then flash steam will be released in the tank. This flash steam needs to be condensed to ensure that both the heat and water content are recovered. Traditionally this has been achieved through sparge pipes, but increasingly the favoured solution is to use a flash condensing de-aerator head where cold make-up, condensate return and flash steam are mixed.

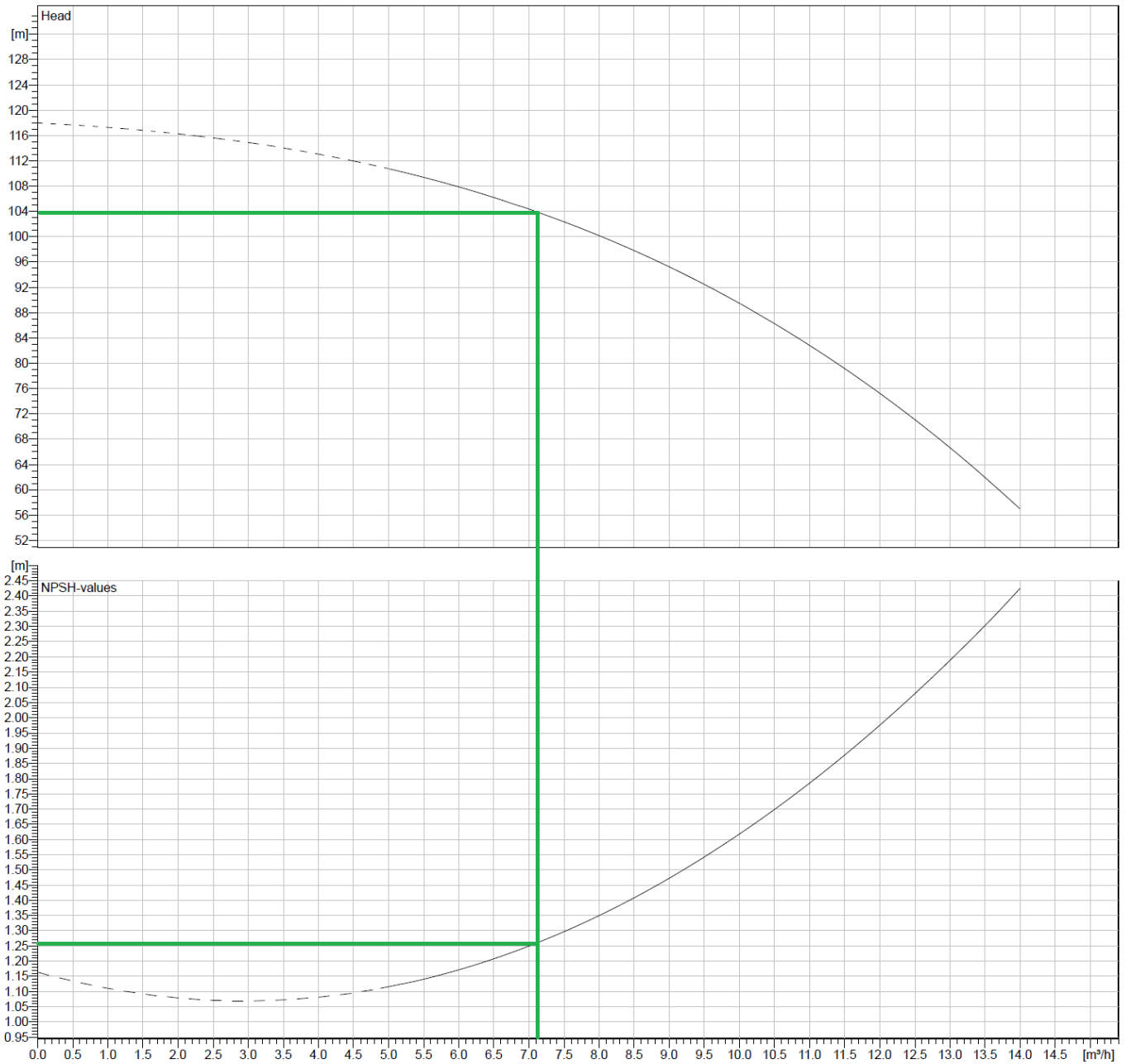
4.8 Cavitation Of The Boiler Feed Pump

If water close to boiling point enters a pump it is liable to flash to steam in the low pressure area at the eye of the pump impeller. When this happens, bubbles of steam are formed as the pressure drops below the water vapour pressure. When the pressure rises again, these bubbles will collapse and water flows into the resulting cavity at a very high velocity. This is known as 'cavitation'; it is noisy and can seriously damage the pump. Boiler feed pump failure will usually cause boiler trips and loss of steam to process.

