Feedwater and Steam System Components

Sebastian Teir, Antto Kulla
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Overview

This chapter will use graphics and photos of an Andritz recovery boiler (manufactured by Foster Wheeler), which is the same boiler that was presented in the chapters on recovery boilers and natural circulation design (figure 1). Although this particular boiler is based on natural circulation, the components presented here are common in most boiler designs.

Figure 1: The feedwater circulation components of the recovery boiler using natural circulation. (Andritz).
Steam drum

The steam drum is a key component in natural, forced and combined circulation boilers. The functions of a steam drum in a subcritical boiler are:

- Mix fresh feedwater with the circulating boiler water.
- Supply circulating water to the evaporator through the downcomers.
- Receive water/steam mixture from risers.
- Separate water and steam.
- Remove impurities.
- Control water chemical balance by chemical feed and continuous blowdown.
- Supply saturated steam
- Store water for load changes (usually not a significant water storage)
- Act as a reference point for feed water control

Steam drum principle

The steam drum principle is visualized in figure 2. Feedwater from the economizer enters the steam drum. The water is routed through the steam drum sparger nozzles, directed towards the bottom of the drum and then through the downcomers to the supply headers.

This recovery boiler operates by natural circulation. This means that the difference in specific gravity between the downcoming water and uprising water / vapor mixture in the furnace tubes induces the water circulation. Drum internals help to separate the steam from the water. The larger the drum diameter, the more efficient is the separation. The dimensioning of a steam drum is mostly based on previous experiences. A drawing of a steam drum cross-section is shown in figure 3.
Water and steam in a steam drum travel in opposite directions. The water leaves the bottom of the drum to the downcomers and the steam exits the top of the drum to the superheaters. Normal water level is below the centerline of the steam drum and the residence time is normally between 5 and 20 seconds.

A basic feature for steam drum design is the load rate, which is based on previous experiences. It is normally defined as the produced amount of steam (m³/h) divided by the volume of the steam drum (m³). Calculated from the residence time in the steam drum, the volumetric load rate can be about 200 for a residence time of almost 20 seconds in the pressure of about 80 bar. The volumetric load rate increases when the pressure decreases having its maximum value of about 800. As can be thought from the units, the size of the steam drum can be calculated based on these values.

**Steam separation**

The steam/water separation in the steam drum is also based on the density difference of water and steam. It is important to have a steady and even flow of water/steam mixture to the steam drum. This is often realized with a manifold (header) designed for partitioning of the flow.

There are different kinds of devices for water separation such as plate baffles for changing the flow direction, separators based on centrifugal forces (*cyclones*) and also steam purifiers like screen dryers (banks of screens) and washers. The separation is usually carried out in several stages. Common separation stages are primary separation, secondary separation and drying. Figure 4 shows a drawing of the steam drum and its steam separators.

One typical dryer construction is a compact package of corrugated or bent plates where the water/steam mixture has to travel a long way through the dryer. One other possibility is to use wire mesh as a material for dryer. The design of a dryer is a compromise of efficiency and drain ability - at the same time the dryer should survive its lifetime with no or minor maintenance. A typical operational problem related to steam dryers is the deposition of impurities on the dryer material and especially on the free area of the dryer (holes).

In this particular steam drum, the primary separators are cyclones (figure 5). These enable the rising steam/water mixture to swirl, which causes the heavier water to drop out of the cyclones and thus let the lighter steam rise above and out of the cyclones. The steam, which is virtually free of moisture at this point, continues on through the secondary separators (dryers), which are called demisters. Demisters are bundles of screens that consist of many layers of tightly bundled wire.
mesh. Demisters remove and capture any remaining droplets that may have passed through the cyclones. The water that condenses from the demisters is re-circulated through the boiler’s circulation process.

**Steam purity and quality**

**Impurity damages**

Impurities in steam causes deposits on the inside surface of the tubes. This impurity deposit changes the heat transfer rate of the tubes and causes the superheater to _overheat_ (CO3 and SO4 are most harmful). The turbine blades are also sensitive for impurities (Na+ and K are most harmful). The most important properties of steam regarding impurities are:

- Steam quality, Water content: percent by weight of dry steam or moisture in the mixture
- Solid contents, Steam purity: parts per million of solids impurity in the steam

**Steam quality**

There are salts dissolved in feedwater that need to be prevented from entering the superheater and thereby into the turbine. Depending on the amount of dissolved salt, some impurity deposition can occur on the inner surfaces of the turbine or on the inner surface of superheater tubes as well. Steam cannot contain solids (due to its gaseous form), and therefore the water content of steam defines the possible level of impurities. The water content after the evaporator (before superheaters) should be \(< \approx 0.01 \%\)-wt (percents by weight) to avoid impurity deposition on the inner tube surfaces. If the boiler in question is a high subcritical-pressure or supercritical boiler, the requirements of the steam purity are higher (measured in parts per billion).

