Avoiding Boiler Problems

By William L. Reeves, P.E.

Boilers represent large capital expenditures. Their operational reliability and availability are often critical to facility profitability. Therefore, training and developing personnel responsible for this equipment is essential. Failure to follow a few well-established practices can result in catastrophe. The most common causes of catastrophic boiler failure include: fuel explosion, low water incident, poor water treatment, contaminated feedwater, improper blowdown techniques, improper warm-up, impact damage to tubes, severe overfiring, improper storage, and pulling a vacuum.

Fuel Explosion
Fuel explosion in the furnace is one of the most dangerous situations in the operation of a boiler. Most fuel explosions in boiler furnaces are caused either by a “fuel-rich mixture” or improper purge techniques. A fuel-rich mixture occurs when high concentrations of unburned fuel exist in the furnace. Depending on the combustion control equipment, this can result from a variety of causes including instrument malfunction, fuel supply pressure variations, and equipment failure.

Many fuel explosions occur after a combustion problem that produces a burner trip. For example, when a fuel oil atomizing tip clogs and its spray pattern is disturbed, the resulting unstable flame can lead to flame failure. If fuel oil is sprayed into the furnace during successive attempts to relight the burner, a large inventory of vaporized fuel can accumulate. Unburned fuel can also accumulate if a burner operates for long periods of time with poor atomization.

A successful relight can ignite this potentially explosive inventory. Figure 1 shows the complete devastation of a utility boiler caused by a fuel explosion.

Unburned fuels in a furnace can ignite in a rapid or explosive manner. These events can be avoided by following a simple rule: Never add fuel or air to a dark, smoky furnace. Instead, “trip” the burners manually and purge the furnace thoroughly with air. Once this is done and the ignition problems are corrected, the burners can be relighted.

Low Water Incident
At temperatures above 800°F (427°C), carbon steel undergoes degradation that destroys its strength and integrity. Since typical furnace temperatures exceed 1,800°F (982°C), the cooling effect of water inside the boiler tubes is critical to prevent catastrophic damage. Continued firing of a boiler with low water will literally melt steel boiler tubes with the result closely resembling a spent birthday candle as illustrated in Figure 2.

To eliminate a low water incident, all installations should have low water cutouts. These could be conductive type or float-actuated type. Also, a critical part of the system is a push-button bypass, which allows routine verification of their functionality. The bypass system allows operating personnel to blow down the dead legs of the devices, thus purging the lines of sludge or buildup, and get an alarm trip to verify the integrity of the cutout devices without actually tripping the burner.

Poor Water Treatment
Water treatment removes ions from the boiler feedwater. Scale is primarily caused by hardness in the boiler water in the form of either calcium or magnesium. Scale buildup eventually leads to overhear-type tube failures. Boiler tubes rely on the water to keep them cool by removing heat transferred through the tube. A buildup of deposits inside the tubes produces an insulating layer, which inhibits this heat transfer process. If this continues long enough, the result is localized overheating and eventual tube failure.

To prevent deposits on tubes, the concentration and type of solids in the boiler feedwater must be maintained within acceptable limits. The higher the operating pressure and temperature of the boiler, the more stringent the requirements for feedwater treatment.

Low-pressure boilers typically use ion exchange water softeners to remove calcium and magnesium hardness. A water softener system is presented in Figure 3. In higher pressure and temperature boilers, which typically feed steam turbines, total demineralization is necessary, including the removal of other constituents such as silica. If not removed, silica vaporizes in the steam and is deposited on equipment such as turbine blades.

Boiler feedwater systems are typically treated by adding chemicals. These chemicals tie up the trace solids introduced into the boiler. The solids form sludge compounds that can be discharged from the boiler instead of depositing on tube surfaces. Proper boiler feedwater treatment is critical to obtain normal life expectancy. Poor water treatment is one of the most destructive “boiler killers.”

Contaminated Feedwater
Contaminated feedwater, which is a combination of both makeup and condensate returns, is a highly complex issue. Entire books have been written on this subject and its effects. Common feedwater contaminants include: oxygen, miscella-

About the Author
William L. Reeves, P.E., is the president of ESI of Tennessee in Atlanta.
Figure 1: The complete devastation of this utility boiler shows the dangers resulting from fuel explosions.

Dissolved oxygen is a common and constant threat to boiler tube integrity. The typical boiler plant has a deaerating feedwater heater to remove the majority of oxygen. In boilers operating below 1,000 psig (7000 kPa), the oxygen scavenger sodium sulfite is continuously fed to the storage tank of the deaerator. It eliminates free oxygen.

