Boiler Project Fundamentals

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This article describes several variables to consider when selecting a steam boiler — from choosing a boiler configuration to understanding boiler water chemistry.

Let's assume that you are tasked with finding a suitable replacement for an aging boiler in your plant. This article will equip you with some key information about steam boilers, including fuel types, boiler configurations, and condensate system considerations.

Before you start the project, you need to arm yourself with some basic knowledge, such as your steam requirements, what type of boiler you prefer, and which manufacturer can meet your needs. You would not ask a car dealer "Which car do you think I should buy?" Therefore, you need to understand your own requirements to help you narrow down the options. So, before you can choose the best boiler for your application, determine your needs and research available technologies.

Ideally, you will have plenty of time to gather information and choose a piece of equipment that meets your needs. If, however, a boiler failure occurs and you are up against a deadline, you may have to get a rental boiler. There are many companies that can fulfill a rental request in about one to two weeks. Installing a replacement boiler in your facility within a week or so is generally not an option, as this can only be fulfilled by a boiler manufacturer that stocks replacement boilers that can match your steam demand; typically, only modular boiler manufacturers have this capability. For the purpose of this conversation, let's assume you have some time to make an informed decision.

Coordinate the project team

When choosing the project team, picking one person to be the main point of contact for the project, both for internal and external personnel, may be the most important factor for team communication. This point of contact should fully understand what the goal of the boiler replacement project is, be easily accessible, and be flexible enough to handle frequent changes.

At the start of the project, schedule a team meeting and ask these questions at the meeting:

• What do we need? Do we need steam or hot water? Do we need humidity? Do we need electricity? Do we just need a certain temperature for our process? How often do we need it?

• How critical is our process? Are we replacing equipment? Are we starting from scratch?

• Are we looking at a 5-yr or 10-yr payback period? Or, is there another driving cost factor?

• Does anyone on this team understand boiler water chemistry?

• Do we want to perform the maintenance on this equipment, or will we outsource maintenance? Are there any guarantees or warranties from any of the manufacturers associated with bundling services?

• What does our state say about boiler operations? What does our insurance company say about boilers?

You should know the answers to these questions to fully understand the scope of the project. There are many organizations that you can hire to answer these questions for you and deliver the optimal boiler system to you on a platter. But if you are a do-it-yourself kind of organization, then you may want to familiarize yourself with the topics addressed in this article before you begin to answer these questions (or start making phone calls to external companies).

Boiler classifications

The most basic definition of a boiler is a closed vessel in which water is heated until the water has reached the desired pressure and temperature. This definition is extremely broad and the project team will need to narrow down the specific type of boiler that will be required. Some manufacturers use the term boiler to refer to different subcategories of boilers, such as power boilers, high-temperature water boilers, steam heating boilers, or hot-water heating boilers.

The American Society of Mechanical Engineers' (ASME) Boiler and Pressure Vessel Code (BPVC) regulates the design and construction of boilers *(1, 2)*. Your boiler requirements will be influenced by how you plan to use the boiler in your process. Do you need power, heating, or something else? ASME divides boilers into two categories: high pressure/temperature and not high pressure/temperature.

ASME BPVC Section I: Power boilers. This section of the code specifies requirements for all methods of construction of power and electric boilers, as well as high-temperature water boilers, heat-recovery steam generators, solar receiver steam generators, and certain fired pressure vessels *(1)*. These are steam boilers in which the steam pressure exceeds 15 psi, and water boilers in which the pressure exceeds 160 psi and/or the temperature exceeds 250°F.

ASME BPVC Section IV: Heating boilers. This section of the code provides requirements for design, fabrication, installation, and inspection of steam heating boilers, hot-water heating boilers, hot-water supply boilers, and potable water heaters intended for low-pressure service that are directly fired by oil, gas, electricity, coal, or other solid or liquid fuels *(2)*. These are steam boilers in which the steam pressure does not exceed 15 psi, and water boilers in which the pressure does not exceed 160 psi and temperature does not exceed 250°F.