**Steam purity**

The solid contents are a measure of solid particles (impurities) of the steam. The boiler water impurity concentration, solid contents after the steam drum and moisture content after the steam drum are directly connected: e.g. If the boiler water impurity concentration is 500 ppm and the moisture level in the steam (after the boiler) 0,1 %, the solids content in the steam (after the boiler) is 500 ppm \(*\) 0,1 % = 0,5 ppm.

**Continuous blowdown**

When water is circulated within the steam generating circuits, large amounts are re-circulated, steam leaves the drum and feedwater is added to replace the exiting steam. This causes the concentration of solid impurities to build up.

To continuously remove the cumulative amounts of concentrated solids, a sparger the length of the drum is situated below the centerline. The continuous blowdown piping is used to blow the accumulations out of the drum and into the "continuous blowdown tank".

*Figure 6: Blowdown piping (Andritz).*
Sampling is done to properly set the rate of blowdown based upon allowable amounts of identified solids. A photograph of the blowdown piping in the recovery boiler is shown in figure 6. [Andritz]

**Steam drum placement**

**Natural circulation boilers**

In natural circulation boilers the steam drum should be placed as high as possible in the boiler room because the height difference between the water level in the steam drum and the point where water begins its evaporation in the boiler tubes, defines the driving force of the circuit. The steam drum is normally placed above the boiler. Controlled circulation and once-through boilers. Figures 7 and 8 shows photos from the installation process of the recovery boiler steam drum.

For controlled circulation and once-through boilers the steam drum can be placed more freely, because their circulation is not depending on the place of the steam drum (pump-based circulation). This is a reason why controlled circulation and once-through boiler have been preferred in e.g. boiler modernizations, when the biggest problem is usually lack of space.

**Other aspects of steam drum design**

Inside the steam drum there are also different kinds of auxiliary devices for smooth operation of the drum.

The ends of feedwater pipes are placed below the drum water level and must be arranged so that the cold-water flow will not touch directly the shell of the drum to avoid thermal stresses.

The water quality is maintained on one hand by chemical feed lines, which bring water treatment chemicals into the drum, and on the other hand by blowdown pipes which remove certain portion of the drum water continuously or at regular intervals.

A dry-box can be placed before the removal pipe for steam. It consists of a holed or cone-shaped plate construction allowing a smooth flow distribution to a steam dryer.

Figure 7: Installation of steam drum (Andritz).

Figure 8: Steam drum installation (Andritz)
Feedwater system
This chapter describes the feedwater system part of the power plant process prior the boiler, i.e. between the condenser (after turbine) and the economizer.

The feedwater system supplies proper feedwater amount for the boiler at all load rates. The parameters of the feedwater are temperature, pressure and quality. The feedwater system supplies also spray water for spray water groups in superheaters and reheaters.

The feed water system consists of a feed water tank, feed water pump(s) and (if needed) high-pressure water preheaters.

Feedwater tank
A boiler should have as large feed water reserve as is needed for safe shutdown of the boiler. The heat absorbed by the steam boiler should be taken into account when dimensioning the feed water reserve (feed water tank). The exact rules for the choice of feed water reserve are included in respective standards. The feedwater tank of the recovery boiler is shown in figures 9, 10 and 11.

Condensate (from turbine) and fully demineralized (purified) makeup water are the normal inputs to the feed water tank. Gas removal takes place in the deaerator before condensate and makeup water reach the feed water tank. The deaerator handles feedwater gas removal and chemical feeding. Low-pressure steam is used to remove gases containing oxygen from the feedwater. The steam used for gas removal (including gases containing oxygen) continues from feed water tank to a specific condenser, where the heat from low-pressure steam is recovered.

The feedwater tank is heated with low-pressure steam (usually 3-6 bars). The steam assists the gas removal from the feedwater tank.

Feedwater pump
The feedwater pumps lead feedwater from the
Feedwater tank to the boiler. Regulations allow using only one feedwater pump for (very) small boilers, whereas for bigger units at least two feedwater pumps are needed. Usually there are two similar and parallel-connected feedwater pumps with enough individual power to singularly supply the feedwater needs of the boiler, in case one was damaged. A photo of a feedwater pump being manufactured is shown in figure 12.

Feedwater pumps are usually over dimensioned in relation to mass flow rate of steam in order to have enough reserve capacity for blowdown water and soot blowing steam etc.

Smaller feedwater pumps are always electric powered, while feedwater pumps for bigger capacity may be steam powered.

