WATER TUBE BOILER CHARACTERISTICS AND TERMINOLOGY

INTRODUCTION

This section introduces large and highly specialized water tube boilers, such as those found in power plants, to loss prevention personnel who are not familiar with such boilers. It is a practical introduction to a complex subject. For more information on boiler theory and design, consult a standard text on the subject. For information about a specific boiler type or installation, consult the manufacturer's literature.

Every boiler has unique features mandated by variations in fuels, operational demands, manufacturer's idiosyncrasies and local prejudice; however, there are many common points. Not all boilers have all the features this section describes, and some boilers have specialized features and requirements that are not discussed. Black liquor recovery boilers, for example, have specific critical needs and requirements associated with their fuel and combustion products.

Where boiler operational needs can conflict with overall facility needs, additional analysis is required to determine whether added safety devices or alternate flow paths are needed. For example, in some applications, fuel or waste heat disposal or processing is more important than the generated steam. Alternate fuel storage or alternate ways to use or dispose of steam, fuel or waste heat may be needed to allow safe facility operation or shutdown with the boiler off line. If no alternative operating scheme can be found, the facility will have to shutdown if the boiler cannot operate.

Water tube boilers have water or steam inside tubes and the products of combustion or other heat source outside the tubes. While water tube boilers can be classified in many ways, this section separately considers only "once-through" boilers and coil-type boilers.

Water tube boilers are used for steam, hot water heating or organic fluid service. This section assumes steam service unless otherwise noted. See PRC.7.1.5 for more information about organic fluid systems. Although they are not the focus of this section, a few of the problems presented by small packaged water tube boilers and coil-type steam generators are identified.

CONSTRUCTION

The tubes in a water tube boiler are connected to **drums** and **headers**. Drums are cylindrical pressure vessels mostly ranging from 24 in. – 60 in. (60 cm – 152 cm) diameter. Headers are generally 12 in. (30 cm) diameter or less. Modern drums and headers are made of formed steel parts assembled by welding. Both generally have dished heads, though headers occasionally have flat heads. All steam boilers, except once-through boilers, have at least one steam drum. The steam drum(s) are at the highest elevation of the steam generating portion of the boiler and are where the generated steam is disengaged from the water. Most boilers have a mud drum, where sediments and solids tend to collect. This drum is located at the low point of the steam generating portion of the boiler.

Boiler tubes which are not connected to drums are connected to headers. The distinction between a drum and a header is arbitrary; practically speaking, a drum has a manway for personnel entry and a header is too small to enter. Boiler tubes are connected to drums and headers three different ways:

- “Rolled” or expanded tubes are mechanically attached by placing the tubes in holes and expanding them with a special tool. Most “tube rollers” or expanders have three parallel hardened steel rollers arranged in a circle in a frame. An operator inserts the frame with the three rollers into a tube end, than drives a tapered rotating mandrel into the space in the middle of the rollers. This rotates and separates the rollers, forcing the tube to expand against the hole.
- Strength welded tubes are welded with full penetration welds into specially prepared holes.
- Rolled and seal welded tubes are first mechanically attached using a roller and then seal welded. The distinction between this and the previous method is the type of weld used. A seal weld only prevents leakage; it is not strong enough to hold the tube in the hole. The roller does that.

The method used is the manufacturer’s choice; there are no clear rules. The higher the pressure, though, the more likely the strength-welded attachment. Also, rolled tubes are sometimes seal welded as part of a repair when, because of wear, hole distortion or excessive rolling, the repair concern cannot obtain a leak-free rolled connection.

Drums and headers and often the attached tube ends are protected from significant heat flux by insulation, either brick, “plastic” refractory or insulating batting.

Tubes are named by location or by the nature of the flow they are designed to carry. **Downcomer tubes** are located in relatively cooler parts of the furnace, or are somewhat isolated from the furnace by baffles, or occasionally are located outside the boiler casing. They are intended to carry water down to the mud drum or the lower headers.

Generating tubes are located in hotter areas and carry water upwards. They will also receive enough heat flux that boiling will take place in them. This means that, at higher elevations in the generating tubes, there will be an increasing percentage of steam mixed with the water. If a boiler is severely over fired, the top ends of the generating tubes may be dried out enough to overheat, loosen and fail.

Waterwall tubes are located around the outside of the furnace. Whether they serve as downcomers or generating tubes will depend upon their location and the heat transfer rate.

The steam/water mixture from the generating tubes enters the steam drum(s), where various separators direct the steam out of the boiler and the water back to the downcomers. Whether baffles, chevron separators (“scrubbers”) or centrifugal separators (“cyclones”), they all direct the mixture through a tortuous path, using the difference in density between steam and water for disengagement.

