Thermal Energy Conservation Technology, Efficiency Improvements in Thermal Utilities

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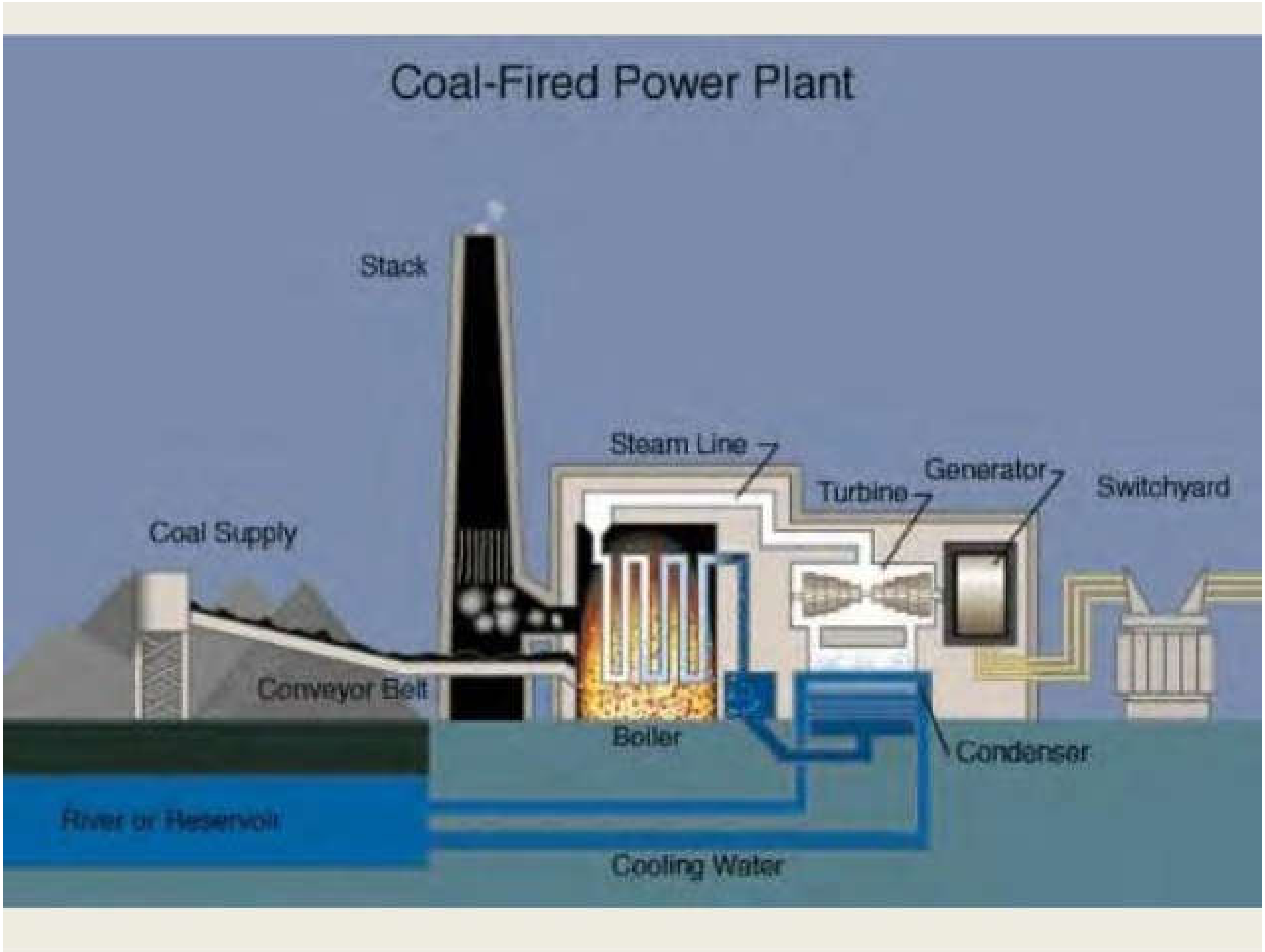

