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Steam Technology MPEP 326X

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Basics, Performance and Calculations of Steam Generator

Types of Temperatures

Superheater Outlet Temperatures (SOT)

- Superheater outlet temperature is defined as the temperature at which the steam leaves the superheater (SH).
- It is usually the highest temperature attained by the steam in a boiler.
- RH steam is sometimes slightly higher than the SH steam in large utility boilers.
- SOT up to ~350°C is usually not controlled, being used mainly for process heating.
- For power application, the SOTs are generally > 400°C and are required to be controlled in two ways:
  - By limiting the temperature within a band of ±5°C for the safety of the turbine casing by means of an attemperator.
  - By keeping the temperature constant up to usually 70% load by sizing the SH larger (a range of 70–100% is then known as the steam temperature control (STC).

Steam Temperature Control (STC)

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.

Automatic combustion control (ACC)

- It is different from STC.
- Combustion control is the regulation of fuel and air in right proportions to provide an optimum combustion, which is usually performed by ACC.
- This is usually designed to operate in auto mode between ~40% MCR and peak load.
- It is more adequate for meeting the load variations in most process and power applications.
- To make ACC to lower MCR is very expensive as the flow measurements are difficult.

Reheater Outlet Temperature

- Reheater outlet temperature (RHOT) is the temperature at which steam leaves the RH.
- Reheater inlet/outlet temperatures are turbine-dependent.
- The RHOT is required to be constant for optimum cycle efficiency.
- Since RH pressure is one-third of the main steam pressure, the RHOT is usually equal to or preferably higher than the SOT.

Feed Water Temperature

Feed water temperature (FWT) varies from as low as 85°C for very low-capacity process plants with no feed heating (when there is no FW) to as high as 270°C in very high-pressure (HP) power plants with several stages of feed heating.

Feed water temperatures to boilers are usually at five levels;

1. In HRSGs, the condensate enters the preheater section of the HRSG directly and it is between 30 and 40°C.
2. At 85°C it can enter the economizer (ECON) only if the fuel contains negligible sulfur to cause no corrosion. Otherwise it needs to be heated in the lower drum or in the external heat exchanger (HX) to safe temperature.
3. At 105°C, this is the most common temperature with process industries.
4. The 130 and 140°C, common with small power plants of ~15 MW where high pressure HP heaters are avoided,
5. When HP heaters are in line, the FWTs are between 160 and 270°C,

Fuels

- Fuels have the most profound effect on the size and shape of a boiler.
- Fuel flexibility in a boiler is most desirable parameter.
- Multiple fuels steam generators used in the case of industrial boilers or in the case of utility boilers.

- **Prime or principal (main fuel)** is the fuel around which the boiler is built and the performance is guaranteed.
- **Start-up fuel** is the fuel with which the boiler is started up and loaded until it is ready for taking the main fuel. Oil firing in case of Pulverized fuel (PF) boilers, gas firing and oil/charcoal for circulating fluidized bed combustion (CFBC) boilers are some examples of start-up fuels.
- **Alternate fuel** is available as an alternative to the main fuel with appropriate guarantees. For example, coal or oil is planned as an alternate fuel during the off-season.
- **Auxiliary or additional fuel** is available in the plant and is to be burnt along with the main fuel in cofiring mode. When the quantities of the main fuel are small.
- **Supplementary fuel** is available in case of an emergency.
- **Cofiring or cocombustion** is the simultaneous firing of two or more fuels. This is useful when the auxiliary fuel is difficult to burn due to high moisture or ash.

Fuel Calorific Value

- Calorific value (CV) or HV is the heat content of the fuel expressed in megajoules per kilogram, kilocalories per kilogram, or British thermal units per pound (BTU/Ib).
- The GCV or higher CV (HCV) is more popular in the United States and United Kingdom, whereas net CV (NCV) or lower CV (LCV) is preferred on the Continent.
- Water vapor is formed from the fuel hydrogen and the evaporation of fuel moisture.
- The water vapor leaves the boiler in the superheated condition only but without transferring its latent heat. Thus, the heat in water vapor of the flue gas is not available for heating and NCV recognizes this aspect.

$$NCV = GCV - (m+9H) * \text{latent heat}$$

Furnace Air Levels

- The type of fuel determines the quantity of air required for combustion.
- It is necessary to provide air in excess of this quantity to assure complete combustion.
- The amount of this excess air is determined by the following factors:
    1. Composition, properties, and condition of fuel when fired
    2. Method of burning the combustible
    3. Arrangement of the grate or furnace
    4. Allowable furnace temperature
    5. Turbulence of the mixing of combustion air and volatile gases