CIRCULATION

Internal circulation is a critical feature of water tube boilers. Most boilers rely on natural circulation, which is driven by the density difference between hotter and cooler water. Cooler water, mixed with the incoming feed water, flows down a portion of the tubes (downcomers) connected to the steam drum. Hotter and less dense water flows upward in tubes (generating tubes) located in hotter areas of the boiler.

Some boilers are designed with forced circulation; they employ pump(s) to circulate the water inside the boiler. For such boilers, the circulating pump(s) are critical objects requiring reliability standards similar to those for main feed pumps. In all cases, proper heat removal from the boiler depends upon proper internal distribution and flow of water, proper rate of heat transfer in all areas, and proper heat input from the fire side.

Internal water distribution is controlled by the designer. For all boilers, the size and number of tubes in each group or “bank” controls the ease of water flow. In natural circulation, the difference in temperature between banks provides the driving force for the flow. Forced circulation boilers additionally contain orifices to distribute the circulating pump discharge. Entry of feed water at the correct location, properly distributed, is necessary for proper circulation in all cases.

Maintenance of baffles provided to control circulation is also necessary for safe operation. Control of water chemistry is also important. Excessive loose scale or sediment accumulation in mud drums or headers may retard circulation enough to cause loosened tubes or other damage.

WATER LEVEL CONTROL

Maintaining the correct water level in the steam drum is critical. If the water level is too low, the top ends of the tubes will be dried and will overheat. This is because steam is a much less effective heat transfer medium than water. If the water level is too high, the separators will flood, and **carryover** will result. This means that water will leave the boiler with the steam, possibly damaging piping, valves, and the equipment served. Steam turbines are especially susceptible to carryover damage.

It is imperative that the water level gauge image be available to the operators. Because control rooms are generally at the ground level and water tube boilers can be several hundred feet high, technology is required. Either mirrors, closed circuit television or fiber optics may be used. Because gauge glasses exposed to very high pressure steam tend to have leakage problems, other level detecting systems have been developed.

ACCESSORY DEVICES

Soot blowers are installed in most large, solid fuel and heavy (#6) oil fired water tube boilers to control accumulation of combustion products on the tube firesides. Soot blowers usually consist of a series of nozzles located on headers which extend through the firebox or gas passes. The nozzles are carefully aligned so that the blowing medium, usually superheated or dry saturated steam, passes between the tubes. Maintaining soot blower alignment is critical, because the stream will rapidly cut through any tube on which it directly impinges. Tubes near the soot blower nozzles may also be shielded.

Most water tube boilers in steam turbine power plants have **superheaters**. These devices raise the steam temperature above its saturation temperature. They consist of tubes and associated headers which are located in a hot portion of the boiler. There may be more than one superheater section, the first called the primary superheater and the other the secondary or finishing superheater. The secondary superheater will be located in the hottest part of the boiler with the primary superheater located further downstream, where the products of combustion are slightly cooler. Abnormally high or low temperatures can cause problems with the boiler and downstream equipment, particularly turbines. Therefore, adherence to design superheat temperature is critical.

Because superheater tubes operate at higher temperatures than other boiler tubes, they are often made of high alloy steels. These steels, while resistant to various types of elevated-temperature induced conditions such as creep rupture, are much more difficult to fabricate and assemble.

High alloy tubes are often susceptible to failure caused by chloride stress corrosion. This is a form of cracking which may occur in some stainless steels after any exposure to chloride ions. Accordingly, tubing intended for installation in a superheater must be carefully handled to avoid any contact with chloride-containing substances. Also, the water used for superheater hydrostatic tests must be particularly pure. Contamination precautions must be carried to extremes; failures have been documented that resulted from marking on tubing with ink that was not chloride free.

In addition, superheaters must be carefully handled during shutdowns to minimize a condition known as exfoliation. Exfoliation results when corrosion products formed because of the different conditions present during shutdown break loose during operation. The resulting debris can seriously erode the first stages of a turbine.

Superheater design presents various other challenges. Because the metal operating temperature is much higher than that of other tubes, thermal expansion is a more serious problem. For this reason, superheaters in most modern boilers are “pendant.” This means that the headers are located in the top of the boiler furnace and the tubes form a series of vertical hairpins before returning to the headers. As a result, any water that gets into the superheater, whether for hydrostatic tests or because of condensation during startup or shutdown, will not drain out. Strict precautions are necessary to keep any accumulated water from being blown into the steam mains or, for boilers which are intermittently fired, to prevent freeze damage in cold weather.

Superheater tubes depend upon steam flow for cooling. Accordingly, the safety valve installed at the superheater outlet must be the lowest set safety valve on a boiler with a superheater. This lower setpoint will cause the superheater outlet safety valve to lift first, ensuring flow through the superheater even if all normal steam flow from the boiler is shut off.

