Steam Boiler Feedwater Storage Technology

Supporting an energy efficient, highly reliable steam system

White Paper
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1.0 Executive Summary

This paper describes best practice for boiler feedwater system design and operation for owners and operators of boiler plant.

The feedwater storage system, or feedtank, and its associated components are vital for the correct and efficient operation of the entire industrial steam and condensate system. A correctly designed and implemented feedtank offers substantial savings in energy and water treatment costs, and increases the reliability of the steam system for a more secure steam supply.

The feedtank is far more than simply a convenient way to store boiler feedwater. It provides a reliable source of feedwater to the boiler to meet fluctuating steam demand and needs to maintain boiler operations and protect the boiler if the water supply fails.

It also has an effective energy storage and water conditioning role by storing the energy returned from the steam and condensate system for re-use in the boiler. Critically, it must balance and deaerate the returned condensate, flash steam and raw water supplies to ensure maximum energy utilisation and liberate oxygen from the system.

In practice two alternatives exist to suit a steam user’s requirements: an atmospheric solution or a pressurised system.

A well-designed atmospheric deaerator raises the feedwater temperature to approximately 85-90°C to remove dissolved oxygen from the water which would otherwise cause corrosion in the steam and condensate system, and lead to rapid deterioration of the boiler. It can also reduce the need for oxygen scavenging chemicals such as sodium sulphite by as much as 75%.

In certain installations that would benefit from a further reduction in the use of treatment chemicals, a pressurised deaerator can be implemented to heat the feedwater to more than 100°C to drive off virtually all the oxygen. Pressurised deaerators are also thermally efficient.

Steam system operators are advised to take advantage of a professional survey of their installed feedwater system to ascertain the most effective ways to lower energy consumption, increase productivity, reduce maintenance and mitigate risk by complying with industry best practice and Health & Safety legislation.
2.0 The role of the feedtank in steam systems

The boiler feedtank plays an often under-estimated, yet vitally important role in the efficient and reliable operation of any industrial or building services steam system. The feedtank provides a reservoir of water for the boiler, and should be sized to allow at least one hour of emergency steam-generating capacity, depending on the criticality of plant operation, in the event of water supply interruption.

It also contributes significantly to energy saving within the steam plant by efficiently storing the energy from returned condensate and heat recovery systems. It must balance the boiler feedwater load with the returned condensate and make-up water to ensure the boiler operates efficiently. It also has an important role as a conditioning unit for the boiler feedwater.

Implementing an effective boiler feedwater system will help to avoid corrosion damage in the boiler and steam and condensate loop. It helps to ensure the entire steam system runs with minimum energy consumption and that modern package boilers are able to meet the fluctuating demands required by many of today’s industries.

A well-designed feedwater system will also help protect a steam system operator’s capital investment by extending the lifetime of the plant.

All industry sectors operating steam boiler plant can benefit by the correct implementation of a boiler feedwater storage system using the latest technologies.
3.0 The need to remove dissolved oxygen and other gases from feedwater

As well as providing a reservoir of water for the boiler, the feedtank offers an opportunity to control the water quality entering the boiler.

Deaeration, which mechanically removes oxygen and other dissolved gases from the feedwater, is proving to be beneficial in many EU markets and is currently gaining favour in the UK. This benefit is driving the need for traditional feedtanks to be upgraded with additional atmospheric and pressurised deaeration equipment.

Removal of oxygen is important because untreated boiler water contains as much as 10 mg/l of corrosion-causing dissolved oxygen at 15°C which, if left untreated, could lead to premature failure of wetted metal surfaces by oxidation corrosion resulting in rusty-looking nodules scattered throughout the boiler and fire tubes. These nodules are the by-product of, and a protective housing for, oxidation corrosion. The size of the nodule does not necessarily indicate the depth of damage. The only way to completely stop the corrosion at this stage is to remove the nodule and the concentration of solids under it.