Performance of Steam Generator

The performance of boiler may be expressed on the basis of many of the following;

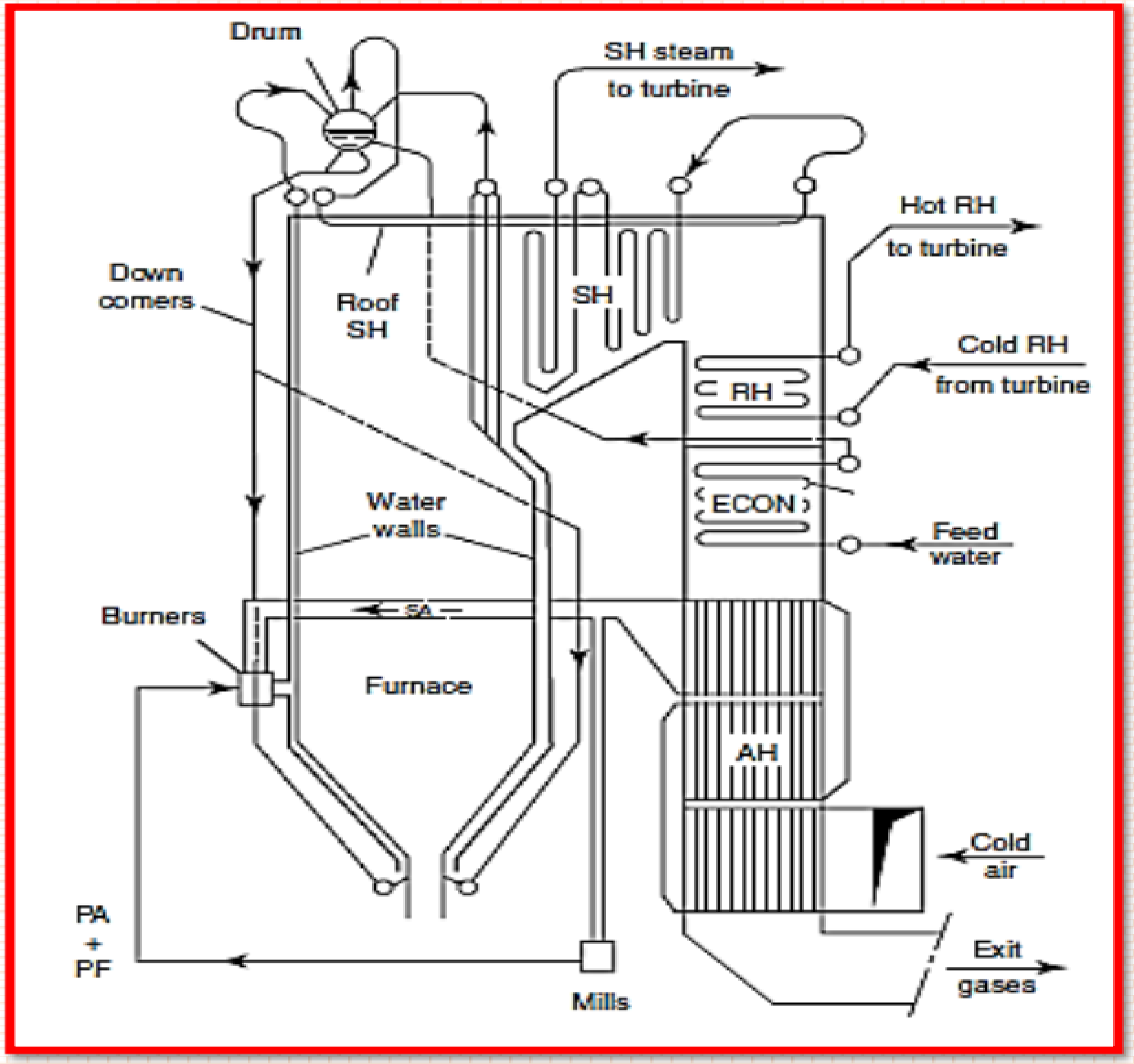
1. Efficiency which can be expressed as the ratio of the heat output (heat absorbed by water and steam/kg of fuel) to the heat input (high caloric value of the fuel/kg of fuel).
2. Combustion rate. It is the rate of fuel burning in kg/m^2 of heating surface/h.
3. Combustion space. It is the furnace volume in m^3/ kg of fuel/h.
4. Heat absorption. It is equivalent evaporation at 100^0C in kg of steam/m^2 of the heating surface.
5. Heat liberated. It is the heat liberated /m^3 of furnace volume/h

Scope of Boiler Plant

Inputs and Outputs

There are four main inputs and four outputs for any conventional steam generator;

Inputs	Outputs
Water	Steam
Air	Gas
Fuel	Ash
Chemicals	Blowdowns and Drains



Drum–type RH utility boiler with ECON and AH as back–end equipment.