You can use steam or hot water boilers to achieve high temperatures, but the infrastructure of the distribution systems will be different. Hot-water distribution systems are typically more efficient than steam distribution systems — because most hot-water systems are closed-loop, they need very little makeup water and there are no flash steam losses that are associated with steam system steam traps. Also, dissolved solids do not accumulate in the boiler of a hot-water system, so there is no need for blowdown.

Although some manufacturers use a similar design for their steam boilers and hot-water boilers, hot-water boilers are typically more efficient than steam boilers. Because steam boilers require much more heat to create steam, there is much more wasted heat energy than in hot-water systems. Some of this heat can be recaptured through the use of economizers, but buying an economizer will usually require an extra cost analysis to determine whether it is needed.

Hot-water systems have some drawbacks over steam systems. Hot water cannot provide temperatures as high as steam can. Also, hot water needs to be pumped to higher elevations, whereas steam can travel through piping to higher elevations without pumping because it travels from areas of higher pressure to areas of lower pressure.

A boiler is very simple in concept, but selecting the right boiler requires a lot of consideration in order to make sure that you are getting the desired output. When evaluating your boiler options, consider the long-term economics (*i.e.,* money saved or money spent over time). Make sure you understand that the decisions you make today will affect costs in the future.

For the rest of this project, let's focus on steam boilers.

Steam boiler system basics

A steam boiler is used to heat water into steam, and the steam is circulated through a closed-loop piping system to transfer heat and/or humidity to a process. If you have processes that require different steam pressures and temperatures within your system, you can use pressure reducers to modify the pressure of the steam for specific pieces of equipment. Alternatively, you can use separate steam boilers with different pressure ratings for each process with a different pressure.

Low-pressure/temperature systems generally operate below 200°F. Medium-pressure/temperature systems generally operate between 200°F and 250°F. Processes that are a long distance away from the boiler room and high-temperature applications may need a high-pressure/temperature boiler to obtain the temperature required at the end process.

The industry standard for high pressure vs. low pressure is 15 psi — boilers operating at 15 psi or lower are classified as low-pressure boilers. Any boiler operating at a pressure higher than 15 psi is considered a high-pressure boiler.

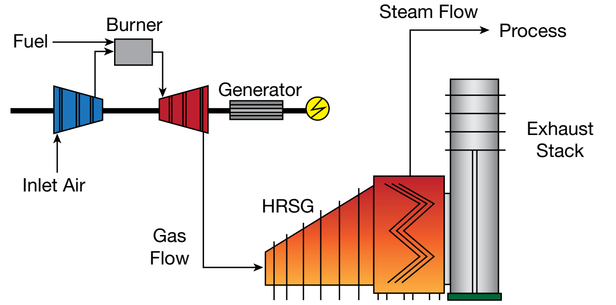
Relationship between pressure and temperature. According to Gay-Lussac's law of pressure-temperature, the pressure of a given amount of gas held at constant volume is directly proportional to the temperature. As the pressure increases, the temperature also increases, and as pressure decreases, the temperature also decreases. To find the corresponding temperatures and pressures of saturated steam, you can refer to a steam table.

You need to include a margin of error when choosing the pressure and temperature of steam leaving the boiler. Don't fall for the common mistake of determining the pressure and temperature leaving the boiler and assuming they will be the same at the end process. There will be some pressure and temperature losses through the steam piping and other components.

Fuel options. Boiler systems transfer energy to water using a combustible gas, fuel oil, or electricity. Electricity is usually reserved for smaller machines. Natural gas is preferred for many reasons, but its use is usually based on availability at your facility. Propane is an option similar to natural gas; however, a natural gas boiler cannot simply be replaced by a propane boiler because the two fuels have different densities.

Diesel No. 2 is a readily available standard fuel for many facilities in North America. It can be easily delivered, and some facilities use it as a backup fuel. Some boiler manufacturers make boilers that can fire either a combustible gas fuel or a fuel oil. Boilers that can burn two types of fuel are known as dual-fuel boilers. A facility normally considers a dual-fuel boiler if it has a critical end process. In the event that it loses the main source of fuel, it has a backup source of fuel available.

