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Better Understand Boilers

A number of factors affect selection, performance, reliability and safety

By Amin Almasi, mechanical consultant

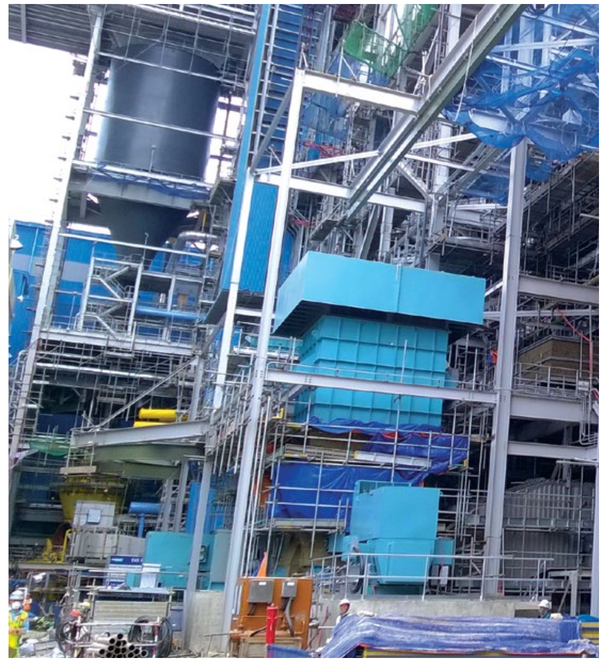
Steam finds wide use in chemical processing for applications ranging from heating fluids to driving equipment. The boilers that generate this steam from water come in many different varieties and sizes. So, here, we'll look at the types and designs of boilers for process plants, as well as issues related to their safety, reliability and efficient operation. We'll also discuss accessories and condition monitoring.

First, let's go over some basics. Only purified water should serve as boiler feed water (BFW). The water may flow through, e.g., horizontal, vertical or spiral-wound tubes. The tubes may be smooth, ribbed, etc. Boilers rely on a combination of radiant and convective heat transfer; they consist of a furnace (hot gas) section and steam-containing parts (tubes, etc.). A lower mean temperature difference between the hot gas and the steam usually mandates an increase in the surface of tubing and boiler weight. High temperature boilers require special alloys such as nickel-based ones for their hot section.

Designers strive to optimize heat transfer and, thus, efficiency. Higher efficiency reduces the fuel input and the combustion product mass rates, which also means less pollution and emissions. It also translates into a smaller size boiler.

VARIANTS

Boilers come in many different types and designs. A commonly used configuration uses a steam drum. In this type, the water enters the boiler through a section in the convection pass called the economizer. From the economizer, it passes to the steam drum. Once there, the water travels via downcomers to the lower inlet water-wall headers. From these headers, the water rises through the water walls and eventually changes into steam due to the heat generated, for instance, by burners. This steam enters the steam drum. It moves through a series of steam and water separators and then dryers inside the steam drum. These remove water droplets from the steam and then the cycle through the water walls is repeated. Forcing the water to the boiler usually requires a special set of feedwater pumps.



BOILER TYPES
Figure 1. Boilers come in many different types and designs.

Many large boilers have a steam drum and use water tubes embedded in the walls of the furnace combustion zone; these units come in different layouts and arrangements to allow picking a configuration offering the best efficiency for a specific application. The saturated steam from the steam drum flows through tubes heated by the hot combustion gases, becoming superheated. The hot gases also preheat the steam entering the steam drum and the combustion air going into the combustion zone.

Another variant is a simpler design known as a once-through boiler. This system has no steam drum. The water goes through the economizer, the furnace wall tubes and the superheater section in one continuous pass; there's no recirculation. Here too, a set of feedwater pumps supplies the motive force for the flow through the boiler.

Dried steam is essential for many applications. For instance, any droplets of liquid water carried over into a steam turbine can produce destructive erosion of the turbine blades. Therefore, the boiler system must generate dried superheated steam.

SUPERCRITICAL ONCE-THROUGH BOILERS

At the critical point of a fluid, distinct liquid and gas phases don't exist and there's no phase boundary between liquid and gas. As the critical point is neared, the properties of the gas and liquid phases approach one another. At the critical point, only one phase exists, a homogeneous supercritical fluid. Some engineers call systems using this approach steam generators, not boilers, because they don't actually boil water. However, the term boilers is widely used for them and, so, we'll refer to them as boilers in this article.

For large supercritical steam boilers, the once-through configuration is the preferred option as there's no need for a steam drum or similar provisions because separate liquid and gas phases don't exist.