Circuits in the Steam Generator

In **water and steam circuit** the boiler scope starts at the non-return valve at the ECON or the drum inlet and ends at the main steam stop valve or non-return valve at the turbine inlet.

In **an air and gas circuit**, the scope begins at the inlet of the pusher fan where the suction is from the atmosphere. The scope ends at the discharge of the induced draft fan at a suitable point, but usually at the stack inlet.

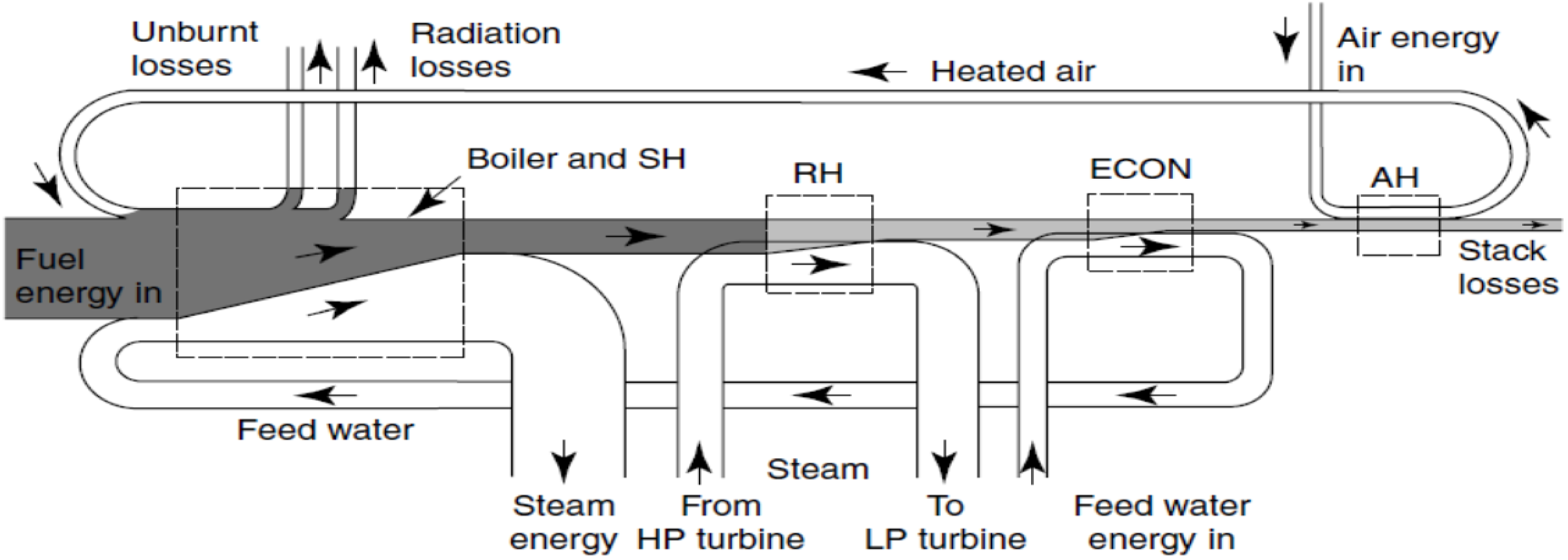
In **a fuel circuit**, the scope starts at the inlet flange of the feeder for solid fuels or at the fuel main stop valve for liquid and gaseous fuels. The scope ends at the ash hoppers.

Heat Balance for Boiler Efficiency

The energy balance shows the energy inputs (combustion of fuel) and steam energy outputs from both SH and RH and the various losses throughout the steam generator.