Most utility boilers have one or more reheat superheaters, normally called **reheaters**. Reheaters raise the temperature of steam which has passed through a portion of the turbine. The reheater for the highest pressure steam will often be located near the finishing superheater and any other reheaters will be located further downstream.

Although superheater or reheater outlet temperature is determined by the balance between steam flow and flue gas temperature, which in turn is controlled by furnace heat release rate and heat absorption rate in the various boiler sections, some additional control may be necessary under some conditions. This control may be accomplished with an **attemperator**, a device which injects feed water into the steam flow upstream of the superheater or reheater, or a portion thereof. The water will flash into steam; the latent heat thus absorbed will reduce the steam temperature at the superheater or reheater outlet.

A similar arrangement may be employed to provide saturated steam to plant auxiliary turbines that are not designed to handle superheated (main) steam. In this case, the feedwater is injected into a main steam branch line, and the device is known as a desuperheater.

Attemperators and desuperheaters require carefully designed control and protective equipment to prevent passing water or cool vapor to downstream components. Problems are most likely to occur during startup, shutdown and low-load conditions.

The **economizer** is usually the last boiler section for heat transfer to the steam system. Although the economizer is nearly the last boiler section in terms of flue gas flow, it is the first section in terms of feedwater flow. Economizers are seldom troublesome except in boilers which operate intermittently or at reduced loads. Because economizers are located near the boiler flue gas outlet, they may be at risk of freezing when the boiler is not operating in cold weather. They may also be subject to severe external corrosion caused by condensed moisture under similar conditions. Economizers frequently contain “extended heating surface” or finned tubes. This type tube is susceptible to fire side fouling and may be particularly susceptible to corrosion.

Most large boilers contain one additional heat exchanger in the flue gas path, the **air preheater**. This unit uses the last of the useful heat in the flue gas stream to preheat the combustion air. Most large preheaters are of the rotary type. They contain a heat transfer medium, usually a steel mesh, that slowly rotates from the flue gas stream to the inlet air stream. If a loss of station power occurs, emergency arrangements are necessary to keep such preheaters rotating to prevent melting the transfer medium. Preheaters and economizers may, under some conditions, operate below the flue gas dew point. Corrosion may be a problem.

Figure 1 represents schematically a typical layout of the main parts of a large power generating boiler. While no real boiler will be exactly as shown, the arrangement of parts will probably be similar.

