XL Risk Consulting

Property Risk Consulting Guidelines

A Publication of AXA XL Risk Consulting

PRC.7.1.0.3

BOILER FUNDAMENTALS

INTRODUCTION

This section describes features and operational concerns and introduces terminology common to most boilers. For a more technical treatment of the subject and additional information on boiler theory and design, refer to one of the standard texts on the subject. For information concerning a specific type of boiler or installation, consult the manufacturer’s literature.

A boiler transfers energy from combustion or a process stream to an operating fluid. Although water and steam are the most common operating fluids, organic liquids or molten metals and their vapors or molten salts may be used. Most statements made in this article for “water” and “steam” apply to other operating liquids and their vapors, however, other such fluids may require additional cautions and protective equipment. See PRC.7.1.5 for more information.

Boiler combustion or process aspects are generally considered separately from the mechanical or pressure-containment aspects. This article does not consider the heat input mechanism or its safeguards. See PRC.4 for information about fuel-firing systems.

BOILER CLASSIFICATION

There are two major boiler categories, low pressure and high pressure. Low pressure boilers, also called heating boilers, are:

- Steam boilers with an allowable pressure of 15 psi (1 bar) or less.
- Hot water boilers with an allowable pressure of 160 psi (11 bar) or less and an allowable temperature of 250°F (121°C) or less.

Steam boilers with a higher allowable pressure are called high pressure boilers and may also be called power boilers, even if the steam they produce does not generate power. Hot water boilers with higher allowable pressures or temperatures are called high temperature hot water boilers. Some boilers, such as organic fluid boilers, are designed to high pressure boiler standards regardless of their design pressure.

High and low pressure boilers are governed by different sections of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code). Section I is for high pressure or power boilers and Section IV is for low pressure or heating boilers.

There are three major boiler configurations: water tube; fire tube; and cast iron. Water tube boilers have water and steam inside tubes which are joined to drums or headers. These tubes are located inside a combustion chamber, furnace, flue space or product stream. Fire tube boilers have the combustion products or heat source inside tubes which are located inside a shell which contains the water and steam. Tubes are connected to tube sheets. Cast iron boilers consist of a number of hollow cast iron sections that contain the water or steam and are heated by a burner.

Most large industrial boilers and all large utility boilers are of the water tube type. Boilers in the medium range, both smaller industrial and larger heating boilers, are mostly fire tube type. Cast iron boilers are restricted to smaller heating applications, where they dominate. Cast iron boilers should not be used in any application that does not return 100% of the water or condensate or in any process application where the water or steam may be contaminated.

BOILER WATER RETURNS

Steam boilers may provide steam directly to a process, turbine or engine, or they may provide heat through a radiator, jacket or other heat exchanger. In most heating applications, the appliance have a steam trap installed at its outlet, which must be at the low point. A steam trap is a valve which opens to pass condensate but which will pass a minimum of steam. Properly functioning steam heating systems will return nearly all of the steam to the boiler in the form of condensate.

Steam traps are also employed in steam piping systems at valves, low points and other locations where condensate accumulations are likely. Condensate can accumulate during plant warm-up and cool down, and during operation, because of heat losses to the surroundings. If condensate is not removed from steam systems, water hammer results.

The condensate from heating appliances and drain points is collected in a tank, except in very small systems where the condensate may return directly to the boiler by gravity. In low pressure systems, the condensate is normally pumped to the boiler directly from the tank. In high pressure systems, the condensate is pumped to a deaereating feed tank, after which the condensate is called feed water. Exclusion and removal of air from a boiler system is an important part of minimizing the corrosion rate. The higher the pressure, the greater the damage a given percentage of oxygen will cause.

Steam supplied to loads such as turbines will either exhaust to a condenser, from which the condensate is pumped for deaereating and reuse, or will exhaust to a lower pressure system for further heat extraction.