A supercritical steam generator operates at pressures above the critical pressure, say, around 220 Barg. Liquid water immediately becomes steam. The efficiency of the overall operation exceeds that of a subcritical steam system.

Other factors also favor supercritical once-through boilers. For instance, by obviating steam drums, these systems avoid the problems and potential incidents (including catastrophic explosions) often posed by steam drums.

Such systems typically involve water entering the boiler at a pressure above the critical pressure, getting heated to a temperature above the critical temperature (say, to 375°C) and then being expanded to dry steam at some lower subcritical pressure. This can occur via different configurations, for instance, a throttle valve located downstream of the evaporator section of the boiler.

Many supercritical once-through boilers used in plants have pressures in the range of 250–350 Barg and temperatures of 500–650°C, well above the critical point of water. However, opting for more moderate conditions, say, just above 240 Barg and 500°C, reduces operational complexity and improves reliability. The high-pressure steam generated can undergo step-by-step reduction to provide medium- and low-pressure steam if needed.

The primary disadvantage of supercritical steam boilers is their need for extremely pure BFW, say, on the order of about 0.1 ppm by weight of total dissolved solids (TDS). Another challenge is operation at part load. At full load, the mass of fluid in the tubes avoids excessively high temperatures. However, at part load, the lower volumes of delivered water and generated steam raise the chance of overheating.

So, an important consideration is how the boiler would operate at partial water flow. A traditional method of part-load operation uses sliding pressure control, with progressive reduction in operating pressure, to minimize temperature variation of the generated steam. When the pressure in the furnace-wall tubes drops below the critical pressure, the mass required to avoid overheating increases dramatically. For this reason, a number of boilers operate with the furnace walls at full pressure and superheaters operating under sliding pressure.

This arrangement relies on a number of throttling duty valves, which can affect plant reliability, availability and maintenance requirements.

Some boilers instead use a spiral-wound furnace, with inclined tubes as opposed to vertical tubes. Such an arrangement reduces the number of tubes in the furnace and, hence, raises the fluid mass in each tube. At the same time, it increases the individual tube length; each tube passes through every part of the furnace heat transfer surface. This smooths out variations in heat input between, for example, mid-wall and corner locations because each tube passes through both regions.

Many different options exist for dealing with part-load operation, with the proper choice depending upon the specific boiler application.

SAFETY, RELIABILITY & OPERATION

Each year, numerous boiler accidents and failures occur. Most stem from malfunction of different parts, error in operation, poor maintenance, corrosion, etc. Properly functioning control and safety devices are absolutely essential. In addition, you must establish and enforce regular testing and verification regimes to provide confidence the safety and control features will work when needed.

Safety or relief valves usually serve as the primary safety feature on a boiler; these valves prevent dangerous over-pressurization. Safety valves are required in case there's failure of pressure controls or other devices designed to control the firing rate. If something goes wrong, the safety valve is designed to relieve all the pressure generated within the boiler. So, you should think of the safety valve as the last line of defence. It should have sufficient relieving capacity to meet or exceed the maximum burner output. Several factors, such as internal corrosion, restricted flow, etc., can impede the ability of a safety valve system to function as desired. Internal corrosion is probably the most common cause of freezing or binding of safety valves. Keep all safety valves free of debris or foreign materials and test their operation regularly. It's not good practice to operate a boiler too close to the safety valve setting. This may cause the valve to leak slightly, resulting in an internal corrosion build-up that eventually will prevent the valve from operating. As a very rough indication, a boiler's steam pressure often is maintained at approximately 75–80% of the safety-valve set pressure.

Water flow or level control and low-water fuel cut-off usually serve as the other important control and safety features of a boiler. These devices perform two separate functions. However, on very simple and small boilers, they often are combined into a single unit that provides both a water control function

The majority of boiler troubles, failures and accidents are avoidable.

and the safety feature of a low-water fuel cut-off device. However, for many boilers, two separate sets of devices should handle these two functions. Usually, a boiler, particularly a medium or large one, should have two independent low-water fuel cut-off devices (a primary and a secondary). Many codes and jurisdictions require two such independent devices on steam boilers.

Modern fuel systems for boilers are complex assemblies, consisting of both electronic and mechanical components. Many things can go wrong with a boiler's fuel system. For instance, ignition transformers may deteriorate or fail; ignition electrodes may burn and become coated; fuel strainers and burner equipment may clog up; fuel valves may get dirty and leak; air/fuel ratios may drift out of adjustment; and flame scanners may become dirty. A fuel system should incorporate many safety features. The burner system, in particular, requires periodic cleaning and routine maintenance. Failure to maintain the equipment in good working order could result in many problems such as excessive fuel consumption, loss of heat transfer or even an explosion.