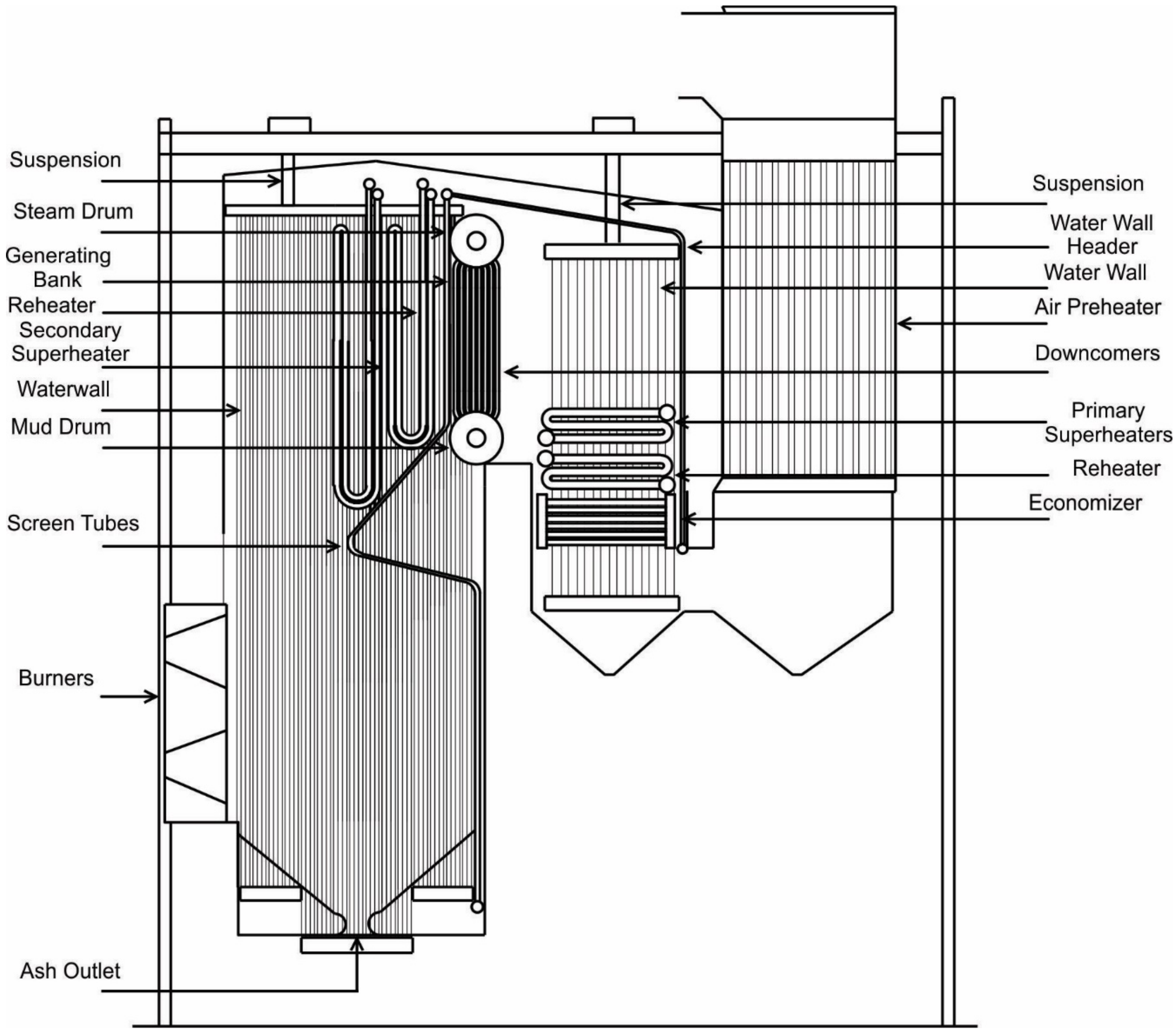

Figure 1. Schematic Representation Of A Large Water Tube Boiler For Power Generation.

COMBUSTION CONSIDERATIONS

On the combustion side, most water tube boilers employ a balanced draft system. Whether the furnace is designed for positive or negative pressure, the correct pressure is maintained by coordinated operation of a **forced draft (FD) fan** at the air inlet and an **induced draft (ID) fan** at the combustion product outlet. Because of its elevated temperature, the gas stream at the outlet has more volume and less density than the gas stream at the inlet; therefore, the ID fan must handle a greater volume flow rate at less efficiency than the FD fan. Also, the ID fan rotating element must be rugged enough to handle hot gases which are contaminated with particulate and possibly corrosive combustion products.

Scrubbers, precipitators or other flue gas treatment devices are normally located downstream of the ID fan.

ONCE-THROUGH BOILERS

In a once-through type boiler, water is pumped into a series of heat exchangers located in a furnace and superheated steam comes out. There are tube banks and headers arranged in sections as described previously, but no drums, no internal circulation and no fixed water level. Obviously, external water treatment is extremely important for such a unit, because no internal treatment is possible. Any contaminants in the water will either end up in the boiler, where they may foul the tubes and cause overheating, or pass out with the steam and cause turbine damage.

Startup and shutdown are interesting and hazardous operations with once-through boilers, because it is necessary to establish flow completely through the boiler before firing it and maintain flow after shutting down the heat source until the unit cools. For significant periods of time during startup and shutdown, hot water or low-quality steam that cannot be directed to the turbine will flow from the unit. This water or steam is hazardous and, because of its high purity and chemical content, it is too valuable to waste.

Therefore, there must be a recirculation flow path that will take fluid from the outlet and return it to the inlet during the startup before and during shutdown after the fluid at the outlet is superheated enough to send to the turbine. A flash tank is needed that will allow expansion during and after the transition from hot water to steam production. Finally, a suitable path to the condenser must be provided so that steam can be condensed and returned to the system until its quality and degree of superheat permit sending it to the turbine. Precautions are necessary to avoid turbine water induction, especially during startup.

The layout of a once-through boiler may be quite similar to that of Figure 1, except that there will be no steam or mud drum and no generating/downcomer bank.

PACKAGED AND COIL-TYPE BOILERS

Packaged water tube boilers are commonly used for steam and high-temperature hot water heating applications. A “packaged” boiler is a complete boiler with fuel train, burners and blowers in a single unit. Packaged steam boilers are generally natural circulation units consisting of a steam drum and a mud drum or lower headers, generating tubes and downcomers. Units designed to burn heavy oils or solid fuels generally have sootblowers. These boilers work very much like the larger boilers previously described, except that they usually do not have superheaters or reheaters. Packaged high-temperature hot water heating boilers are generally once-through type.

Coil-type boilers are generally small, sometimes portable forced-flow steam generators. They are very compact, but can produce large amounts of high pressure steam very quickly. They are often used for applications, such as steam cleaning, that do not return condensate. Therefore, external water treatment is generally required.

Because of the high heat concentration and compact design, coils that fail generally cannot be repaired. Facilities in which coil-type steam generators are important should therefore maintain a spare coil.