Any system water loss must be replaced by a makeup system. Losses occur when steam or condensate leaks or when steam is supplied:

- Directly to a process.
- To a location from which condensate return is impractical.
- To heating applications where there is danger of contamination.

Makeup water for heating systems is added to the condensate tank or directly to the boiler. For high pressure systems, makeup feed is usually introduced to the condenser or the deaereating feed tank.

Hot water systems circulate water through the boiler and the radiators or heat exchangers served. Circulation is usually pumped, though natural convection is possible. Because the average system temperature will not be constant, the water will expand and contract. To avoid excessive pressure fluctuations, an expansion tank containing an air or inert gas cushion is provided. To maintain a minimum pressure and to provide makeup water for leaks, there will usually be a connection to a water source through a pressure regulating valve.

If the air cushion is lost, the condition is known as a water-logged expansion tank. Heating of the system will raise the pressure and lift the relief valve(s). Subsequent cooling will drop the pressure, requiring makeup feedwater. Operating in this condition may damage the boiler by thermal shock, and scale from the excess makeup will eventually foul the boiler.

PRESSURE CONTROL

Safe boiler operation requires pressure control within the design limits. Steam boilers require at least two pressure control devices, one for normal operation and one high limit backup control, and at least one safety valve. Hot water boilers require at least two temperature control devices, one for normal operation and one high limit backup control, and at least one relief valve.

Each boiler requires at least one pressure gauge which should have a range of approximately twice the intended working pressure, but at least 150% of the boiler maximum allowable working pressure. Hot water boilers should also have a temperature gauge which indicates the water temperature at or near the boiler outlet.

WATER LEVEL

Maintaining the correct water level in a steam boiler is critical. If the water level is too low, the top ends of the tubes or the top row of tubes will overheat, because steam is a much less effective heat transfer medium than water. Overheating may loosen or crack the tubes, causing leaks. In extreme cases, metallurgical damage or melting will occur. If the water level is too high, the devices intended to remove entrained water from the steam leaving the boiler will be flooded, and water carryover will result. This means that water will leave the boiler with the steam, possibly causing severe damage to piping, valves, and the equipment served. Steam turbines are particularly vulnerable to damage from water carryover.

The fundamental device for detecting water level is the gauge glass. It is imperative that the level gauge image be usable by the operators. For large water tube boilers, which may be as much as several hundred feet high with the control rooms generally at ground level, technology is required. Either mirrors, closed circuit television or fiber optics may be used. Because gauge glasses on very high pressure units tend to have leakage problems, other level detecting systems have been developed.

Although impractical for high pressure boilers, many Codes still require gauge cocks as a backup to the gauge glass. These are two or three small valves which can be opened to determine whether steam or water is present at their level. The cocks are located at heights corresponding to the proper operating water level range.

All boilers require at least one low water fuel supply cutout device (LWFCO or LWCO); any steam boiler which is not continuously attended should have at least two. A LWFCO shuts off the burner if the water level falls below the safe operating level. See PRC.7.1.0.6 for more information.

Hot water boilers may not have a gauge glass. They are, however, equally susceptible to severe damage caused by overheating in the event of low water. Therefore, they require at least one LWFCO which must be properly maintained.

HEAT TRANSFER

Proper heat input depends upon firing fuel of the correct combustion properties, mixed with the proper amount of air, at the correct rate. It also requires maintenance of any baffles provided to control the flow of combustion products in the boiler fire box, furnace or tube banks.

Proper heat transfer depends most upon the condition of the boiler tube surfaces. Scale and corrosion product deposits on the water side of the tubes may retard heat transfer sufficiently to cause overheating that will bulge, blister or rupture the tubes. Soot and corrosion product deposits on the fireside of the tubes will insulate the tubes, reducing efficiency. Deposits on either side of the tubes, in sufficient quantity, may unbalance the boiler internal circulation enough to cause extensive damage. Excessive deposits also may contribute to various types of local corrosive attacks and cracking.