If your process is critical enough to need dual-fuel inputs, you also need to consider a backup source of electrical power to operate the boiler system, as well as your other emergency power loads. For example, hospitals or critical government facilities may have backup electrical power such as generators, as well as backup fuel for their boilers. In the chemical industry, if you have an expensive chemical process in a reactor that needs to maintain the same temperature over time, then having redundancy in your steam system such as dual-fuel and backup sources of power would be critical. In most cases, the primary fuel is typically natural gas and fuel oil is the backup fuel, but the backup could be propane, depending on the fuels available at your site.



▲ **Figure 1.** A heat-recovery steam generator (HRSG) recovers heat, usually from a gas turbine. In the figure, the first few blocks represent the gas turbine, which is making electricity. The exhaust fumes exit the gas turbine and enter the HRSG unit, which creates steam. This plant produces both electricity and steam.

Typical boiler configurations

There are a few general types of steam boilers: heat-recovery steam generators, firetube boilers, watertube boilers, and modular style boilers. Each boiler type has different manufacturers, with slight design differences that cannot all be captured here. The following sections provide an overview of the various boiler constructions.

Heat-recovery steam generator

A heat-recovery steam generator (HRSG) is a type of heat exchanger that recovers heat from a hot gas stream and produces steam (Figure 1). The steam can be used in a process or used to drive a steam turbine for electricity production.

You might choose an HRSG if your plant is generating electricity via a gas turbine generator. Or you might install an HRSG if you have a process that is producing large amounts of hot gases and you want to reclaim that heat and use the steam elsewhere in the plant. These boilers are not standard, and their installation should be left to boiler manufacturers that are capable of this type of work.

The advantages of the HRSG design include:

• electricity output

• steam output.

The disadvantages of the HRSG design include:

• a large amount of input energy is required to justify this configuration

• few organizations are capable of installing this type of equipment.

Firetube boilers

A firetube boiler's main components include a firebox, a series of submerged water tubes, a feedwater inlet line, a combustion gas outlet stack (flue), and a steam outlet (Figure 2).

The term *firetube* is very descriptive. The fire, or hot fluegas from the burner, is channeled through a group of steel tubes that are surrounded by a shell filled with water. Every set of tubes that the fluegas travels through before making a turn is considered a pass. In Figure 2, the gas passes through the shell two times before exiting, so this boiler is called a two-pass firetube boiler. Their high efficiency and reliability make firetube boilers suitable for steam-intensive industries and either continuous or batch operation.

The advantages of the firetube boiler design include:

• relatively inexpensive

• easy to clean

• less strict water treatment requirements

• simple construction

• available in sizes from 600,000 Btu/hr to 50,000,000 Btu/hr

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• easy tube replacement (many companies have this capability)
• well-suited for space heating and industrial process applications.

The disadvantages of the firetube boiler design include:
• not suitable for high-pressure applications of 250 psi and higher
• excessively heavy per pound of steam generated
• relatively slow to raise the steam pressure because of the large volume of water
• requires frequent tube replacements
• extended maintenance necessitates multiple units so at least one is available when the other is down for service
• fuel must be used to keep the unit warm and ready for use.

Watertube boilers

A watertube design is the opposite of a firetube design. Here, the water is inside the tubes and the combustion gas passes around the outside of the tubes. Watertube boilers may vary in design, although their basic principle of operation is the same. This type of boiler consists of two drums, a series of water-filled tubes, a feedwater inlet line, and a combustion gas outlet stack (Figure 3). The tubes are connected to a steam drum and a mud drum. The water is heated and steam exits from the upper drum. Watertube boilers are better suited for applications that require large amounts of steam, such as industrial process applications, and are used less frequently for heating applications.

