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Boiler Systems – Boiler Components

By Irvin J. Cotton, Arthur Freedman Associates, Inc. and
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This is part two of a three-part series on boilers. In part one, the authors discussed boiler design and classification. Part two will discuss boiler components, and part three will describe the various chemistries used in boiler water treatment.

Boiler Components

The main components in a boiler system are the boiler feedwater heaters, deaerator, boiler, feed pump, economizer, boiler, superheater, attemperator, steam system, condenser and the condensate pump. In addition there are sets of controls to monitor water and steam flow, fuel flow, airflow and chemical treatment additions. Water sample points may exist at a number of places. Most typically the condensate, deaerator outlet, feedwater (often the economizer inlet), boiler, saturated steam and superheated steam will have sample points.

Feedwater Heater

Boiler efficiency is improved by the extraction of waste heat from spent steam to preheat the boiler feedwater. Heaters are shell and tube heat exchangers with the feedwater on the tube side (inside) and steam on the shell side outside. The heater closest to the boiler receives the hottest steam. The condensed steam is recovered in the heater drains and pumped forward to the heater immediately upstream, where its heat value is combined with that of the steam for that heater. Ultimately the condensate is returned to the condensate storage tank or condenser hotwell.

Dearators

Feedwater will often have oxygen dissolved in it at objectionable levels. The oxygen comes from air in-leakage from the condenser, pump seals, or from the condensate itself. The oxygen is mechanically removed in a deaerator. Deaerators function on the principle that oxygen is decreasingly soluble as the temperature is raised. The disengagement of the oxygen from the water is accomplished by passing a stripping stream of steam through the feedwater. Deaerators are generally a combination spray and tray type. One problem with control of deaerators is ensuring sufficient temperature difference between the incoming water temperature and the stripping steam. If the temperature is too close, not enough steam will be available to strip the oxygen from the make-up water.

Economizers

Economizers are the last stage of the feedwater system. They are designed to extract heat value from exhaust gases to heat the steam still further and improve the efficiency of the boiler. They are simple finned tube heat exchangers. Economizers are prone to corrosion due to their high surface area. Any residual oxygen in the feedwater can cause corrosion in the economizer. Economizers are also susceptible to failure from the hot side due to impurities in the hot gas stream.

Not all boilers have economizers. Usually they are found only on water tube boilers using fossil fuel, as an energy conservation measure. On large systems, the surface area of the economizer may be as large as or larger than the boiler system. It is critical to ensure proper operation and chemical treatment of these units.

Steam and Mud Drums and Circulation

Feedwater enters the boiler steam drum from the economizer or from the feedwater heater train if there is no economizer. The colder feedwater helps create the circulation in the boiler. Colder water in the downcomer, which is outside the heat transfer area, sinks and enters the mud drum through a bottom header. The water is heated in the heat transfer tubes and forms steam. The steam-water mixture is less dense than water and rises in the riser tubes to the steam drum. The steam drum contains internal elements for feedwater entry, chemical injection, blowdown removal, level control, and steam-water separation. The steam bubbles disengage from the boiler water in the riser tubes and steam flows out from the top of the drum through steam separators.

The lower, or mud drum is connected to the steam drum by a set of riser and downcomer tubes. The mud drum acts to concentrate solids such as salts formed from hardness and silica or corrosion products carried into the boiler. Colder, denser water flows to the mud drum through a small number of downcomer tubes, and rises to the steam drum through a much larger number of riser tubes.

Continuous blowdown is taken from the upper drum, where the water is more concentrated and removal of dissolved solids is more efficient. Bottom blows from the mud drum are usually carried out intermittently for brief periods, to effect removal of the accumulated suspended solids.

Some systems are designed with natural circulation. The difference in these designs is based on the overall space requirements and boiler tube design. Natural circulation units produce a head difference between the downcomer tubes and riser tubes sufficient to overcome frictional resistance to flow in the risers, and produce a velocity of circulation sufficient to maintain the necessary steam flows. The flow of water should be about ten times the steam flow rate, or a recirculation ratio of ten to one. If the circulation is sufficient to overcome flow resistance in the riser tubes the water will circulate naturally.