The flow of water in different parts of the boiler as well as the temperature profile in the furnace and hot gas sections demand care; these are key operational parameters that require measurement. For example, stack temperature reflects the temperature of the flue gas leaving the boiler. A higher-than-usual stack temperature indicates the tubes may be getting a build-up of soot or scale and inefficiencies exist in the heat transfer regime.

The majority of boiler troubles, failures and accidents are avoidable. One of the most effective tools to prevent such problems is condition monitoring. Most boiler problems and issues don't occur suddenly but develop slowly over a long period of time. The best way to detect important changes that may otherwise go unnoticed is to comprehensively record condition data and carefully evaluate those data periodically.

For the best performance, safety and reliability, maintain the fire in the furnace section as uniformly as possible to avoid an excessive rate of combustion, undesirable variations in temperature, and possible explosions. The destructive force in a boiler explosion comes from the instant release of energy whether in combustion system or steam sections. ●

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Cure Steam Heater Burping

Understand how this ailment can arise

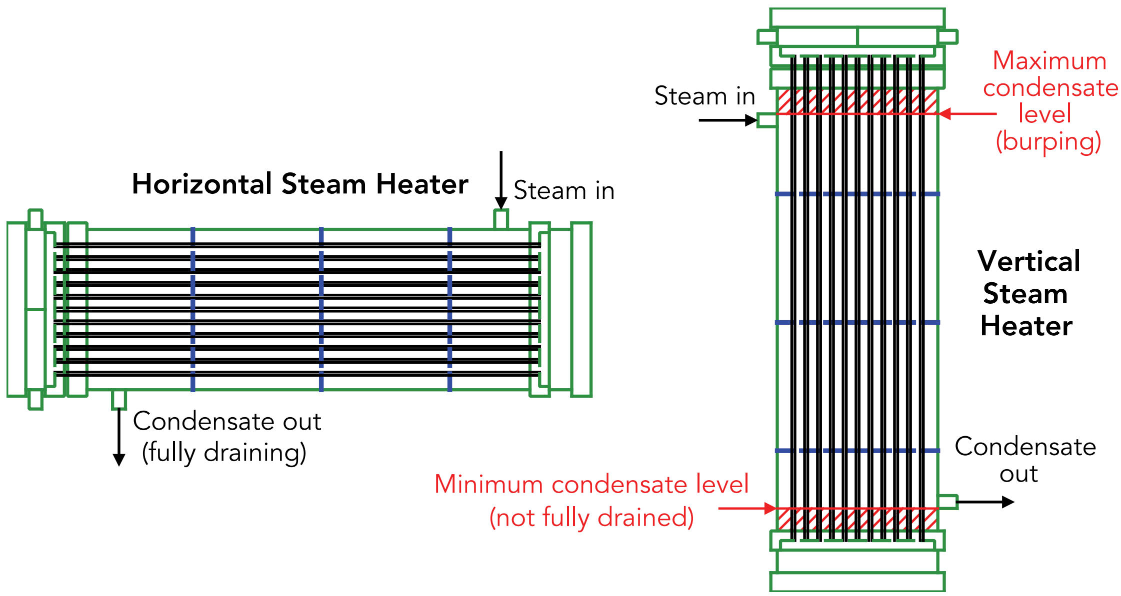
By Andrew Sloley, Contributing Editor

Plants often use steam to handle process heating duties because it's relatively cheap and has high heat-transfer coefficients. Such duties include both sensible heating and vaporization (reboilers, vaporizers and evaporators).

While most shell-and-tube exchangers are installed horizontally, smaller units or ones in constrained areas may have a vertical orientation. Figure 1 illustrates the steam configuration of both horizontal and vertical shell-and-tube exchangers.

Both exchangers use a tube support rather than a baffle configuration on the tube side. Because the duty comes from condensing steam, the steam side of the exchanger is isothermal. With a constant temperature on the steam side, baffles on that side offer no heat transfer benefit. Configurations with baffles may make sense if subcooling the condensate is necessary. Here, we'll restrict ourselves to the simpler configuration that uses tube supports and lacks baffles on the steam side.