So it is important to maintain feedwater temperature as high as possible to minimise the content of dissolved oxygen and avoid the formation of nodules. Feedwater at an elevated temperature also reduces the risk of thermal shock in the boiler when cold water hits the hot surfaces of the boiler wall and its tubes. Furthermore, hot feedwater improves the boiler’s responsiveness to varying load demands.

A higher temperature feedwater supply also reduces the work the boiler has to do to raise steam. Almost 10% less energy is required to raise 1 kg of steam at 10 bar g from water at 70°C than at 10°C.

The target for dissolved oxygen in the feedwater at the economiser inlet or, in the absence of an economiser, the boiler feedwater inlet, is zero dissolved oxygen. If a high proportion of make-up water is used, heating the feedwater can substantially reduce the amount of oxygen scavenging chemicals that need to be introduced into the feedwater system to help eliminate dissolved oxygen, reducing the cost of treatment chemicals.

Correct boiler water treatment and conditioning is covered in BS EN 12953 part 10 Shell boilers. Requirements for feedwater and boiler water quality, and is referenced in BG01 Guidance on Safe Operations of Boilers. Boiler operators are advised to follow the guidance contained in these standards.

Figure 1: The oxygen content of feedwater is reduced as its temperature is increased
4.0 The components of an effective feedwater system

The design of a feedwater system should focus on the effective integration of water treatment and heat recovery to support a more efficient, more reliable and lower emission steam system.

4.1 Feedtank construction

While horizontal or vertical cylindrical feedtanks are not uncommon, most installations have a rectangular-shaped tank because this offers the optimum volume of water storage for the floor area it occupies.

Figure 2: An atmospheric deaerator and its systems

Probably the most commonly used material for the feedtank is carbon steel, which is relatively low cost but susceptible to corrosion. This drawback can be overcome with a suitable coating, but this substantially increases the tank’s capital cost. Furthermore, the need for regular maintenance not only increases the operating cost, but difficult, time-consuming work procedures may be required to access confined spaces should the coating need to be re-applied.
Cast iron sectional tanks are sometimes used, but are also likely to corrode and can suffer leaks at the joints between the sections.

Austenitic stainless steel feedtanks have a higher initial cost but this is typically more than justified by a long operational life, low maintenance costs and by avoiding the cost of replacing a failed lower specification system. Therefore Type 304L is generally selected as the most appropriate grade of stainless steel.

### 4.2 Feedtank capacity

Conventionally, the feedtank is sized to provide the boiler with enough water for at least one hour’s operation at maximum boiler evaporation to cover the interruption of make-up water supply. The length of emergency steam-generating capacity required depends on how critical the steam supply is to the facility’s operation and also needs to take into account the volume of condensate return available.

This may not be practical in larger plants which instead can be fitted with a smaller ‘hotwell’ feedtank with additional cold treated water storage. The hotwell should have sufficient capacity, called ullage, above its normal working level to accommodate any surges in the rate of condensate return.

A high condensate rate can occur at start-up due to:

- Condensate lying in the plant and pipework suddenly being returned to the tank
- A higher condensing rate while the cold downstream pipework is brought up to operating temperature

### 4.3 Make-up water

Cold water from the water treatment plant makes up any losses in the system. Many treatment plants need an on/off flow of water through them to perform cost effectively. A feedtank modulating control can create a constant but small demand for water resulting in a ‘trickle flow’ that can degrade a softener’s performance. To avoid this, and to comply with regulations requiring an air break of 25mm, a small plastic or galvanised steel cold make-up tank is often fitted. The flow from the softener is on-off controlled into the make-up tank. From there a modulating valve controls its flow into the feedtank.

To avoid the relatively cold make-up water sinking to the bottom of the feedtank, (where it will be drawn directly into the boiler feedwater line), and to ensure uniform temperature distribution, it has been common practice to sparge the make-up water into the feedtank at a higher level.

The make-up tank can also provide a heat sink for the boiler blowdown flash recovery system.

### 4.4 Water level control

A modern feedtank will typically be fitted with level probes that give an output signal to modulate a control valve. The signals from the probe can be linked to a control valve on the cold water make-up supply. The probe is fitted with a protection tube inside the feedtank to protect it from turbulence, which could cause false readings.