Oxygen pitting is one of the most serious types of oxygen corrosion. Pitting is the concentrated corrosion of a very small area. A tube failure can occur even though a relatively small amount of corrosion and loss of metal has been experienced. Because of the rapid and catastrophic effects of oxygen corrosion, boiler feedwater should be checked periodically to verify that the deaerating heater and oxygen scavenger are eliminating free oxygen from the boiler feedwater.

Undetected contamination of condensate returns is another common cause of boiler feedwater contamination. Contaminants can vary from metals such as copper and iron to oils and process chemicals. Metal contamination is usually a function of the materials of construction of the process equipment and the condensate system. Oils and process chemicals generally enter the condensate system due to process equipment failures or corrosion-caused leaks in equipment such as heat exchangers, pump and gland seals, etc.

The biggest risk associated with condensate system contamination is catastrophic failure of a piece of process equipment, which results in the introduction of significant quantities of undesirable chemicals or compounds into the boiler. For this reason, prudent boiler operations should include continuous monitoring of the quality of condensate being returned from the process.

Introduction of ion exchange resin into the boiler feedwater system sometimes causes severe boiler fouling. This problem is frequently caused by the failure of the ion exchange vessel internal piping or lateral screens. An inexpensive and very worthwhile method to alleviate the chance of this type of contamination is to install a resin trap on the outlet of any ion exchange vessel. Resin traps not only protect the boiler from contamination, but they also prevent the loss of very expensive resin in the event of a failure.

Boiler feedwater contamination can be a slow degenerative

<table>
<thead>
<tr>
<th>Drum</th>
<th>Total</th>
<th>Total</th>
<th>Silica,</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blacked</td>
<td>Alkalinity</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>Solids, ppm</td>
<td>ppm</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>0-300</td>
<td>3,500</td>
<td>700</td>
<td>150</td>
<td>15</td>
</tr>
<tr>
<td>301-450</td>
<td>3,000</td>
<td>600</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>451-600</td>
<td>2,500</td>
<td>500</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>601-750</td>
<td>1,000</td>
<td>200</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>751-900</td>
<td>750</td>
<td>150</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>901-1,000</td>
<td>625</td>
<td>125</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

* psig x 6.895 = kPa

September 2001
Improper Blowdown Techniques

The concentration of suspended solids in boiler water is reduced through a continuous blowdown system along with intermittent bottom blowdowns. The maximum recommended concentration limits according to the American Boiler Manufacturers Association (ABMA) is presented in Table 1. High conductivity or other contamination of boiler feedwater can create problems such as drum level instability and foaming. These problems lead to nuisance water level alarms, moisture carryover in the steam, and superheater fouling.

A well-designed continuous blowdown system will constantly monitor boiler water conductivity and adjust the blowdown rate to maintain a certain control range. Intermittent bottom blowdown of wall headers and the mud drum is critical to remove potential sludge buildup. A lengthy blowdown of furnace wall headers while firing the boiler will potentially cause overheating damage due to the interruption of the natural water circulation. Instead, the furnace wall header blowdown valves should be operated each time the boiler is shut down before the system reaches atmospheric pressure.

Improper Warm-up

Improper warm-up is one of the most severe hardships a steam boiler must endure. Going through the cycle of start-up, operation, and shutdown creates high equipment stresses and consequently, more severe maintenance issues than continuous operation at maximum rated capacity. Good design and slow transition from start-up to operation prolong life and reduce the possibility of failure.

A typical boiler is constructed of different materials including very thick drum metal, thinner tube metal, refractory and insulation materials, and thick iron castings. All these materials heat and cool at different rates. This situation worsens when a material is exposed to different temperatures at the same time. For example, a steam drum that is operating at normal water level has the bottom half of the drum cooled by water and the top half initially cooled by air and eventually cooled by steam. On a cold start, the water heats up very quickly, so the bottom half of the drum expands much faster than the top half, which is not in contact with water. Consequently, the bottom of the drum will become longer than the top, causing the drum to warp. When severe, this phenomenon is called “drum humping” and can lead to stress fractures of the generating tubes between the steam and mud drums.

Refractory damage is the most prevalent damage associated with too rapid warm-up from a cold start. Refractory transfers heat slowly and therefore completely heats up much slower than metal. Also, when the air inside the furnace is cool, the refractory absorbs moisture from the air. A gradual warm-up is required to prevent refractory cracking and to drive moisture from the refractory before it becomes steam and causes the refractory to spall as the steam escapes. The standard warm-up curve (Figure 4) for a typical boiler provides for boiler water temperature increases of no more than 100°F (55°C) per hour.