The most common methods of duty control in a steam heater are to vary the pressure of the steam or the condensate level in the exchanger (see: "Don't Let Heater Control Get You Steamed," http://bit.ly/2LSbcO6). Varying the pressure changes the steam temperature to control the duty. Varying the condensate level changes the surface area split between condensing (with a high heat-transfer coefficient) and condensate subcooling (with a low heat-transfer coefficient) to control the duty.



STEAM FLOW IN SHELL-AND-TUBE EXCHANGERS
Figure 1. Horizontal exchangers fully drain condensate but vertical units do not.

Horizontal exchangers have a full range of operation for both control systems. As shown in Figure 1, steam enters the top of the shell and condensate leaves the bottom. In a properly configured unit with correctly sized tube supports (or baffles) and nozzles, the exchanger has full flexibility to drain condensate from the top edge of the tube bundle to the bottom edge. With pressure control, the entire surface is available for condensing at all times. With level control, the condensate level can move from below the bottom tube to above the top tube without a problem.

Vertical exchangers lack this capability. Nozzles on the shell have a minimum offset from the head flanges due to fabrication welding requirements or clearances necessary for bolting and piping attachment. This nozzle offset can create limits or problems for both minimum and maximum exchanger duties.

At the bottom of the exchanger, some tube surface lies below the level of the nozzle. This section of the exchanger always holds some condensate. So, the effective maximum surface area of the exchanger never equals the actual physical surface area. This loss of area may be small — but will limit maximum exchanger heat duty.

At the top of the exchanger, some surface area lies above the level of the steam-inlet nozzle. For pressure control systems, this

Some vertical exchangers are susceptible.

surface area is available for heat transfer and, so, doesn't raise any special issues.

However, with condensate level control systems, it can pose a problem. If condensate level reaches the top of the nozzle, the condensate will prevent steam from entering. Steam trapped in the vapor space above the condensate may continue to condense, lowering the pressure above the condensate. Once the pressure above the condensate drops enough to offset the condensate's static head, steam flows again. This flow is temporary, though, because the incoming steam causes the pressure above the condensate to rise. The exchanger burps, with steam entering intermittently. In some instances, such burping can lead to control problems and exchanger damage.

The burping problem occurs at low exchanger duties. It's most common at low rates, startup and when other exchangers in a heat-integrated network have higher-than-normal performance. Trim duties in steam heaters may be very low in these situations, which may require temporary operation changes to decrease heat transfer effectiveness. One method to reduce burping is to lower steam system pressure — this will allow the condensate level to drop, thus avoiding the burping problem. ●

ANDREW SLOLEY is a contributing editor for *Chemical Processing*. He can be reached at ASloley@putman.net.

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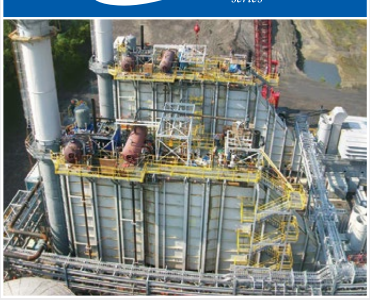

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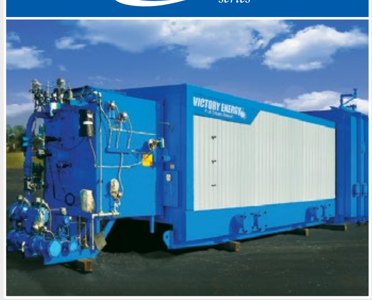

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FOLLOW A LEADER

When a Crisis Strikes, Be Ready

Secure your uninterrupted power supply before you need it

By Aaron Naylor, Indeck Power Equipment Co.

Throughout the life of your plant's boiler, there inevitably will be a need for temporary steam. Of the many reasons a plant needs a rental boiler, a global pandemic that requires essential companies to provide services that a whole country relies on undoubtedly is a stressful cause.

With any unplanned outage or power deficit, time lost is money lost. In the wake of a crisis, it is critical to restore your plant's operating capacity as quickly as possible. Although all plant operation managers hope their facilities are out of danger, an optimistic outlook is insufficient in protecting your facility against extreme events. However, facilities equipped with comprehensive and well-practiced emergency plans can restore their plant's power capacity efficiently and safely after an unforeseen event occurs.

Incorporating the guidelines below will help to ensure your plant's crisis plan is comprehensive so that you can bring your plant online quickly and continue serving a country in need.

KNOW YOUR FACILITY AND ITS EMERGENCY PLANS

The most effective time to prepare for a disaster is before one occurs. When it comes to reducing plant downtime, having staff well-versed in your facility's disaster preparedness plan is just as critical as the plan itself. Emotions can run high in times of crisis, and keeping a checklist of items that need to be addressed is highly effective in eliminating oversights in your facility's pre- and post-emergency event procedures.