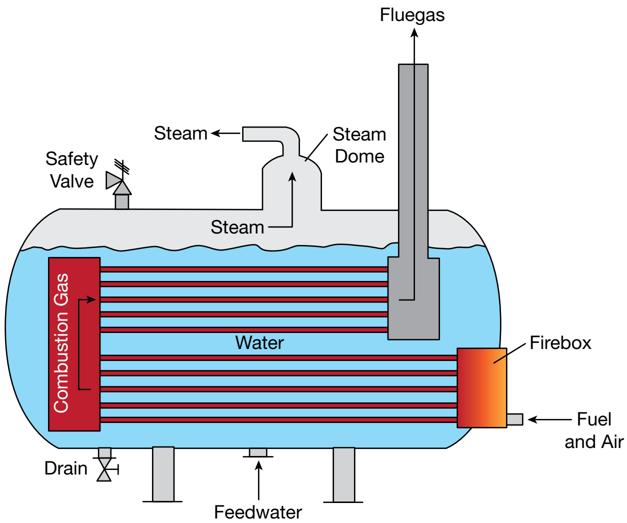
The advantages of the watertube boiler design include:
• available in a much wider range of sizes than firetube designs, up to several million pounds per hour of steam
• able to handle higher pressures, up to 5,000 psig
• capable of recovering faster from load changes than firetube boilers
• able to reach very high temperatures.

The disadvantages of the watertube design include:
• high initial capital cost
• cleaning is difficult
• tube replacement is almost impossible
• excessively large volume of space is required.

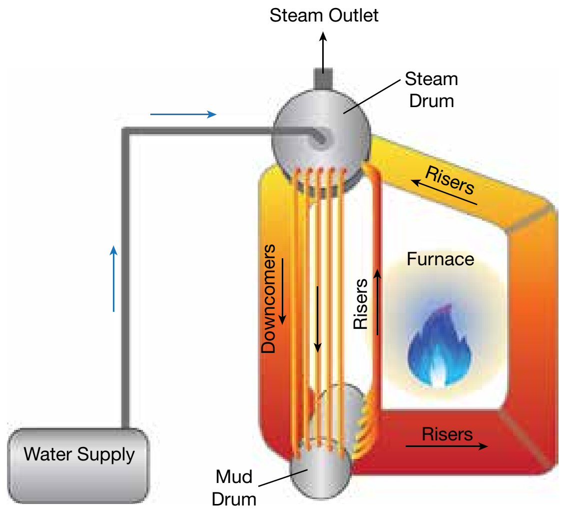
Modular boilers

A modular boiler system is unique and has many advantages over both the firetube and watertube designs. The main components of a modular system are a feedwater inlet, lower header, series of tubes or coils, upper header, and steam separator (Figure 4). This design may seem similar to the watertube boiler, but its application is what sets it apart from the traditional watertube design. A modular boiler converts water to steam in only one pass. Flames engulf the tubes, quickly transfering heat to the water and turning the water to steam faster than traditional designs. This is made possible by advances in technology and by the fact that the flame temperature is not required to be as high as in traditional designs. Also, because there is a smaller volume of water to turn to steam, the steam is generated very quickly. In fact, some modular steam boilers can heat up from a cold 70°F condition to steam-producing capacity in less than five minutes. And, a lower flame temperature produces less nitrogen oxides (NOx).

Because each individual boiler needs less than five minutes to achieve full steaming capability and one controller can sequence multiple boilers, you have the ability to scale



▲ **Figure 2.** In a firetube boiler, hot fluegas from the burner is channeled through a group of steel tubes that are surrounded by a shell filled with water. The gas heats the water and creates steam.

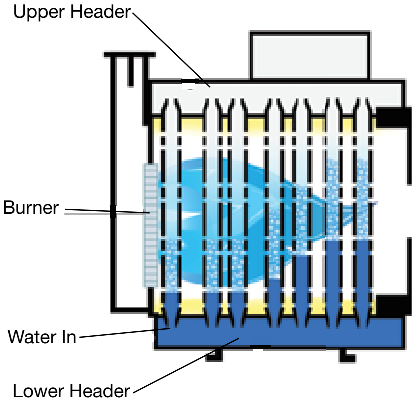


▲ **Figure 3.** In a watertube boiler, water inside the tubes is heated by combustion gas outside of the tubes. Steam leaves the system from the top of the steam drum.

your steam needs with a near-instantaneous response time at large capacity (Figure 5). For example, the modular boiler room shown on p. 53 — operated by a beverage manufacturer in the Southeast U.S. — has a total capacity of 1,500 hp of steam production, only requires 334 ft^2 (31 m^2) of space, and can be production-ready in less than 5 min from shutdown condition.