Impact Damage to Tubes

When you look at a boiler under construction, it is clear that all parts are not created equal. This is particularly true for the boiler tubes that make up the furnace and convection sections. The failure of a single tube with a value of only a few hundred dollars can easily shutdown a multimillion-dollar boiler facility.

Considering that the tubes in industrial boiler applications may be as little as 0.120 in. or 0.095 in. (3 or 2 mm) thick, it is not difficult to see how easily these tubes can be damaged. The most common causes of tube damage are:

- Hitting the tube with a sharp object during fabrication or maintenance;
- Poor soot blower alignment (a soot
blower uses steam to remove soot, chemical ash and other deposits from parts of the boiler; and

- Sootblowing with wet steam causing tube erosion.

During the design of a new boiler, one of the biggest "bangs for the buck" is specifying increased tube thickness. This often minimal cost increase provides additional margin in the event tube damage does occur. Also, when boiler tubes are bent, the tube thickness decreases in the bend, thus reducing design margin over the code requirement.

Severe Overfiring

For many manufacturing plants, maximizing production availability and throughput is the key to profitability. This mindset pushes every piece of equipment to its maximum capability.

Operating boilers beyond their Maximum Continuous Rated capacity (MCR) has long been an issue of discussion. For many years, boiler manufacturers have rated their equipment for a specific MCR with a 2 to 4 hour peak rating, often 110% of MCR. The question frequently asked is, "If the boiler will operate at 110% of MCR for four hours, why can’t it operate at 110% continuously?" The answer is complex.

Safety and performance margins built into the peripheral equipment ensure that the assembled system meets performance guarantees. These margins include such items as additional fan volume and static capability, pump capacity and TDH margins, oversized material handling systems to accommodate operating logistics, etc. Designers of steam-generating systems want to be sure no piece of auxiliary equipment is the limiting factor. Typically, the conservative design of all this equipment allows overfiring the boiler above and beyond the peak 110% MCR rating. Without the self-limiting capability of the auxiliary equipment, demands to maximize production often result in continuous and sometimes severe overfiring.

Yikes, that’s hot.

With a Raytek® infrared thermometer you can take critical temperature data without having to climb a ladder – especially important when measuring hard-to-reach or hot locations, electrical connections or moving parts.

The Raytek STTM ProPlus portable thermometers measure temperatures from -25 up to 1400° F (-32 to 760° C).

Measure quickly, easily and safely.

- Balance Room Temperatures
- Identify Leaky Ductwork
- Evaluate Steam Distribution Systems
- Inspect Compression Lines

Learn more about the Raytek ST ProPlus and the entire family of noncontact temperature measurement solutions from Raytek – a more intelligent way to measure temperature.

Starting at $349.** MSRP

www.raytek.com/proplus

(800) 866-5478
Physical limitations of the boiler, such as furnace size or steam piping, can cause sudden and dramatic problems such as emissions or pressure drop that limit boiler operating capacity. Other physical limitations might not be so obvious. These limitations lead to other problems associated with severe overfiring that may include:

* Short or long-term overheat damage to refractory, tube metallurgy, breeching, etc.;
* Long-term erosion of boiler tubes, baffles, breeching, and particulate clean-up devices;
* Long-term corrosion of furnace wall and superheater tubes; and
* Steam moisture and solids carryover that cause problems with superheater tubes, steam turbine blades, and other process equipment.

The type of fuel has a dramatic effect on the potential problems associated with severe overfiring. Erosion problems are typically associated with solid fuels such as coal, wood, sludge, plant waste, etc., that have ash and particulate constituents. Regardless of fuel, overfiring increases the gas weights and velocities, which have a square function relationship to pressure drop and the effects of erosion. Severe eddy effects can be generated in boiler back passes, resulting in dramatic localized tube erosion.

Boiler designers carefully consider the heat flux through fur-
nace wall tubing and membrane as well as the surface operating temperatures of tube walls, refractory, etc. Overfiring the furnace results in higher heat flux and higher refractory surface temperature. The total steam flow relates to certain downcomer flows and pressure drops to ensure adequate cooling of furnace wall panels, etc. Overfiring the boiler results in higher flow rate in downcomer circuits, which raises the pressure drop, thus impeding flow. The combination of these two conditions can result in a substantial increase in tube and membrane operating temperatures. The short and long-term effects of running at higher temperatures can degrade the tube metallurgy and strength.

Corrosion problems can be compounded when undesirable compounds in oil and solid fuels come in contact with tubes operating at higher operating temperatures. Also, overfiring can result in flame impingement on furnace wall tubing, resulting in localized corrosion.