Coal-Fired Power Plant
Stack
Steam Line
Generator
Turbine
Switchyard
Coal Supply
Conveyor Belt
Boiler
Condenser
River or Reservoir
Cooling Water

BOILER

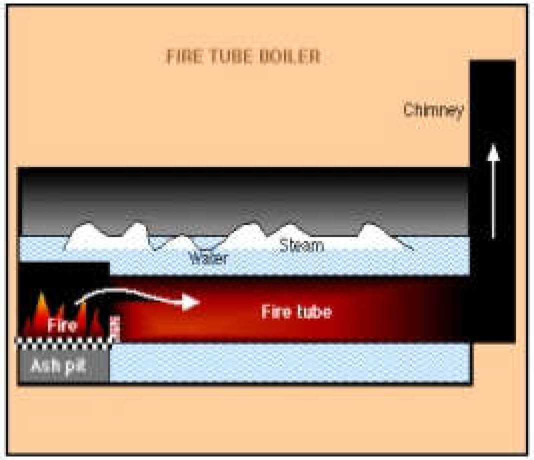
- The boiler system comprises of:
  - feed water system,
  - steam system and
  - fuel system.
- The feed water system
  - provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair.
- The steam system
  - collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use.

BOILER

- The fuel system
  - includes all equipment used to provide fuel to generate the necessary heat.
  - The equipment required in the fuel system depends on the type of fuel used in the system.
- The two sources of feed water are:
  - (1) Condensate or condensed steam returned from the processes and
  - (2) Makeup water (treated raw water) which must come from outside the boiler room and plant processes.

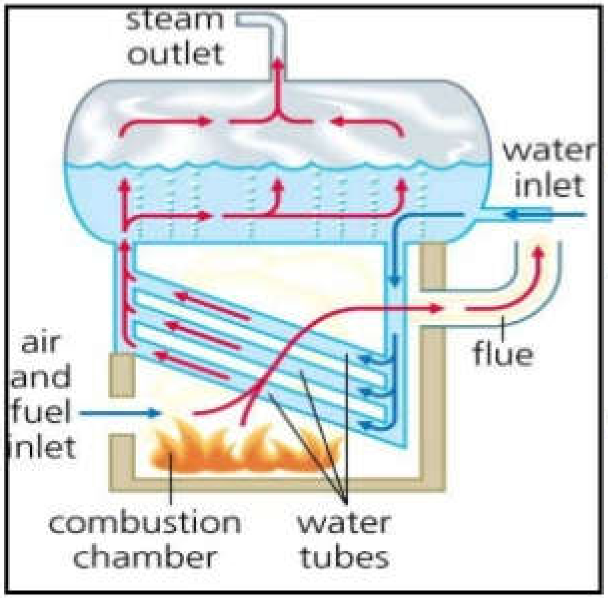
Type of Boilers

1. Fire Tube Boiler



- Relatively small steam capacities (12,000 kg/hr)
- Low to medium steam pressures (18 kg/cm^2)
- Operates with oil, gas or solid fuels

2. Water Tube Boiler



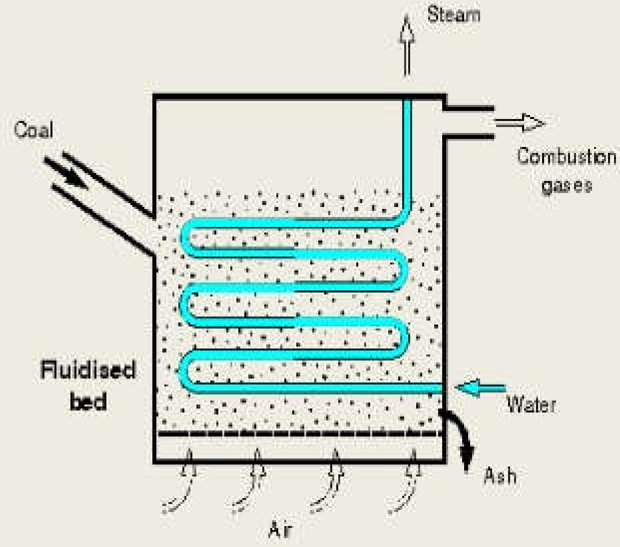
- **Used for high steam demand and pressure requirements**
- **Capacity range of 4,500 – 120,000 kg/hour**
- **Combustion efficiency enhanced by induced draft provisions**
- **Lower tolerance for water quality and needs water treatment plant**