The advantages of the modular boiler design include:
- safer due to small water volume
- small footprint, typically occupying half the space of a traditional boiler system (Figure 6)
- high efficiencies throughout the entire range of operation
- quick response to varying loads
- flexible for small or large industrial applications
- when demand is low, spare machines can be turned off to save fuel
- quick maintenance turnarounds.

The disadvantages of the modular boiler design include:
- high water quality requirements
- cannot be used for applications above 450 psi
- requires operator training (whereas many operators are familiar with more traditional boiler designs).



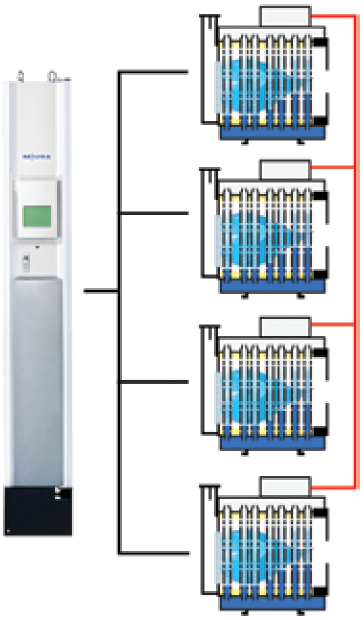
▲ **Figure 4.** In a modular boiler, water is converted to steam in a single pass through the boiler. The flames from the burner completely engulf the tubes, which boils water faster than traditional watertube boilers.

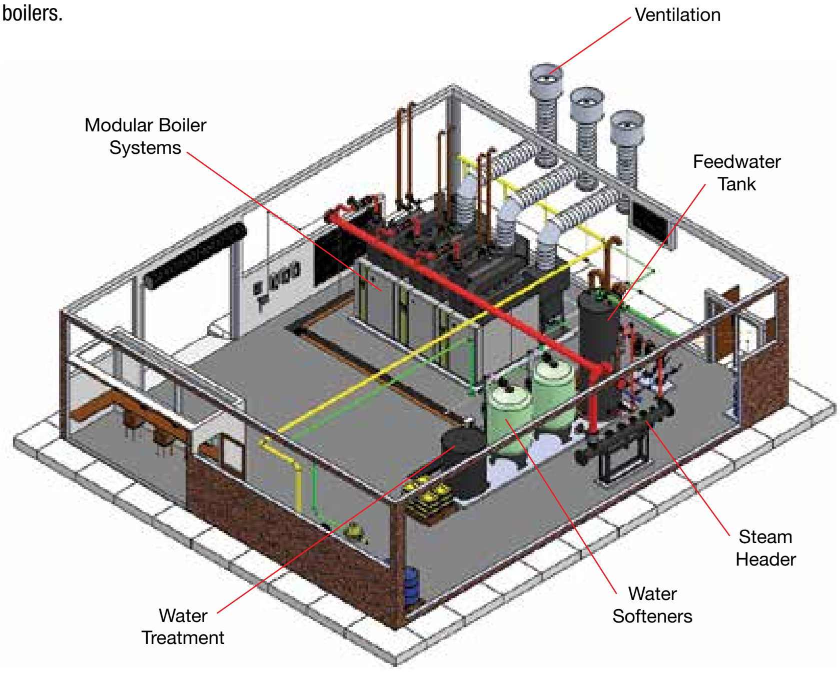
Steam and condensate

When selecting a new steam boiler, you must consider how the steam will be used and how the condensate will be returned to the boiler room. Some processes have zero condensate return, and some have 100% condensate return.

As mentioned previously, steam — like any other liquid or gas — flows from areas of high pressure to areas of low pressure. Naturally, the steam pressure is at its highest as it exits the boiler. The higher pressure in the boiler forces the steam out through the main steam line. The steam is piped to points that require its energy and, as the heat and pressure are transferred to the various plant equipment or processes requiring energy, the steam condenses into liquid, which is

▼ **Figure 5.** A single automation system can control several modular boilers.