For critical equipment, it does not hurt to double-check that protection procedures have been properly implemented.

SECURE YOUR UNINTERRUPTED POWER SUPPLY IN ADVANCE

The underlying goal of a facility's disaster plan is to have backup, so build an emergency rental package before the crisis escalates.

If you purchased your equipment from a single-source steam/hot water provider, that provider will have a detailed history of your plant's equipment. From this information, the company will be able to build out a flexible emergency rental package.

Open communication is key in delivering the necessary equipment. Most emergency rental boiler providers can deliver trailer-mounted boilers (superheat or saturated steam) in a few days (Figure 1).

Effective emergency preparedness plans have protocols in place that allow for quick identification and communication of a plant's temporary power requirements to their temporary steam provider.

Additionally, partnering with a single-source steam and hot water provider allows for integrated emergency service scheduling with their in-house transportation and rental departments.

PREP YOUR SITE FOR HOUSING TEMPORARY STEAM

Single-source steam power providers may be able to provide clients with a contingency planning quotation that includes a forecast of installation and utility requirements, which allows those clients to prepare their sites proactively. With this resource forecast, clients can account for the required tie-ins so boiler installation/start-up runs smoothly soon after the boiler arrives.

ESTABLISH A REALISTIC TIMELINE FOR RECOVERY

Keep in mind, during these unprecedented times, your facility may be short-handed. Employees who work at your facility might become affected by the pandemic and be unable to return to work immediately.

A plant's crisis recovery timeline will account for a reduced labor force as well as post-event vulnerabilities. This, in turn, will allow a plant's operational manager to set realistic expectations as to when all permanent equipment will be fully operational.

BEFORE STARTING YOUR BOILER BACKUP

Like the start-up of your emergency temporary equipment, ensuring your permanent boiler can be turned on safely is key. A

MOBILE BOILERS
These trailer-mounted boilers are ready for quick deployment if an emergency arises.

thorough check of your boiler's internal components should be conducted as well. All fixed components should be confirmed to be level. If any of your boiler's parts need to be replaced, contact a steam power provider for replacement parts.

If you have a reason to believe any of your control system's digital or electrical components are malfunctioning, consult with the manufacturer to run a program reset/diagnostic report before operating.

PLANNING IS KEY

When a crisis strikes, it comes at a great expense — financially, physically and emotionally. Having a crisis preparedness plan is key in reducing time lost and minimizing physical damage when an unexpected outage occurs. An easy-to-follow, well-practiced contingency plan addressing how to prepare your plant is critical to bringing your equipment back online quickly and safely.

Partnering with a full-service steam and hot water provider to create a comprehensive emergency temporary steam package for your facility can bring peace of mind to plant operators and added value to a plant's emergency preparedness plan.

AARON NAYLOR is service manager for Indeck Power Equipment Co. Email him at anaylor@indeck-power.com.

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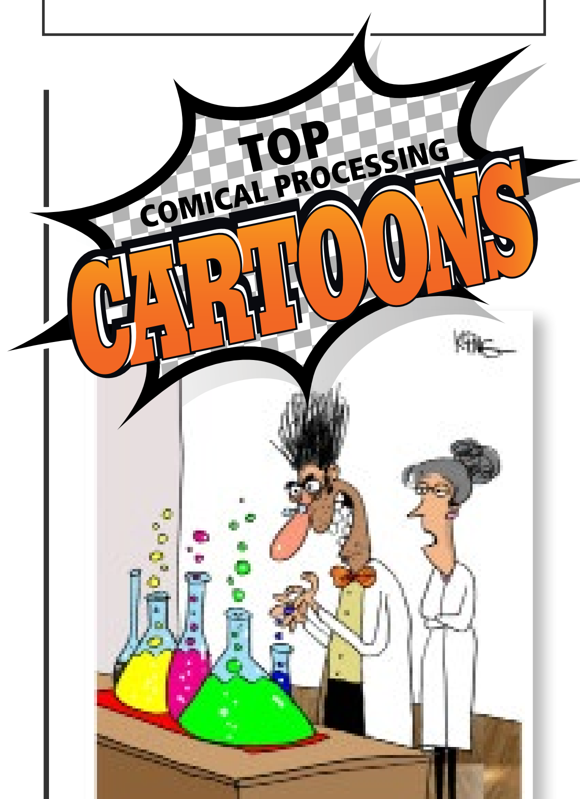

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