Fluidized bed Combustion (FBC) boiler

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream

Further, increase in velocity gives rise to bubble formation, vigorous turbulence and rapid mixing and the bed is said to be fluidized.

Coal is fed continuously in to a hot air agitated refractory sand bed, the coal will burn rapidly and the bed attains a uniform temperature

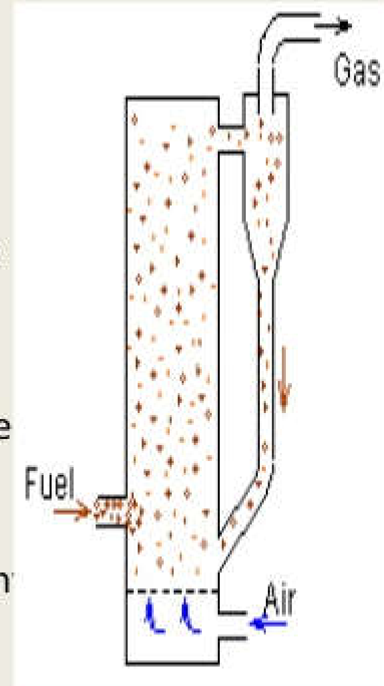


Fluidized Bed Combustion

Fluidized-bed boiler (Contd..)

Advantages :

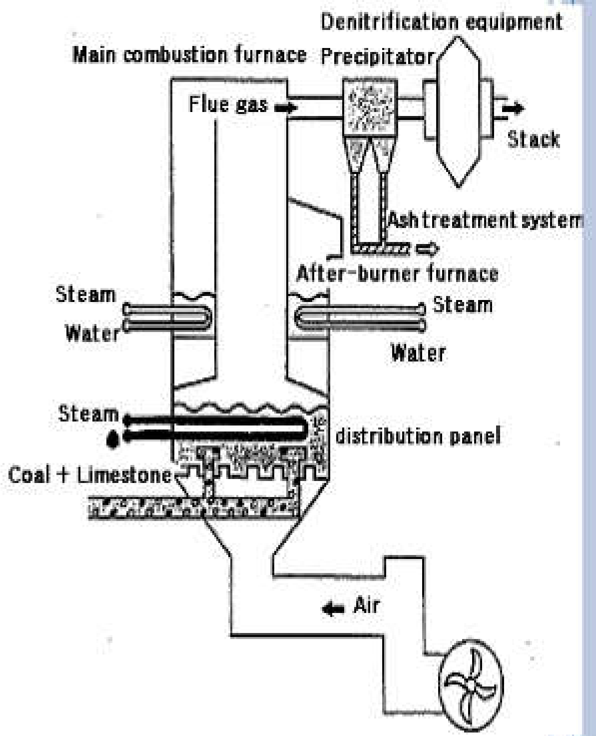
- Higher rates of heat transfer between combustion process and boiler tubes (thus reduced furnace area and size required),
- combustion temperature 850°C is lower than in a conventional furnace. The lower furnace temperatures means reduced NO_x production.
- In addition, the limestone ($CaCO_3$) and dolomite ($MgCO_3$) react with SO_2 to form calcium and magnesium sulfides, respectively, solids which do not escape up the stack; This means the plan can easily use high sulfur coal.
- Fuel Flexibility: Multi fuel firing