Guidance Note BG01 recommends that all feedwater storage solutions incorporate a low level water alarm.

### 4.5 Feedtank connections

Piping to and from the feedtank needs to deal with condensate return, make-up water, flash steam heat recovery input and boiler feed.

Returning condensate to the boiler feedtank is recognised as a highly effective way to improve steam plant efficiency. Condensate also contains around one-quarter of the energy of the steam from which it came. Allowing condensate to pass to drain wastes valuable energy, water and water treatment chemicals.

Returning condensate to the boiler feedtank can save thousands of pounds per year in energy alone. Using hot condensate to heat the boiler feedwater leaves the boiler with less work to do in converting the water to steam. In other words, less fuel is needed to produce steam from hot water rather than cold water. Every 6°C rise in feedwater temperature equates approximately to a 1% fuel saving.
Re-using as much condensate as possible minimises the cost of chemicals to treat raw make-up water. It also reduces the amount of fresh water needed and cuts the losses from boiler blowdown.

4.6 Sparge pipes
Typically, pressurised condensate will create flash steam when released in the feedtank. This flash steam needs to be condensed to ensure that both the heat and water are fully recovered. The traditional method of doing this has been to introduce it into the feedtank through sparge pipes. These are simply pipes mounted inside the tank, with equally spaced holes along the length of each pipe and with the end blanked off. The flash steam exits the pipes through the holes as small bubbles, which will condense within the feedwater.

Sparge pipes are inexpensive to make and easy to install, but above about 2 bar g condensate pressure they can be noisy and cause high levels of vibration. They are also notoriously difficult to size correctly to balance maximum and minimum running loads. Also, the flash steam bubbles may not condense before they reach the surface of the liquid, reducing the effectiveness of feedwater heating.

Steam injector replaces sparge pipes to bring quiet efficiency for mushroom producer

Spirax Sarco solved a severe noise problem and overcame shortages of sterilisation steam by installing a steam injector in the boiler feedtank at a mushroom producer. The injector also cut the consumption of water treatment chemicals by about 75%.

A crucial part of the farm’s intensive operation is sterilisation using steam at 5.5 bar g. “We need continuity of production and efficient sterilisation which is key to maintaining optimal performance,” said the producer’s plant engineer.

The new steam injector replaced a sparge pipe to mix steam with the water in the boiler feedtank. The sparge pipe was inefficient, resulting in an inconsistent boiler feedwater temperature. When the feedwater temperature was low, the boiler used excessive energy and took longer to generate steam, which led to steam supply problems. Inconsistent feedwater temperature also meant that extra treatment chemicals were needed to protect the boiler, because cooler water holds more of the dissolved oxygen that causes corrosion.

The sparge pipe was also noisy and caused vibration, which was a big concern as anyone working in the boiler house had to wear ear protectors. As well as being a nuisance for personnel, vibration can cause extra wear and tear on the steam system.

The steam injector draws water from the surrounding tank into a nozzle, where it mixes with the steam before being discharged. As well as being quiet, the injector increases circulation so that the water temperature is consistent throughout the feedtank. This enables the operator to top up the boiler at a steady 87°C.
4.7 Steam injectors
A steam injector draws in water from the bottom of the tank and mixes it with steam to distribute heated liquid to the feedtank. The steam injector body is more sophisticated than a simple sparge pipe to allow the use of steam at higher pressures. A turbulent zone is created within the injector, which ensures thorough mixing of the steam and liquid.

This agitates and circulates the water to maintain a constant temperature throughout the feedtank, helping to avoid cold spots.

Steam injectors are smaller than sparge pipes, making them easier to install. They are also robust and generally quieter than sparge pipes.

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Is your feedtank steam injector making the right noises?

A few minutes listening to a feedtank fitted with a steam injector can reveal whether or not the system is operating correctly.

