RECOVERY BOILER EQUIPMENT AND OPERATION

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The recovery boiler is the most essential and most expensive part of the kraft recovery process. This is where the organic matter dissolved during pulping is destroyed and its energy value recovered. This is where sulfide is formed and the inorganic chemicals are recovered for reuse. The recovery boiler is an integral part of the steam and power balance at the mill. The economic viability of the mill depends critically on efficient and reliable recovery boiler operation.

OVERVIEW

A recovery boiler accomplishes three major tasks; burning the black liquor, recovering the inorganic chemicals for reuse, and generating superheated steam. Recovery boilers consist of a water-walled furnace, where combustion of black liquor is completed followed by a series of heat traps where the hot combustion gases are cooled and superheated steam is generated. **Slide 2**

There are three key parameters that are considered in designing a recovery boiler:

- heat input per plan area
- furnace volume per heat input
- flue gas temperature leaving the furnace.

These are involved in determining the dimensions of the furnace cavity. As the size of boilers has increased, the height has increasingly been determined by the need to have enough waterwall surface area to cool the gas to the desired furnace exit temperature. Alternatively, screens can be used to provide some gas cooling and shorten the furnace. The furnace volume and residence time is usually more than ample for combustion and this in turn has allowed moving combustion air higher in the furnace. Conversely, some old boilers were designed with short height and large screens were used to cool furnace gases to the desired superheater inlet temperature. These short, low residence time boilers have been notorious for plugging because of the difficulty in achieving complete burnout of the black liquor particles.

BLACK LIQUOR BURNING

Burning of black liquor takes place in the furnace section. The furnace cavity can be considered to be that part of the waterwall enclosure extending from the hearth to the tip of the nose arch. The nose arch acts as a shield for the superheater section and helps turn the furnace gases so they pass through the superheater in a more or less cross flow pattern.

The furnace can be divided into the lower furnace and the upper furnace based on the functions that occur. The lower furnace is where liquor is sprayed in, combustion air is introduced, the char bed accumulates, and smelt is formed to drain out of the unit. The upper furnace provides residence time to complete combustion and surface area to cool combustion gases. Traditionally, the tertiary air level was considered the boundary between the lower furnace and the upper furnace. This distinction has blurred in recent years with the trend toward greater vertical air distribution.

Slide 5 shows a cross-section of the lower furnace with three levels of air and the liquor gun ports visible. Black liquor combustion requires intermixing the black liquor with combustion air which enter the furnace separately from openings in the waterwalls **Slide 6** is an illustration of a liquor spray gun showing its location in the furnace.

Figure 7 shows the components of the combustion air and flue gas removal systems. Air is supplied with a forced draft (FD) fan and flue gases removed with an induced draft (ID) fan. These are regulated to maintain a balanced draft (slight negative pressure) within the furnace. If there is too much draft, infiltration air is pulled in and efficiency is lost. If draft is inadequate, fire shoots out of the furnace openings.

Combustion air also enters the furnace through ports located on the walls making up the furnace cavity. There is considerable variability in how air is introduced. The lowest air level is called primary air. Primary air enters close to the hearth from all four walls. Secondary air is located above the primary and below the liquor guns. It may be on two walls or all four walls and there may be more than one level (e.g. high primary). Tertiary air is introduced above the liquor guns normally on either a two-wall interlace pattern or concentrically. There are now units operating with quaternary air or even more air levels.

INORGANIC CHEMICAL RECOVERY

The inorganic chemicals in the black liquor (sodium, potassium, sulfur, and chlorine) are recovered as a molten salt mixture, called smelt. It consists primarily of Na_2S and Na_2CO_3 with small amounts of Na_2SO_4 and other materials. The Na_2S, which is necessary for kraft pulping, requires a local reducing (oxygen deficient) environment. The effectiveness of the recovery boiler in producing this desired chemical (as opposed to Na_2SO_4) is measured by the reduction efficiency. The inorganic chemicals are much heavier than the combustion gases and tend to fall toward the hearth. At normal furnace temperatures they are in a molten (liquid) state and can be drained from the boiler through smelt spouts.

One feature of recovery boilers is the presence of a char bed on the hearth. char bed. The char bed consists of a pile of partially pyrolyzed black liquor solids, carbonaceous material and inorganics that accumulate on the hearth. It acts as a fuel reservoir and provides residence time for slower chemical reactions to occur. The shape of the char bed affects gas flow patterns in the furnace and helps shield molten smelt from exposure to combustion air.

Figure 9 shows a representation of a char bed in a recovery boiler. It also provides a representation of smelt flowing out of the boiler through spouts. **Figure 10** shows two different pictures of actual char beds taken with bed cameras.