Circulating Fluidized Bed Boiler

4. Fluidized Bed Combustion (FBC) Boiler

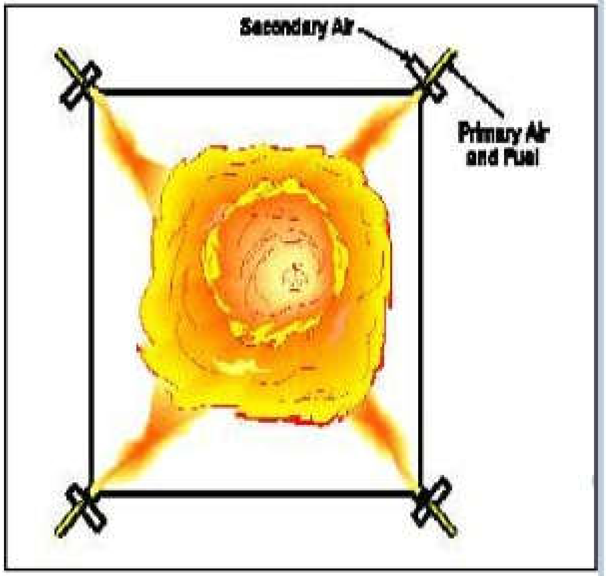
- Particles (e.g. sand) are suspended in high velocity air stream: *bubbling fluidized bed*
- Combustion at 840° – 950° C
- Fuels: coal, washery rejects, rice husk, bagasse and agricultural wastes
- Benefits: compactness, fuel flexibility, higher combustion efficiency, reduced SOx & NOx



6. Pulverized Fuel Boiler

- Pulverized coal powder blown with combustion air into boiler through burner nozzles

- Combustion temperature at 1300 - 1700 °C
- Benefits: varying coal quality coal, quick response to load changes and high pre-heat air temperatures



Pulverized Fuel Boiler (Contd..)

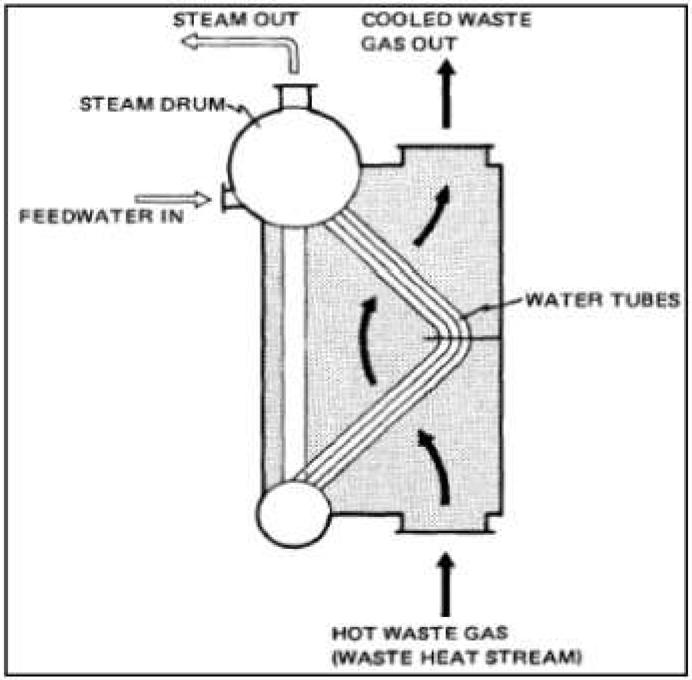
Advantages

- Its ability to burn all ranks of coal from anthracitic to lignite, and it permits combination firing (i.e., can use coal, oil and gas in same burner). Because of these advantages, there is widespread use of pulverized coal furnaces.

Disadvantages

- High power demand for pulverizing
- Requires more maintenance, flyash erosion and pollution complicate unit operation

7. Waste Heat Boiler



- Used when waste heat available at medium/high temp
- Auxiliary fuel burners used if steam demand is more than the waste heat can generate
- Used in heat recovery from exhaust gases from gas turbines and diesel engines

Why Boiler Blow Down ?

When water evaporates

- Dissolved solids gets concentrated
- Solids precipitates
- Coating of tubes
- Reduces the heat transfer rate

Intermittent Blowdown

- The intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica etc) within prescribed limits so that steam quality is not likely to be affected
- TDS level keeps varying
- fluctuations of the water level in the boiler.
- substantial amount of heat energy is lost with intermittent blowdown.