Boiler water side conditions are controlled by controlling the water chemistry. In a steam boiler, water is evaporated and removed from the boiler. Any nonboiling material, such as dissolved mineral salts or oil, that is introduced with the boiler feedwater will remain in the boiler. If the feedwater contains mineral salts, or hardness, these will concentrate in the boiler. Some salts are particularly troublesome because their solubility decreases with increasing temperature. These salts will “plate out” at the hottest parts of the boiler, which are those with the most heat transfer. This “scale” fouls heat transfer surfaces, reduces efficiency, and will eventually cause boiler failure. Oil in a boiler will also foul the heat transfer surfaces. Oil may also mix with the boiler chemicals to form soap, which will cause foaming and carryover. Some feedwater contaminants, such as silica, can vaporize with the steam and condense in the system, causing damage.

Two main types of programs are used to control the water chemistry: internal and external. Internal water treatment involves addition of chemicals to the boiler. External treatment involves purification of water before it is introduced to the system.

Boilers in closed steam or hot water heating systems require very little chemistry control. After the initial system fill, little or no water is added. Should the system leak or otherwise lose water, however, makeup feed will be necessary. Unless the makeup water is unusually pure, external treatment is necessary to control the introduction of impurities.

There are many internal treatments available; however, all attempt to scavenge dissolved oxygen, minimize the corrosion rate, prevent scale deposition on the heat transfer surfaces, and control the cleanliness of the steam. Treatment chemicals are added by batch feeders or continuously by metering pumps.

Water chemistry control at some point requires removal of dissolved and suspended solids and sediments. This is accomplished by a blowdown, or controlled drain, of boiler water. Bottom blowdowns, through a connection technically known as the bottom blowoff line, are used to remove sediment and to make large corrections in boiler water dissolved solids content. Surface blowdowns are used to control floating and suspended solids and oil. Continuous blowdowns, from either the surface or bottom of the boiler, are sometimes used in conjunction with chemical metering pumps to attempt to maintain constant conditions.

Blowdown water must be piped to a safe and environmentally acceptable place. This usually requires a blowdown tank, which is a properly sized, atmospherically vented vessel per NB-27. The piping from the boiler to the tank and the tank elevation must be arranged so that the boiler can gravity drain for cleaning and inspection.

If internal and external chemistry controls fail to prevent excessive buildup of scale and other deposits, mechanical or chemical cleaning will be necessary. Neither evolution should be attempted by an inexperienced organization.

FEED AND MAKEUP WATER

Steam boiler operation requires a reliable water source:

- Suitable in quality.
- Sufficient in quantity to equal the rate of steam generation.
- Available at a pressure sufficiently higher than the boiler pressure to assure adequate flow.

All boilers need at least two feed water sources. For power boilers, the sources must be independent. This means that loss of a given power source can not effect both sources. This requirement is normally realized by having at least one steam driven and at least one electric motor driven pump.

Water returned from system appliances is called condensate; after treatment, usually in a deaereating feed tank, it is called feedwater. In heating systems, there is often no treatment, and both terms are used arbitrarily. In all cases, water introduced to compensate for losses, both by design and because of leakage, is called makeup feed.

Hot water boilers also require a makeup water source. For heating boilers, a connection to the domestic water supply through a pressure-reducing valve is usually satisfactory. High-temperature hot water boilers, and any other hot water boilers which are subject to damage if fired with insufficient water circulation, should be provided with a flow switch which is arranged to shut off the burner if the flow through the boiler drops to an unsafe rate.

Cast iron boilers require care in the introduction of makeup feed water. Some mineral salts come out of solution and form scale when heated. If the makeup water connection is made to a boiler section, this scale will accumulate at a place where it is difficult to remove it. Therefore, the makeup water connection should be in the return or feed line just upstream of the boiler, and the connection should be dismantled and cleaned whenever the boiler is inspected.