Not all of the inorganic chemicals proceed directly to the hearth. Some of it forms a fine dust, consisting primarily of Na_2SO_4 with some Na_2CO_3 which flows with the flue gases. This is collected in an electrostatic precipitator and returned to the black liquor being fired. In addition, some inorganic collects on heat transfer surfaces and is removed by sootblowers. This material either falls directly to the hearth or is collected in ash hoppers and returned to the black liquor.

STEAM GENERATION

Superheated steam generation has three basic heat requirements: heating the feedwater to the boiling point, supplying the latent heat of vaporization, and heating the steam form saturation to final temperature. Feedwater heating takes place in the economizer, steam temperature raising in the superheater, and evaporation (steam formation) in the generating bank, waterwalls, and screen section. **Slide 12** As boiler pressure is increased the relative heat transfer loads for steam generation are decreased and those for raising feedwater and steam temperature are increased.

Slides 13, 15 and 16 illustrate the water/steam circuits in a two-drum boiler. The economizer is a feedwater heater. Feedwater enters the boiler through th economizer lower headers and flows up through the economizer. The heated feedwater then flows to the steam drum which is primarily a steam-water separator and distribution device. The generating bank is a natural circulation steam generator with water flowing down the back part of the generating bank and a steam-water mixture flowing upward in the front of the bank.

The lower drum is referred to as a mud drum. Waater flows out of the mud drum through downcomers to the lower furnace headers and then flows through the floor tubes, up through the furnace waterwalls and through the roof tubes to the steam drum A separate downcomer feeds the screen tubes, which form their own steam-generating loop.

Clean saturated steam from the steam drum then goes to the superheater where it is raised to the final steam temperature.

An alternative approach is a single-drum recovery boiler. **Slide 17** In a single-drum unit, there is no mud drum and the drum is located outside of the furnace envelope. All streams come to or leave from the one drum, which is functionally a steam drum. External downcomers take water to floor and lower waterwall headers. External downcomers feed the screen, if used and the bottom generating bank header. Crossover tubes bring water from the economizer outlet header to the drum and supply tubes take saturated steam to the superheater inlet header.

Gas flows out of the furnace through the screen section, if used, and then through the superheater, generating bank, and economizer.

The primary purpose of the furnace screen is to protect the front of the superheater from overheat. It also functions to control gas temperature entering the superheater.. On some units a larger screen is used to provide some of the gas cooling otherwise provided by the waterwalls. Some units have been built without a furnace screen.

Superheaters usually consists of several banks of tubes with various arrangements of steam flow vs. gas flow. Low temperature superheaters may use a counterflow between steam and flue gas. Higher temperature superheaters often introduce colder steam into the front superheater bank in order to protect the tubes from overheat. Many superheaters have an interstage attemporator in which water is injected into the steam in order to reduce (and control) its temperature. Typically, the attemporator flow drops off as the superheater fouls. Superheater banks are often made up of platens which may be made up of tangent tubes or tubes with some backspacing. Various means of supporting superheaters at the roof or from headers are used. **Slide 21** shows a representation of flue gas passing through a superheater.

The generating bank follows the superheater and is part of the steam generating circuits. Hot gases enter the generating bank trough a generating bank screen located above the furnace arch. The rear wall tubes are bent out of plane to form an opening for the hot gas to flow through. The generating bank is made up of closely spaced tubes and in order to avoid plugging, the entering gas temperature must be safely below the sticky temperature of the entrained ash. Traditionally, 1200°F has been used as a target gas temperature entering the generating bank. Even lower values are used if the ash is known to contain elements that aggravate plugging.

Details of generating bank construction depend on whether the boiler is of one or two drum design. In a one drum boiler, the generating bank tubes are connected to headers and the gas flows parallel to the tube. In a two-drum boiler the tubes are connected to the steam drum and the mud drum and the gas passes through in cross-flow.

Older economizer designs used baffles to obtain a cross-flow of hot gas over the economizer tubes. More modern designs use a parallel flow design. **Slide 23** shows both gas flow arrangements. Earlier economizers used a design in which the economizer tubes entered radially into a large diameter header. Over the last 15-20 years the mini-header design has evolved in which the elements consist of a small number of tubes connected to a small (≤4"diameter). In both cases finned tubes are commonly used to increase the heat transfer surface.

A common feature of both superheaters and economizers is that the working fluid within (steam and water respectively) experiences a large increase in temperature as it flows through. This concurrently increases the temperature of the tube metal along the flow path. In this situation, any difference in flow rate or heat pickup between parallel tubes can cause different amounts of thermal expansion and hence generate stresses. Thermally induced stresses are a common problem in superheaters and economizers.

PERIPHERAL EQUIPMENT

In addition to the boiler itself, there is a lot of peripheral equipment that is essential to the operation of the recovery boiler. This includes:

- fans
- black liquor system
- auxiliary fuel system
- spouts and dissolving tank
- sootblowers
- precipitator
- direct contact evaporator (if used).