To help avoid this problem, it is essential to provide the best possible Net Positive Suction Head (NPSH) to the pump so that the static pressure is as high as possible. This is achieved by locating the hot well as high as possible above the boiler, and generously sizing the suction pipework to the feed pump.

The NPSH for pumps can be defined as the difference between liquid pressure at pump suction and liquid vapour pressure, expressed in terms of height of liquid column. Suction head is the term used to describe liquid pressure at pump suction in terms of height of liquid column.





Typical Pump Curve -m (head) v m^3/h flow

5 HAZARDS

De-aerators and hot wells present certain hazards for boiler house operators and other personnel:

Temperature – normal precautions are required for the protection of personnel from touching hot surfaces, and consideration of the potential for leaks of steam and scalding water. Provision is required for the protection of personnel from steam issuing through vents and from scalding water splashing from overflows and drains.

Chemicals – water treatment chemicals are sometimes dosed directly into the tank, so the safe handling and management of these chemicals must be considered. Chemical Safety Data Sheets are required at the point of use and point of storage of all chemicals.

Asbestos – thankfully increasingly rare, but very old plant rooms may have asbestos insulation either still in situ from an original installation or as a dust that has collected from earlier stripping activities.

Work at height – high level tanks and fittings must be provided with safe access for routine inspection and maintenance activities. A hooped ladder, railings and toe boards will be a minimum suggested requirement.

Confined spaces – a tank that is large enough for a man to enter for inspection or maintenance purposes may well be considered as a confined space and the appropriate control mechanisms must be employed to keep entry to a minimum and make it as safe as possible if no alternative exists.

6 LEGISLATION

The following is a non-exhaustive summary of key regulations applying to de-aerators and hot wells. A range of supporting material can be found on the HSE website including Approved Code of Practice documents, Health and Safety Guidance, and Legal Reference documents.

Note: Be aware that Approved Codes of Practice (ACoP) and other guidance documents are often withdrawn by HSE and not replaced; for this reason CEA have created new guidance documents. As an example, the Management of Health and Safety at Work Approved Code of Practice (ACoP – L21) has been withdrawn and is no longer available. If you are looking for information on how to manage risks in your 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.

A revised and enhanced online version of 'Managing for Health and Safety' (also known as HSG65) is now available. The guidance is divided into four sections:

- Core elements of managing for health and safety;
- Are you doing what you need to;
- Delivering effective arrangements;
- Resources.

The first two sections of Managing for Health and Safety are targeted at leaders, owners, trustees and line-managers, whilst the third part will be particularly useful to those who need to put in place or oversee their organisations arrangements for health and safety. It will also be of value to workers and their representatives.

6.1 The Management of Health and Safety at Work Regulations 1999 (MHSWR)

MHSWR apply to every employer and self-employed person who carries out any work activity whether or not they own or control a pressure system.

Note: All future references to employers in this guidance should be read to include self-employed persons.

The MHSWR 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 should identify sensible measures to control identified risks that may otherwise result in injury or danger.

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

Should you be unfortunate enough to have an accident or incident with equipment on your plant and especially if somebody is injured, HSE will often use the MHSWR to prosecute both **you and your company** when apportioning blame. This is irrespective of the accident falling under other regulations such as PER, PSSR etc.

6.2 The Pressure Equipment (Safety) Regulations 2016 (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 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.

De-aerators working at temperatures greater than 110°C are covered by the regulations while those working at 110°C or below are not.

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 ESR 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 ESR.

6.3 The Pressure Systems Safety Regulations 2000 (PSSR)

In general terms, the PSSR do not apply to atmospheric de-aerators and hot wells as there is no 'relevant fluid'; pressurised systems (i.e. those operating above 100°C) are within the scope of the Regulations. Steam pipework and controls that are connected to the hot well may be included in the Written Scheme of Examination for the system.