Continuous Blowdown

- A steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water.
- This ensures constant TDS and steam purity.
- Once blow down valve is set for a given conditions, there is no need for regular operator intervention.
- Even though large quantities of heat are wasted, opportunity exits for recovering this heat by blowing into a flash tank and generating flash steam.
- This type of blow down is common in high-pressure boilers.

Boiler Water Treatment

- **Method :** It is carried out by adding chemicals to boiler to prevent the formation of scale by converting the scale-forming compounds to free-flowing sludges, which can be removed by blowdown. **Limitation**: Applicable to boilers, where feed water is low in hardness salts, to low pressures- high TDS content in boiler water is tolerated, and when only small quantity of water is required to be treated. If these conditions are not applied, then high rates of blowdown are required to dispose off the sludge. They become uneconomical from heat and water loss consideration.

Chemicals: Different waters require different chemicals. Sodium carbonate, sodium aluminate, sodium phosphate, sodium sulphite and compounds of vegetable or inorganic origin are all used for this purpose. Internal treatment alone is not recommended.

External Water Treatment

- **Propose:** External treatment is used to remove suspended solids, dissolved solids (particularly the calcium and magnesium ions which are a major cause of scale formation) and dissolved gases (oxygen and carbon dioxide).
- **Different treatment Process** : ion exchange; demineralization; reverse osmosis and de-aeration.
- Before any of these are used, it is necessary to remove suspended solids and colour from the raw water, because these may foul the resins used in the subsequent treatment sections.
- Methods of pre-treatment include simple sedimentation in settling tanks or settling in clarifiers with aid of coagulants and flocculants. Pressure sand filters, with spray aeration to remove carbon dioxide and iron, may be used to remove metal salts from bore well water.
- Removal of only hardness salts is called softening, while total removal of salts from solution is called demineralization.

De-aeration

- In de-aeration, dissolved gases, such as oxygen and carbon dioxide, are expelled by preheating the feed water before it enters the boiler.
- All natural waters contain dissolved gases in solution. Certain gases, such as carbon dioxide and oxygen, greatly increase corrosion. When heated in boiler systems, carbon dioxide (CO_2) and oxygen (O_2) are released as gases and combine with water (H_2O) to form carbonic acid, (H_2CO_3).
- Removal of oxygen, carbon dioxide and other non-condensable gases from boiler feedwater is vital to boiler equipment longevity as well as safety of operation. Carbonic acid corrodes metal reducing the life of equipment and piping. It also dissolves iron (Fe) which when returned to the boiler precipitates and causes scaling on the boiler and tubes.
- De-aeration can be done by mechanical de-aeration, by chemical deration or by both together.

Demineralization is the complete removal of all salts. This is achieved by using a “cation” resin, which exchanges the cations in the raw water with hydrogen ions, producing hydrochloric, sulphuric and carbonic acid. Carbonic acid is removed in degassing tower in which air is blown through the acid water. Following this, the water passes through an “anion” resin which exchanges anions with the mineral acid (e.g. sulphuric acid) and forms water. Regeneration of cations and anions is necessary at intervals using, typically, mineral acid and caustic soda respectively. The complete removal of silica can be achieved by correct choice of anion resin. Ion exchange processes can thus be used to demineralize.

Reverse Osmosis

Reverse osmosis uses the fact that when solutions of differing concentrations are separated by a semi-permeable membrane, water from less concentrated solution passes through the membrane to dilute the liquid of high concentration. If the solution of high concentration is pressurized, the process is reversed and the water from the solution of high concentration flows to the weaker solution. This is known as reverse osmosis.

The quality of water produced depends upon the concentration of the solution on the high-pressure side and pressure differential across the membrane. This process is suitable for waters with very high TDS, such as sea water.