▲ **Figure 6.** Compact modular boiler designs utilize a low-volume pressure vessel and have output capacities comparable to much larger traditional boilers. The smaller boiler footprint provides design flexibility, lower construction costs, and more options within small spaces.

transferred via the condensate system. You need to be attentive to steam traps and their maintenance *(3)*, because they help remove the condensed steam from the steam line so that it does not cause damage elsewhere in the steam system (Figure 7).

The condensate system is usually at atmospheric pressure. In some low-pressure, saturated-steam heating applications, the steam distribution piping may be configured to slope back to the boiler so that the steam distribution piping also acts as the condensate return piping (*i.e.,* a single-pipe system). Other low-pressure applications may employ a two-pipe system with separate steam supply piping and condensate return piping, with the condensate system open to the steam system. As heat is transferred from the steam, condensate forms and collects in discharge legs. Once enough condensate has accumulated, a steam trap drains the condensate to a smaller condensate receiver or directly to the central condensate receiver. A series of pumps in the condensate-feedwater system then transfers the condensate from the central condensate receiver to the boiler.

Ideally, the amount of steam flowing from the boiler and the amount of water pumped back to the boiler would be equal in a closed-loop system. In reality, every system has losses due to leaks, blowdown, steam trap losses, and blowoffs due to excess pressures. And, a real system needs to have chemicals added and impurities discharged. You need to consider all of these additions and losses when determining the amount of makeup water that is required, as well as the size of the feed tank or deaerator.

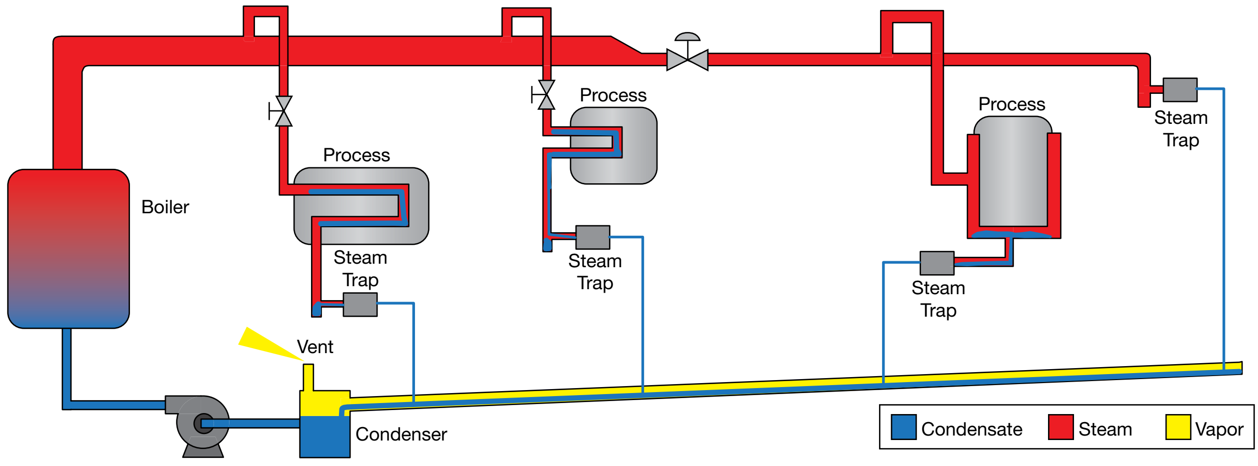
Makeup water must be added to the boiler water system periodically. Knowing how much should be added and how often enables you to benchmark your operation and monitor the health of the steam system. For example, if you typically add 700 gal per week to the steam system, and one month you notice that you had to start adding 2,000–3,000 gal per week, you need to determine the reason for that change. Water loss is a serious issue that should not be overlooked.

Boiler water chemistry

Chemistry is vital to keeping the capital investment in your steam boiler from being destroyed in a few years. But how much chemistry do you need to know?

Do you need chemistry control? Yes. Do you need to hire a chemist? No. Over the years, monitoring the chemistry of boiler rooms has become less cumbersome. It used to be that a plant needed an onsite chemist to take samples, analyze the samples in an onsite laboratory, and adjust the chemicals from in-stock inventory to meet the boiler manufacturer's specifications. Now, you have options. You can hire a third-party company to perform sampling and adjustment of chemicals, using the chemical companies they prefer. You can take water samples and mail them to a company to analyze them for you, and make your own adjustments based on their evaluation. You can use more advanced chemical analysis equipment to take automated measurements, and upload them in real-time to a chemical supplier's website. Or, you can use a combination of these approaches.