For completeness of the material in this guidance, the following notes apply to PSSR.

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

'Owner' – This means 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.

'User' – This means 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 more responsibilities in relation to installed systems.

The owner/user of a steam system is responsible for complying with the following requirements of PSSR:

- Safe Operating Limits (SOL) have been set and are not adjusted without informing the Competent Person and 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 are examined by a Competent Person in accordance with the requirements of the scheme.
- All repairs and modifications must be carried out by people suitably competent in such work (Regulation 13). You must discuss and agree any changes with the "Competent Person" and include any changes within your written scheme of examination (WSE).
- The statutory technical documentation and other records must be kept and, where required, be made available for examination.
- Records must be transferred when the ownership of a system changes (Regulation 14).

Duty holders must keep all reports produced under the WSE for the entire life of the vessel; these records should go with the vessel if it is sold on to another party.

The results of all tests and examinations must be recorded and retained for a suitable period (Regulation 14). A period of at least two years is recommended for records of routine tests. These may be kept on-site or at a designated central location but wherever they are kept, they should be secure, safe and easily accessible.

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

- Written Scheme of Examination (WSE).
- Record of periodic tests (e.g. Non-Destructive Testing (NDT), Hydraulic test).
- Certificates of thorough examination.
- Records of servicing and modifications.
- Examination reports.
- Risk assessment.
- Manufacturer's records and instructions.
- Maintenance records.
- Training records.
- Audit reports.
- Test logs.
- Water treatment records.

6.4 The Provision and Use of Work Equipment Regulations 1998 (PUWER)

Any employer who either provides equipment for use at work (including boiler systems) or has control over the way 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 logbook, when provided, must be kept up to date.

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

6.5 The Water Industry Act 1991

Section 111 prohibits waste steam or any liquid at a temperature higher than 43°C being discharged into public sewers, as well as prohibiting the discharge of any material likely to interfere with the free flow of fluids.

6.6 The Construction (Design and Management) Regulations 2015 (CDM)

Although installing or replacing a hot well may not be a large enough project on its own to be notifiable under CDM, the principles of the regulations should still be followed, and if the tank is part of a major installation the regulations will apply in full and should be considered at every stage of the project from conceptual design through installation to maintenance and ultimate demolition.

Clients must appoint a Principal Designer and a Principal Contractor to ensure that the CDM Regulations are properly followed.

7 DESIGN CONSIDERATIONS

7.1 Pressurised De-aerators

Pressurised de-aerators are not as common in the UK as in other countries. They can be more expensive than a conventional hot well, both to install and maintain, and since they are pressurised they fall within the PSSR and require inspection by a Competent Person.

However they do have some significant advantages, especially for shell boilers operating at higher pressures. Being pressurised, the temperature within the de-aerator can be held much higher than in a hot well without any detrimental effect on the feed pumps. The thermal shock as the feed water enters the boiler is greatly reduced, especially in boilers operating at 15 bar and above. Lastly, because the de-aerator is operating above 100°C the amount of oxygen scavenger requirement is greatly reduced. This has the effect of reducing TDS hence reducing blow down volumes.

When considering installing a pressurised de-aerator the following are recommended:

1. Consult the site 'Competent Person' as a pressurised vessel will be listed in the Written Scheme of Examination.
2. Employ a company who has a well proven track record in the design and installation of pressurised de-aerators.
3. Ensure the de-aerator is built to approved standards such as BS PD 5500.
4. Ensure that the boiler feed pumps are capable of accepting the increase in temperature of the feed water.
5. Ensure the de-aerator has its own pressure control system with a safety valve to avoid any chance of over pressurisation.
6. Automatic level control and make-up supply is required, and it is recommended that high and low level alarms are fitted.

7.2 Hot Wells

Hot wells may be constructed as pressure vessels to a suitable standard such as: PD 5500 Specification for unfired fusion welded pressure vessels, BS EN 13445 Unfired pressure vessels, ASME VIII or an equivalent standard.