Heat Inputs	Heat Outputs	Heat Loss
Fuel	SH steam	Stack
Air	RH steam	Unburnt
		Radiation
		Unaccountable

Energy Balance in Boiler



Energy Balance in a Boiler Plant

Boiler efficiency

- Like any other equipment, a boiler has to be designed to operated at the optimum condition – maximum efficiency.
- As the fuel costs have increased, the boilers have also improved in their efficiency.
- Heat release from fuel in the firing equipment and the heat absorption in the heating surfaces of the heat released are main processes that determine the boiler efficiency.
- Boiler efficiency that is measured on the basis of Gross calorific value GCV or Net calorific value NCV indicates how much of the total fuel heat is converted into the heat in steam.

$$\eta_{boiler} = \frac{m_s(h_1 - h_{feed})}{fuel\ mass * heating\ value\ of\ fuel} * 100 = \frac{fuel\ heating\ value - losses}{fuel\ heating\ value} * 100$$

Breakup of Losses

Any efficiency calculation has the following two parts:

1. Combustion calculation.
2. Estimation of loss account to arrive at the efficiency by difference.

Gross efficiency of boiler = 100 – (% Loss 1+2+3+4+5+6)

Where ;

1. Stack loss consists of
   a. Dry gas loss (Ldg)
   b. Moisture loss (Lm)
   c. Humidity loss (Lh)
2. Unburnt loss (Lub)
3. Radiation loss (Lr)
4. Unaccountable loss (Lu)
5. Losses of Blowdown and Sootblowing
6. Internal Power Consumption

Stack Losses

These are measures of:

1. How well the flue gases are cooled.
2. How the flue gas quantities are kept.

NOTES;

- The stack loss typically forms ~70–80% of total loss.
- Stack losses limited to avoid the low-temperature corrosion in the of ECON and AH sections.
- The stack losses depend on the excess air for the fuel, which depend on the type of firing and the tightness of setting.
- A tight boiler setting inhibits the inward leakage of air or outward leakage of flue gas for balanced and forced draft boilers, respectively.

- **The moisture loss (Lm)** varies from 8 to 20% for most fuels depending on the

■ Fuel moisture ■ Fuel H_2 ■ Excess air ■ Exit gas temperature.

$$\text{Moisture loss (Lm)\%} = \frac{(9H_2 + m) * (H_s - h_a) * 100}{GCV}$$

Where

H_2 = Percent hydrogen in fuel by weight, kg/kg;

m = Percentage of moisture in fuel by weight, kg/kg;

H_s = Enthalpy of steam at T_g;

h_a = Enthalpy of water at T_a, kcal/kg.

The dry gas loss (Ldg), as the humidity loss (Lh) is rather small at <0.1%.

$$\text{Dry gas loss (Ldg)\%} = \frac{W_g (T_g - T_a) * C_p * 100}{GCV/_{NCV}}$$

Where

W_g = Weight of gas leaving the system, kg/kg of fuel;
T_g = Temperature of flue gas leaving the system, ^oC;
T_a = Temperature of air entering the system, ^oC;
C_p = Mean specific heat of gas between T_g and T_a, kJ/kg.K.

$$\text{Humidity loss (Lh)\%} = \frac{W_h * (H_s - h_a) * 100}{GCV/_{NCV}}$$

Where

W_h = Weight of moisture, kg/kg of fuel.

Unburnt Loss

- Unburnt loss is a measure of how well the fuel is burnt in the firing equipment for the excess air chosen.
- Efficiency of heat release of the firing equipment is measured by the amount of carbon burn up, which is;

$$C_b = \frac{(100\ -\ \%\ \text{carbon in the residue})}{\%\ \text{total carbon at inlet}}$$

Radiation Loss

Radiation losses are below 1%, and become smaller as the boiler size.

Unaccountable Losses (Lu)

Unaccountable losses cannot be exactly quantified and are small enough to be combined and assigned a reasonable value. They comprise, usually,

- Heat loss in ash.
- Effects of sulfation reactions in fluidized bed combustion (FBC) boilers.
- Unstated instrument tolerances and errors.
- Any other immeasurable losses.

Losses of Blowdown and Sootblowing

- Blowdown water from the steam drum
- Soot-blowing steam (used to remove soot from heat exchanger surfaces within the boiler) use a part of the steam produced by the boiler. This lowers the boiler efficiency

Internal Power Consumption

- The power plant itself consumes a part of the electricity produced.
- This is due to the various auxilary equipment required, like feedwater pumps, circulation pumps and air/flue gas blowers.
- In forced circulation boilers the share of electricity consumed by the circulation pump is about 0.5% of the electricity produced by the plant.
- The largest power consumer is the feed water pump (about 2%).
- The power consumption of the flue gas fan and the air blower are 0.75 – 1% each.
- Normally the internal power consumption is about 5% of the electricity produced by the power plant.

Thanks for Your Attention