If the force is not sufficient to produce a rapid enough flow in the riser tubes to prevent excessive steam buildup in the risers, a circulation pump is used to boost the flow to the needed levels. This is a forced circulation design. Forced circulation is often employed at higher operating pressures where the steam-water mixture density in the risers is not too much different from the downcomer density.

Level Control

Level control in the steam drum is a complex matter. When steam load is increased one would expect the drum level to initially drop because of the greater mass leaving the drum than entering it. However, the pressure drop causes the entrained steam bubbles to swell, and the drum level initially rises. The opposite effect is seen when steam load is decreased.

A single element level controller can cause serious problems, especially in the case of steam load increases. The initial swelling causes the feedwater flow to drop, leading to even more swelling until the drum may actually dry out. A two-element controller, that uses level sensing and steam flow sensing can provide for more reliable level control.

Too low a level can result in steam bubbles entering the downcomer and resulting in a higher than design steam to water ratio in the riser tubes. This can increase the tendency for flow-accelerated corrosion and can increase carryover of steam since the steam separation devices are designed for a specific range of velocities and a higher than design velocity could result.

Boiler Tubes

Boiler tubes are usually fabricated from high strength carbon steel. The tubes are welded to form a continuous sheet or wall of tubes. Often more than one bank of tubes is used, with that bank closest to the heat source providing the greatest share of heat transfer. They will also tend to be the most susceptible to failure due to flow problems or corrosion/deposition problems.

Deposits build up on the boiler tubes by corrosion processes and precipitation of sparingly soluble salts. Both of those processes occur preferentially on the hot side of the tubes (the side facing the heat source). As steam bubbles form, the surrounding water is more concentrated with salts and suspended solids. If the solubility is exceeded the material will come out of solution and deposit on the walls.

A good measure of water treatment performance is the determination of deposit weight density. During maintenance inspections, tubes are cut from various parts of the boiler. The tubes are split along the hot-cold side boundary. A portion of the tube is cleaned by chemical or mechanical means, and the amount of removed material is determined by mass balance. The deposit weight density is the weight of removed deposits divided by the surface area from which they were obtained. In addition, chemical analysis is used to determine the makeup of the deposits. Deposit Weight Densities should be reported by hot versus cold side measures, and a historical record should be maintained so as to be able to determine the rate of buildup, the nature of the deposits, and to identify any unique events.

Superheaters

The purpose of the superheater is to remove all moisture content from the steam by raising the temperature of the steam above its saturation point. Steam leaving the boiler is saturated: that is, it is in equilibrium with liquid water at boiler pressure (temperature).

The superheater adds energy to the exit steam of the boiler. It can be a single bank or multiple banks of tubes either in a horizontal or vertical arrangement that is suspended in the convective or radiation zone of the boiler. The added energy raises the temperature and heat content of the steam above the saturation point. The main consequences of superheated steam are that the lack of moisture precludes corrosion in the steam lines. In the case of turbines, excessive moisture in the steam can adversely affect the efficiency and integrity of the turbine. Superheated steam has a larger specific volume as the amount of superheat increases. This necessitates larger diameter pipelines to carry the same amount of steam. Due to the temperatures higher alloy steels are used. It is important that the steam be of high purity and low moisture content (entrained water droplets) so that non-volatile substances will not build up in the superheater.

Attemperators

Attemperation is the primary means for controlling the degree of superheat in a superheated boiler. Attemperation is the process of partially desuperheating steam by the controlled injection of water into the superheated steam flow. The degree of superheat will depend on the steam load and the heat available, given the design of the superheater. The degree of superheat of the final exiting steam is generally not subject to wide variation because of the design of the downstream processes. In order to achieve the proper control of superheat temperature an attemperator is used.

A direct contact attemperator injects a stream of high purity water into the superheated steam. It is usually located at the exit of the superheater, but may be placed in an intermediate position. Usually, boiler feedwater is used for attemperation. The water must be free of non-volatile solids to prevent objectionable buildup of solids in the main steam tubes and on turbine blades.

Since attemperator water comes from the boiler feedwater, provision for it has to be made in calculating flows. The calculation is based on heat balance. The total enthalpy (heat content) of the final superheat steam must be the mass-weighted sum of the enthalpies of the initial superheat steam and the attemperation water.