Normally the feedwater tank is placed above the feed water pumps in the boiler room. The difference in altitudes between feedwater pumps and feedwater tank is defined by a parameter called NPSH (net positive suction head). It is related to the cavitation of feedwater pumps and it defines the minimum altitude difference between feedwater pump and feedwater tank.

The feedwater pump head \([\text{N/m}^2]\) can be calculated according to the following equation:

\[
\Delta p_{\text{pump}} = p_p + \Delta p_{\text{flow}} + \rho g H_{\text{geod}}
\]

where \(p_p\) is the maximum operating pressure at the steam drum, \(\Delta p_{\text{flow}}\) is the loss in the feedwater piping and economizer, and \(\rho g H_{\text{geod}}\) is the pressure required to overcome the height difference between feed water tank lower level and drum level (visualized in figure 13).

### Feedwater heaters

There are two types of feedwater heaters in power plant processes: high-pressure (HP) and low-pressure (LP) feedwater heaters. Of these, the HP feedwater heaters are usually situated after the feed water pump (before the economizer) in the power plant process. LP feedwater heaters are normally situated between condenser and feed water tank (deaerator) in the process. High-pressure feedwater heaters are also called closed-type feedwater heaters since fluids are not mixed in this type of heat exchanger. Normal construction of a HP feedwater heater is a shell-and-tube heat exchanger - feedwater flows inside the tubes and steam outside the tubes (on shell side). A photo of a feedwater heater is shown in figure 14.
In a large conventional power plant the typical arrangement of feedwater heaters is a block of open-type (LP) feedwater heaters and a block of HP feedwater heaters after the feedwater pump in the process. The typical number of LP feedwater heaters in a large power plant is 2 and the number of HP feedwater heaters 5, respectively.

The procedure for optimal placement of HP feedwater heaters begins by defining the enthalpy difference between feed water pump outlet and economizer inlet. This enthalpy difference is then divided by the amount of HP feedwater heaters and the result is the enthalpy rise in every HP feedwater heater stage.

**Steam temperature control**

Steam consumers (e.g. turbine, industrial process) require relatively constant steam temperature (±5°C); therefore means of boiler steam temperature control is required.

Steam temperature control system helps maintaining high turbine efficiency, and turbine material temperatures at a reasonable level at boiler load changes. An uncontrolled convective superheater would cause a rise in steam temperature as the steam output increases.

Methods for steam temperature control are:

- Water spraying superheated steam
- Steam bypass (superheater bypass)
- Flue gas bypass
- Flue gas re-circulation
- Heat exchanger system
- Firing system adjustment

**Dolezahl attemperator**

The Dolezahl attemperator (or simply attemperator or de-superheater) is a steam temperature control system that uses condensate as spray water. The location of the attemperator on the recovery boiler is shown in figures 1 and 15.

In a Dolezahl attemperator system saturated steam from steam drum is lead to a condenser that is cooled by feedwater. Condensate (saturated water) continues from condenser to spray water groups.
(injectors). The injectors spray water into the steam and thus reduce the temperature of the superheated steam. Injectors are usually located between superheater stages.

The main advantage of Dolezahl attemperators is the high quality of spray water since the impurities do not follow with the steam flow from the steam drum. Complexity (condenser and tubing) and thus expensiveness is the biggest disadvantage of Dolezahl attemperator systems. Nowadays Dolezahl attemperators are mostly used in special boiler applications.

**Spray water group**

Water spraying the steam flow is the most common method for live steam temperature control. Main advantages of water spraying-based temperature control are the speed and effectivity of the regulation. This makes their use possible in large-scale boilers. It can be used for reheat steam temperature control as well, but usually reheat steam temperature control is performed by combining water spraying with some other method (e.g. flue gas bypass).

The main function of spray water group is to reduce steam temperature by injecting water into steam flow when needed. It is also used to prevent superheater tubes against excessive temperature rise (too much superheating), which could lead to superheater tube damage. The sprayed water can be feedwater (normally) or condensate (condensate steam from boiler process). The system using condensate is called an attemperator.

**Water atomizer types**

The two existing types of steam coolers are categorized by their way of cooling water atomization:

- Atomizer based on pressurized water flow
- Atomization by steam flow

The atomizer principle based on pressurized water has many possibilities of water spraying directions and nozzle types. This type of system is applicable when variations in steam flow are not large and the temperature difference between incoming steam to be cooled and outgoing already cooled steam is big enough.

Steam based atomizer uses steam as medium for atomization. Medium and low-pressure steam is also used as sprayed matter in idea to get more effective cooling. The atomization steam flow is normally constant, being about 20 % of the cooling water flow.

The choice of spray water atomizer type is based on needed operation range (here needed minimum operational load) and is usually very much case-specific.