A soft roar indicates normal running conditions
This is caused by steam condensing inside the discharge tube, as it mixes with recirculating water drawn through the holes into the injector body. This noise increases with steam pressure, water temperature and the number of injectors, but is rarely objectionable at steam pressures below 8 bar g. Even above 8 bar g, little vibration should be experienced.

A soft bumping noise, sometimes with heavy vibration
This is caused by steam condensing inside the discharge tube, as it mixes with recirculating water drawn through the holes into the injector body. This noise increases with steam pressure, water temperature and the number of injectors, but is rarely objectionable at steam pressures below 8 bar g. Even above 8 bar g, little vibration should be experienced.

A crackling noise
This indicates that the steam pressure at the inlet to the steam injector is too low. Steam is travelling at a lower velocity than during normal operation. Steam bubbles collapse on the injector body and in the connecting pipework, inducing cavitation. This noise can indicate the steam injector system is oversized.

A vibrating noise
This can indicate a poor steam injector installation in a rectangular tank made from relatively flexible panels. An injector fitted in the centre of such a panel may induce vibration and noise; better is to mount the injector nearer the corner of the tank where the structure is stiffer.

Note: If excessive noise, vibration or movement of pipework is experienced then it is essential that the feedtank is not operated until the problem has been identified and rectified.
5.0 Deaerator systems

Dissolved oxygen in the feedwater corrodes boilers, while carbon dioxide dissolved in the feedwater produces corrosive carbonic acid, which attacks the boiler system. Although dissolved gases and low pH can be chemically controlled, it is more economical and thermally efficient to remove these gases mechanically. This mechanical process is called deaeration.

5.1 Atmospheric deaerator systems

Feedtanks fitted with a deaerator head, steam injection system and the necessary controls can be thought of as atmospheric deaerators. The deaerator head mixes high oxygen content cold make-up water with flash steam from the condensate and the blowdown heat recovery system. Oxygen and other gases are released from the cold water and can be automatically removed through a vent before the water enters the main feedtank.

5.2 Pressurised deaerator systems

In certain boiler plants, pressurised deaerators are sometimes installed and live steam is used to bring the feedwater up to approximately 105°C to drive off the oxygen. A pressurised deaerator comprises a pressurised tank fitted with a deaerating head and various control systems. Pressurised deaerators 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 insurance inspections. 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 deaerator needs to be operated in conjunction with a feedtank that provides additional storage capacity.

The head section of a deaerator 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 deaerated 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.
Two ways to break water into droplets

There are two common methods of separating water into small drops inside the deaerator head:

- Tray type deaeration: the water flows over a cascade of perforated trays
- Spray type deaeration: the water is forced through a spring-loaded nozzle to create a spray

Tray type deaeration offers a very long service life of typically 40 years and achieves a very high turndown that is suited to power plant applications. Spray type deaeration is lower cost with a lifespan of around 20 years and a turndown of around 5:1, making it the more common choice for process industries.
A modulating control valve is used to maintain the water level in the storage section of the pressurised deaerator vessel. Modulating control provides stable operating conditions, avoiding an in-rush of relatively cool water that an on-off system would generate, ruining the ability of the deaerator 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 deaerator. 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 deaerator (operating under water conditions outlined in BS EN 12953):

• To reduce oxygen levels to a minimum (< 20 parts per billion) without the use of chemicals. This will eliminate corrosion in the boiler feed system
• To save water treatment chemical costs
• Chemicals added to control the oxygen content of the boiler water will themselves require blowing down. Therefore by reducing / eliminating the addition of chemicals, the blowdown rate will be reduced with associated cost savings
• To prevent contamination where the steam is in direct contact with the product, for example: foodstuffs or for sterilisation
6.0 The Spirax Sarco feedwater system portfolio

Spirax Sarco offers a range of bespoke atmospheric feedtanks, deaerator heads and pressurised deaerator systems, as well as all the auxiliary controls and products that together make up a feedwater system.