Most well-designed steam-generating equipment can be operated above MCR for short periods. Operating peripheral equipment at their physical limits does not often create problems. Conversely, operating the steam generator continuously above MCR may cause costly long-term maintenance problems that are not easily detectable during the short term. Where the production demand warrants overfiring steam-generating equipment, the business decision should be based on the relative value of the incremental production versus the increased maintenance costs.

Improper Storage
Storing a boiler improperly can lead to corrosion on either the fire or water sides. Fireside corrosion often occurs on a boiler in cold standby that has previously fired sulfur-laden fuels. Inevitably, there are areas where ash is not removed completely from the tube surface during normal sootblower operation. Among the most vulnerable areas is where the tubes enter the drum at tube-baffle interfaces and refractory-to-tube interfaces. When the boiler is hot, corrosion is generally not a problem since moisture is not present. However, upon shutdown, this ash and refractory can absorb moisture, and a concentrated corrosive attack will occur over time. Localized pitting can be quite severe, rendering an otherwise sound tube inadequate.

"Hot storage" is one way to prevent this type of fireside tube corrosion. Hot storage techniques such as using mud drum heaters or routing the blowdown from an operating boiler through the inactive unit are generally sufficient to keep temperatures of the boiler tubes above the acid dew point. The other practical storage method, particularly on small boilers, is dry storage. In this method, the boiler is sealed up with desiccant inside and...
Pulling a Vacuum

Boilers are designed to operate at high positive pressures but not even the slightest vacuum. A potential vacuum is created when a boiler is shut down. As the unit cools, steam condenses and the water level drops, allowing the pressure to drop, potentially into a vacuum. A vacuum in a boiler can cause leaks on rolled tube seats of generating tubes, which are designed for a mechanical fit to withstand high pressures. Opening the steam drum vent when there is still a slight pressure on the boiler avoids this problem.

Preventive Measures

Some common practices for avoiding boiler problems include:

- Observe the burner flame frequently to identify combustion problems early.
- Investigate the cause of any trip before numerous attempts to relight.
- Before lighting a boiler, purge the furnace thoroughly. This is particularly important if oil has spilled into the furnace. The purge will evacuate the inventory of unburned gases until the concentration is below the explosive limits. If in doubt, purge, purge, purge!
- Verify that the water treatment system is operating properly, producing boiler feedwater of sufficiently high quality for the temperatures and pressures involved. Although zero hardness is always an absolute criterion, other water quality standards based on operating pressures and temperatures as recommended by the ABMA should be followed. Never use untreated water in a boiler.
- Blow down all the dead legs of the low water trips, water column, etc., on a regular basis to prevent sludge buildup in these areas that lead to device malfunction. Never, under any circumstance, disable a low water trip.
- Verify that the water leaving the deaerator is free of oxygen, that the deaerator is operating at the proper pressure, and that the storage tank water is at saturation temperature. A continuous vent from the deaerator is necessary to allow the discharge of non-condensable gases.
- Continuously monitor the quality of condensate coming back from the process to enable dumping the condensate to sewer in the event of a catastrophic process equipment failure.
- Adjust continuous blowdown to maintain conductivity of the boiler water within required operating limits and operate the mud drum blowdown on a regular basis (consult your water treatment specialist). Never blow down a furnace with header while the boiler is operating.
- Inspect the boiler water side on a regular basis. If there are any signs of scaling or solids buildup on the tubes, adjust the water treatment.
- Regularly inspect the deaerator internally for corrosion. This is an important safety issue because a deaerator can rupture from corrosion damage. In the event of a rupture, all the water in the deaerator will immediately flash to steam, filling the boiler room with deadly steam.
- The standard warm-up curve (Figure 4) for a typical boiler is not to increase the boiler water temperature more than 100°F (55°C) per hour. It is not unusual for a continuous minimum fire to exceed this maximum warm-up rate. Consequently, during start-up, the burner must be fired intermittently so this rate is not exceeded.
- Make sure all personnel who work on boilers understand that the thin tubes are quite fragile. Encourage workers to admit any accidental damage so it can be inspected and/or repaired as necessary.
- If production demands necessitate overfiring the boiler, make periodic assessments of potential effects of overfiring and communicate them to management.
- When a boiler is shut down for an extended period of time, keep it in hot standby. Use a nitrogen blanket system to prevent the introduction of air and oxygen into the boiler during cooling and storage, and inject sodium sulfite to react with any free oxygen in the boiler water. When a boiler is stored dry, place desiccant in the boiler drums along with the nitrogen blanket to absorb any free moisture.
- Ensure that the steam drum vent valve is open whenever the boiler pressure is less than 5 psig (136 kPa).•