Fans

Combustion air is supplied through one or more forced draft (FD) fans. Older units often had a single fan with dampers used to control the air distribution and pressure at different air levels. The most modern units have a separate FD fan for each air level.

One or more induced draft (ID) fans are used to remove the flue gas from the unit by pulling it out. In a clean fan arrangement, the ID fan is located after the precipitator. The disadvantage of this arrangement is the increased likelihood of air infiltration into the precipitator. In a dirty fan arrangement, the ID fan is located after the economizer or direct contact evaporator. The disadvantage of this arrangement is that the fan can get out of balance and vibrate as it gets dirty.

Recovery boilers operate as balanced draft units. This means that the pressure within the furnace should be very close to the local atmospheric pressure. If the interior pressure is greater, (not enough draft) fire will blow out the furnace openings. If there is too much draft excessive amounts of cold infiltration air will be drawn into the furnace and other parts of the boiler. The ID fan speed is normally modulated to control the draft.

Black Liquor System

The black liquor system includes the equipment for preparing the liquor for firing and introducing it into the furnace. This includes the following;

- liquor guns with spray nozzles
- pumps and piping
- mix tank for saltcake and recycled dust addition
- liquor heaters
- solids monitoring and automatic diversion system.

In a typical system, the liquor guns are attached manually to a furnace header (ring header) through which liquor ready for firing is supplied. The solids monitoor (normally two refractometers) is located after the mix tank and final liquor heater. There is a motorized divert valve which automatically takes liquor out of the furnace if the monitor indicates solids are below 58%.

Auxiliary Fuel System

The auxiliary fuel system consists of the burners and ignitors, the fuel piping and controls, and the flame safety system. Both oil and natural gas are used as auxiliary fuels. Auxiliary fuel burners are generally located at either of two locations Hearth burners are located near the hearth just above the primary air level. They are used during startup and shutdown and to assist with unstable firing conditions or when there is low heat input to the furnace. Load burners are located above the liquor guns (typically at the tertiary air level). They are used primarily for extra steam generation when there is insufficient liquor available to meet the desired steam load. Black liquor combustion is normally self-sustaining and auxiliary burners are not required during normal recovery boiler operation.

Spouts and Dissolving Tank

The molten smelt that is produced within the recovery boiler is removed from the furnace through the smelt spouts into a dissolving tank where it is dissolved to form green liquor. The spouts are water-cooled troughs mounted in or onto the furnace at spout openings located near the hearth. The spout openings can be subjected to varying smelt levels and flows and require some form of corrosion protection. They have also been subject to cracking problems.

Spout cooling water systems are designed to minimize the pressure inside the spout while providing an adequate flow of cooling water. Some systems are designed to have a small vacuum inside the spout itself. Most use an elevated head tank system and gravity flow through the spout. The collected cooling water is then cooled and pumped back to the head tank.

An agitated tank is used to dissolve the smelt and form green liquor. Shatter jets are used to break up the smelt stream as it flows out the furnace to prevent the accumulation of molten smelt within the tank. Control of the density of the green liquor within the dissolving tank is a key to stabilizing the entire recovery cycle.

Sootblowers

Sootblowers are used to remove deposits from the heat transfer surface (superheater, generating bank, and economizer) within the boiler. The sootblower lances are mounted on carriages outside the boiler. When a sootblower is activated, the lance moves into the boiler and rotates. Steam jets located near the front of the lance strike the deposits and blow them off the tube surfaces. Most sootblowers blow continuously as they move into the boiler and then retract. Some are set up to blow while traveling in but to retract quickly with a reduced steam flow on the second part of the cycle. **Slide 31** shows a representation of deposit removal with a sootblower.

Electrostatic Precipitator

The electrostatic precipitator is used to remove dust from the flue gas leaving the recovery boiler. It is located at the end of the train just ahead of the stack. The dust that is removed at the precipitator is primarily sodium sulfate (saltcake) and it is recycled to the black liquor and refired into the recovery furnace. Precipitator dust also tends to be enriched in chloride and potassium. If the mill has plugging problems due to chloride accumulation in the recovery cycle, some of the precipitator dust may be dumped in order to purge chloride. Some chloride removal processes also start with precipitator dust.

The precipitator efficiency determines the dust load and stack opacity. Thus effective precipitator operation is critical to meeting the environmental restraints on the recovery boiler.

Direct Contact Evaporator

On many older recovery boilers, a direct contact evaporator is used as the final black liquor concentration step before firing. In a direct contact evaporator the black liquor at about 50% solids is brought into direct contact with hot flue gas. The evaporative cooling drops the flue gas temperature about 250-300°F while raising the liquor solids content to 63-65%. The direct contact evaporator is a potential source of TRS and black liquor oxidation is required before the black liquor can be introduced into the direct contact evaporator.

There are two types of direct contact evaporators in use, cascade evaporators and cyclone evaporators. **Slide 34** shows an illustration of both types of direct contact evaporator.