**Feedtanks** ranging from 2,000 litres to 30,000 litres capacity feature all wetted parts in welded austenitic stainless steel. This material is proven to be the most effective for most boiler feedtank applications. Carbon steel stiffeners are used externally on all tank sides and bases to increase tank rigidity.

**Flash condensing deaerator head** comprising three parts – the mixing unit with a PN16 or Class 150 mounting flange, the immersion tube with a plate top flange, and two gaskets. The plate flange is sandwiched between the mixing unit and a mating flange welded to the top of the Spirax Sarco feedtank to act as a stiffener. All parts are manufactured from weldable austenitic stainless steel and held in place with stainless steel studs and nuts.

**Pressurised deaerator systems** feature an innovative hybrid spray-type/tray-type design to ensure the effective break up of water into fine droplets for efficient steam-to-water heat transfer. Available in sizes up to 3,500 kg storage capacity, the systems provide a full 15 minutes of water storage to protect process productivity. Additional air vents on the storage tank eliminate the potential for corrosion at the water line that other pressurised deaerators can suffer, while fully modulating capacitance-type level controls ensure more consistent water levels than are possible with conventional float-type controls.

**Steam injectors** are available in three sizes to cover most requirements. They ensure quiet but vigorous mixing of steam and feedwater to drive off the dissolved oxygen content down to approximately 2 parts per million (ppm) in atmospheric feedtanks to minimise the oxygen-scavenging chemicals required.

**Survey and design services:** Spirax Sarco can survey old feedwater installations that need updating or replacing. Spirax Sarco also offers support for feedwater design to ensure that boiler plant can benefit from the capabilities described in this White Paper.
Spirax Sarco expertise helped a major UK industrial site make massive savings in energy and maintenance costs by correcting the poor condition of the site’s steam and condensate system.

The boiler efficiency alone improved by an estimated 12% to save between £30,000 and £40,000 annually in fuel costs. In addition, previous corrosion problems had cost £10,000 in boiler tube replacements, which are no longer an issue. Manual blowdown was also ejecting 10% of the steam being generated by the boiler and that rate has now dropped to 5%.

Problems with the old set-up were not confined to the boiler house. During an initial site survey, Spirax Sarco found that large sections of the condensate pipework were corroded and had to be replaced, while corrosion in the pipes that heat the production process allowed product to contaminate the entire steam and condensate system.

Spirax Sarco took a two-pronged approach to solving the problems, assessing the situation by conducting a mechanical survey across the site and a separate steam system conditioning audit. Problems with the condition of the steam began during the feedwater treatment process, where the water softening system was malfunctioning. This was allowing the ions responsible for water hardness (principally chloride) to slip through into the boiler. The ions caused scale build up on the boiler tubes and impaired the heat transfer efficiency.

In addition, the boiler feed temperature was too low, which allowed dissolved oxygen into the boiler where it caused corrosion. Spirax Sarco recommended fitting a steam injection system to heat the boiler feedwater to 90°C in order to drive off dissolved gases. The engineers also fitted a Spirax Sarco deaerator head in the feedtank to help keep the oxygen level under control.
7.0 Conclusion: Deaerators are critical for efficient and reliable steam systems

The deaerator plays a far more significant role in the efficient running of industrial steam systems than simply acting as a feed of water to the boiler.

The feedtank principally provides a water reservoir to balance the boiler feedwater load with returning condensate and treated make-up water. It also acts as an energy storage unit for the heat from returned condensate and heat recovery systems. The inclusion of an atmospheric or pressurised deaerator is also well placed to be an effective conditioning unit for the boiler feedwater and can deliver significant operating benefits.

The correct design of the feedwater system can substantially increase the safety, reliability and lifecycle efficiency of boiler plant. Furthermore, the correct integration of water treatment and heat recovery within the deaerated feedwater system provides a more energy efficient, lower emission steam system.

Steam system operators are advised to review their feedwater system to ascertain how it may be upgraded in order to benefit their energy efficiency, productivity, maintenance routines and compliance with Health and Safety requirements. A Spirax Sarco survey of the boiler house is a cost effective way to begin this review.

Find out more
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