One of the most important aspects of boiler water chemistry is preventing oxygen from interacting with the hot metal in the boiler. This can be achieved by using a deaerator, an oxygen scavenger, or a chemical that inhibits the oxygen from interacting with the boiler, or a combination of these methods. You will most likely also need a water softener, depending on the hardness of the water in your area. Hard water can create scale in your boiler, which reduces the heat transfer and the boiler's efficiency. Scale causes the metal heat-transfer surfaces within the boiler to



▲ **Figure 7.** Steam traps remove condensed steam from the steam headers. Condensate flows to a condensate return line and can be recycled back to the boiler.

absorb more heat, which requires higher temperatures to maintain operation. This extra heat absorption causes additional damage, such as warping of metal surfaces and damaged seals and gaskets. These issues, if left unchecked, could lead to a pressure vessel failure or even a boiler explosion.

The pH of the condensate water is typically low, because as steam condenses, carbon dioxide reacts with water to form carbonic acid. Thus, condensate treatment is necessary to raise the pH and protect the condensate pipes from corrosion. The pH in the boiler should be higher than the condensate pH for several reasons, but mainly to avoid an acidic water environment that can cause corrosion of the pressure vessel. Some water treatment programs use two chemicals to adjust pH in the boiler and condensate, while others require three or four.

Consider which services a water-treatment chemical supplier can provide that will be the most beneficial to your team. Each chemical company offers something unique based on its specialty. Some can perform daily or weekly sampling, while others employ automatic sampling equipment. For example, automatic pH sensors, automatic hardness sampling stations, and other sensors can be connected directly to the process monitoring systems or to websites hosted by the chemical manufacturer that are updated as information is received. Some chemical dosing systems can be programmed to automatically adjust the chemical addition rate based on steam usage.

The National Board of Boiler and Pressure Vessel Inspectors has published a manual *(4)* for understanding water chemistry operating ranges (or bands). Boiler manufacturers specify chemistry operating bands specific to their boiler design that the water must be kept within. If your chemical supplier provides chemistry reports, it will be easy for a maintenance person to see whether the system is doing well or if an adjustment is needed. Additionally, some boiler manufacturers provide chemicals specifically for their boiler systems, and guarantee that those chemicals will work for their boiler.

When choosing a company to monitor and maintain the water chemistry of your boiler system, ask these questions:

• Will the company provide you with chemistry results to double check their work, or will they just tell you to buy more chemicals?

• Do they help you understand what water health means for your boiler system?

• Will the chemical service provider guarantee that there will never be any corrosion in the boiler if you use its chemicals as instructed? Look for a company who makes this (or a similar) claim.

Closing thoughts

What are you getting for your money? Do you know what you need? Are the companies involved giving you what you asked for? If not, choose another company. Do you have to keep a boiler warm 24/7, just in case? That takes a lot of energy and wastes money. There are many ways to save money, but you must weigh the cost vs. gain for almost every option that goes into a boiler system.

What you spend now will pay off in the future. It is important to understand where money is being lost. Tracking boiler efficiency is one way to do that. Steam boiler efficiency can be calculated by:

$$\text{Steam Boiler Efficiency \%} = \frac{\text{Heat exported by outlet steam}}{\text{Heat supplied by fuel}} \times 100$$

This equation enables you to determine how much of the fuel you are paying for is actually being used to heat the process. Or, conversely, it allows you to figure out how much fuel is being wasted.

This article just scratches the surface of what you need to know and consider when embarking on a boiler system project. Now, it's time for your team to answer the basic questions (or hire someone to answer them for you), set some realistic deadlines, and try to complete the project on time. You will need the assistance of the boiler manufacturer to teach you the maintenance and supplemental support information for your new system. Don't be too proud to ask for help from those with more experience. Learn as much as you can, so you can pass this knowledge on to someone else. CEP

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