All new hot wells shall have a permanently attached nameplate containing the following information:

- The manufacturer's name.
- A serial number unique to that vessel.
- The date the vessel was manufactured.
- The standard to which the vessel was designed and constructed (if any).
- Where the maximum allowable pressure is other than atmospheric, the maximum allowable pressure of the vessel.
- Where the minimum allowable pressure is other than atmospheric, the minimum allowable pressure.
- The design temperature if anything other than 100 °C.
- Where a vessel has a design pressure in excess of 0.5 bar, the vessel must meet the requirements of The Pressure Equipment (Safety) Regulations and bear a recognised Certification Mark.

7.3 Pipework

Steam piping is subject to rapid pressurisation, high velocity flow, erosion, thermal shock and vibration, all of which can be severe. Pipework shall be suitably supported. Pipe bends shall be of large radius and their length kept as short as possible. Pipework from the tank up to and including the connection to the boiler shall have a design pressure and temperature not less than those of the design pressure of the associated boiler.

The BS EN 13480 series contains guidance on the design, manufacture, installation and testing of metallic industrial piping although other standards may also be suitable if they provide an equivalent level of safety;

- **BS EN 13480-1** specifies the general requirements for industrial piping systems and supports, including safety systems, made of metallic materials with a view to ensure safe operation.
- **BS EN 13480-2** specifies the requirements for materials.
- **BS EN 13480-3** specifies the design and calculation of industrial metallic piping systems, including supports.
- **BS EN 13480-4** specifies the requirements for fabrication and installation.
- **BS EN 13480-5** specifies the requirements for inspection and testing.
- **BS EN 13480-6** specifies additional requirements for buried pipework.

Guidance on conformity assessment procedures can be found in:

PD TR 13480-7:2002 Metallic industrial piping. Guidance on the use of conformity assessment procedures.

Guidance on suitable fittings is contained in:

BS 759-1:1984 Valves, gauges and other safety fittings for application to boilers and to piping installations for and in connection with boilers. Part 1: Specifications for valves, mounting and fitting

8 EXAMINATION AND MAINTENANCE

The tank should be drained, cleaned internally, and thoroughly examined at regular intervals, determined either by the Competent Person where the tank falls within a WSE or by risk assessment where it falls outside the scope of PSSR. Factors affecting the inspection interval include the method and materials of construction and the quality of the treated water within. Due attention shall be paid to the reports of previous inspections and remedial works arising therefrom.

The tank must be positively isolated from the boiler(s) for examination purposes e.g. by valve or spool removal or with double isolation and blank flange, spade or line blind. The electrical supply to any automated valves must be locked off and, where fitted, any compressed-air system must be isolated and de-pressurised. This positive isolation procedure is essential to ensure safety during examination of the tank.

It should be noted that during the preparation of a hot well or de-aerator for examination, it is usually necessary to completely drain the tank. Care must therefore be taken to ensure that final emptying of the tank is only made to drain when the water temperature is below the permissible limit of 43°C.

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APPENDIX 1 - REFERENCES AND FURTHER READING

The following is a list of applicable documents current at the time of preparation of this publication. This is an indicative, not comprehensive list.