Condensate Systems

Although not a part of the boiler per se, condensate is usually returned to the boiler as part of the feedwater. Accordingly, one must take into account the amount and quality of the condensate when calculating boiler treatment parameters. In a complex steam distribution system there will be several components. These will include heat exchangers, process equipment, flash tanks, and storage tanks.

Heat exchangers are the places in the system where steam is used to heat a process or air by indirect contact. Shell and tube exchangers are the usual design, with steam usually on the shell side. The steam enters as superheated or saturated and may leave as superheated, saturated, or as liquid water, all depending on the initial steam conditions and the design load of the exchanger.

Process equipment includes turbines, whether used for HVAC equipment, air compressors, or turbine pumps. Condensate tanks and pumps are major points for oxygen to enter the condensate system and cause corrosion. These points should be monitored closely for pH and oxygen ingress and proper condensate treatment applied.

In part 3, the authors will discuss chemical treatment. More details on boiler systems can be obtained from the AWT Technical Reference and Training Manual.

About the Authors

Irvin J. Cotton is principal consultant with Arthur Freedman Associates, Inc. He has been involved with water treatment for over 33 years. Mr. Cotton is a member of the Editorial Board for Material Performance magazine. He is also a member of ASME, NACE International, ASTM, AIChE, and AWT. He has over 40 publications in all areas of water technology and treatment.

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Quiz

The Analyst - Winter 2003, "*Boiler Systems – Boiler Components"* By Irvin J. Cotton, Arthur Freedman Associates, Inc. and Orin Hollander, Holland Technologies, Inc.

The purpose of this quiz is to ensure the CWT (Certified Water Technologist) has read and understands the technical paper or article. The quiz answers are based strictly on the content and perspective of this article. The AWT and Certification Committee make no representation to the factual content of the article. Each article has been reviewed and the Certification Committee has made every attempt to avoid articles with misleading statements. Any questions concerning the scoring of any quiz will be referred back to the article for clarification.

1. Which one of the following would not be considered a "main" component in a boiler system?
   a. Superheater
   b. Feedwater Pump
   c. Steam trap
   d. Condenser
   e. Economizer

2. Which of the following statements about dearators is false?
   a. Oxygen is mechanically removed in the dearator.
   b. The temperature between the stripping steam and incoming water should be equal.
   c. Oxygen stripping is accomplished by passing a stripping stream of steam through the feedwater.
   d. One type of dearator is a spray and tray type.

3. Continuous blowdown is taken from:
   a. The upper drum.
   b. Middle of the water column.
   c. Bottom of the mud drum.
   d. Where ever most convenient for the boiler operator.

4. Bottom blowdowns are usually carried out for the removal of accumulated suspended solids.
   a. True
   b. False

5. Boiler tubes are usually fabricated from:
   a. Stainless steel
   b. Copper
   c. Aluminum
   d. Carbon Steel
   e. Titanium

6. For superheaters, it is important for the steam to:
    a. Be of low purity and high moisture content.
    b. Be of high purity and low moisture content.
    c. Be of low purity and low moisture content.
    d. Be completely saturated.

7. The mud drum is connected to the steam drum by a set of tubes called the boiler water circulation tubes.
    a. True
    b. False

8. Economizers are:
    a. The first stage in the feedwater system.
    b. Designed to remove dissolved oxygen from the feedwater.
    c. Designed to cool the feedwater prior to it entering the boiler.
    d. Designed to extract heat from exhaust gases and further improve the efficiency of the boiler.

9. Too low a level in the steam drum can result in the following:
    a. Steam bubbles enter the downcomer and resulting in a higher than design steam to water ratio in the riser tubes.
    b. Cause the feedwater pump to overfill the boiler, resulting in boiler water carryover.
    c. An unsafe condition and immediate evacuation of the steam plant.
    d. Over concentration of boiler water causing foaming and carryover.

10. Feedwater heaters are:
    a. Plate and frame type heat exchangers.
    b. Shell and tube heat exchangers.
    c. Double pipe heat exchangers
    d. Cross flow heat exchangers