- Free copies of all legislation are available from www.legislation.gov.uk.
 - Legislation marked with an asterisk is supported by Approved Codes of Practice and Guidance (ACoP) published by HSE.
 - Legislation marked with a double asterisk is supported by more than a single ACoP.
1. Health and Safety at Work etc. Act 1974
 2. Management of Health and Safety at Work Regulations (MHSWR)
SI 1999 No. 3242
 3. Provision and Use of Work Equipment Regulations (PUWER) *
SI 1998 No. 2306 (SI 1999 No. 305 in Northern Ireland)
 4. Electricity at Work Regulations
SI 1989 No. 635 (SI 1991 No. 13 in Northern Ireland)
 5. Confined Spaces Regulations *
SI 1997 No. 1713 (SI 1999 No. 13 in Northern Ireland)
 6. Control of Substances Hazardous to Health Regulations (COSHH)*
SI 2002 No. 2667 (SI 2003 No. 34 in Northern Ireland)
 7. Dangerous Substances and Explosive Atmosphere Regulations (DSEAR)**
SI 2002 No. 2776 (SI 2003 No. 152 in Northern Ireland)
 8. Control of Noise at Work Regulations
SI 2005 No. 1643 (SI 2006 No. 1 in Northern Ireland)
 9. Construction (Design and Management) Regulations (CDM)*
SI 2015 No. 51 (SI 2016 No. 146 in Northern Ireland)
 10. The Construction Products Regulations 2013 -SI 2013 No. 1387
 11. Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations - SI 2016 No. 1107 (SI 2017 No. 90 in Northern Ireland)
 12. Pressure Equipment (Safety) Regulations (PER) - SI 2016 No. 1105
 13. Pressure System Safety Regulations (PSSR)*
SI 2000 No. 128 (SI 2004 No. 222 in Northern Ireland)
 14. BS 759-1 Valves, gauges and other safety fittings for application to boilers and to piping installations for and in connection with boilers. Specification for valves, mounting and fitting
 15. BS 5925 Code of practice for Ventilation principles and designing for natural ventilation
 16. BS 7671 Requirements for electrical installations. IEE Wiring Regulations
 17. BS EN 12952 Water Tube Boilers
 18. BS EN 12953 Shell Boilers
 19. BS EN 13445 Unfired pressure vessels

20. BS EN 13480 Metallic industrial piping
21. BS EN ISO 14122 Safety of machinery. Permanent means of access to machinery
22. BS EN 45510-3-2 Guide for procurement of power station equipment. Shell Boilers
23. PD5500 Unfired fusion welded pressure vessels
24. PD TR 13480-7:2002 Metallic industrial piping
25. HSE Pressure Systems website <http://www.hse.gov.uk/pressure-systems/index.htm>
26. Business Energy & Industrial Strategy Pressure Equipment (Safety) Regulations 2016 Guidance
27. L5 Control of substances hazardous to health The Control of Substances Hazardous to Health Regulations 2002. Approved Code of Practice and guidance. HSE Books
28. L22 Safe use of work equipment Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance. HSE Books
29. L101 Safe work in confined spaces. Confined Spaces Regulations 1997. Approved Code of Practice, Regulations and guidance. HSE Books
30. L108 Controlling noise at work The Control of Noise at Work Regulations 2005 Guidance on Regulations
31. L122 Safety of pressure systems. Pressure Systems Safety Regulations 2000. Approved Code of Practice. HSE Books
32. L138 Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance. HSE Books
33. L153 Managing health and safety in construction. Construction (Design and Management) Regulations 2015. Guidance on Regulations

APPENDIX 2 - GUIDANCE NOTES ON RELATED TOPICS

- BG01 Guidance on Safe Operation of Steam Boilers
Jointly published by The Safety Federation and the CEA
- BG02 Guidance on Safe Operation of Hot Water Boilers.
Jointly published by The Safety Federation and the CEA
- BG03 Boiler Blowdown Systems; Guidance for Industrial Boilers
Published by the CEA
- BG04 Boiler Water Treatment; Guidance for Shell Boilers, Coil Boilers, Steam Generators
and Hot Water Boilers
Jointly published by ICOM Energy Association and CEA
- BG05 Guidance on Design and Operation of Biomass Boilers
Published by the CEA
- BG07 Thermal Fluid Systems; A Practical Guide for Safe Design, Operation and
Maintenance
Published by the CEA
- BG08 Temporary Steam and Hot Water Boiler Plant - Guidance for safe installation and
use
Published by the CEA
- BG11 Guidance on the Safe Operation of Water Tube Boilers
Published by the CEA
- GS4 Safety in pressure testing
HSE Books
- HSG250 Guidance on permit-to-work systems
HSE Books
- INDG178 Written schemes of examination: Pressure Systems Safety Regulations 2000
HSE Books
- INDG258 Safe work in confined spaces
HSE Books
- INDG362 Noise at work A brief guide to controlling the risks
HSE Books
- INDG436 Safe management of industrial steam and hot water boilers
HSE Books

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New title

Revised text throughout to correct minor errors and improve readability.

Revised typical hot well diagram.

Amended requirements for sparge pipe locations and chemical quill locations.

Recommendation for pumped circulation in very large tanks.

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