Ion-exchange process (Softener Plant)

- In ion-exchange process, hardness is removed as the water passes through bed of natural zeolite or synthetic resin and without the formation of any precipitate.
- The simplest type is 'base exchange' in which calcium and magnesium ions are exchanged for sodium ions. The sodium salts being soluble, do not form scales in boilers. Since base exchanger only replaces the calcium and magnesium with sodium, it does not reduce the TDS content, and blowdown quantity. It also does not reduce the alkalinity.

Recommended Boiler Water Limits

Factor	Upto20 kg/cm²	21 - 40 kg/cm²	41-60 kg/cm²
TDS, ppm	3000-3500	1500-2000	500-750
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25^{0}C (mho)	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25^{0}C	10-10.5	10-10.5	9.8-10.2
Silica (max) ppm	25	15	10

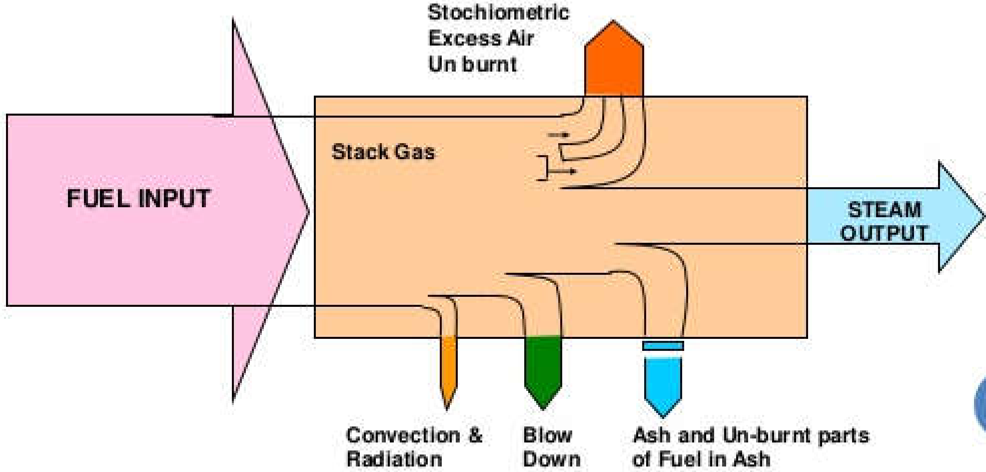
Assessment of a Boiler

Boiler performance

- Causes of poor boiler performance
  - -Poor combustion
  - -Heat transfer surface fouling
  - -Poor operation and maintenance
  - -Deteriorating fuel and water quality
- Heat balance: identify heat losses
- Boiler efficiency: determine deviation from best efficiency

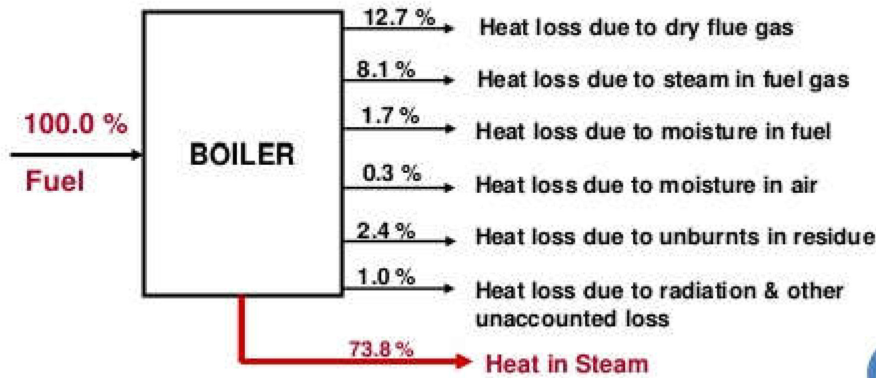
Heat Balance

An energy flow diagram describes geographically how energy is transformed from fuel into useful energy, heat and losses



Heat Balance

Balancing total energy entering a boiler against the energy that leaves the boiler in different forms



Heat Balance

Goal: improve energy efficiency by reducing *avoidable* losses

Avoidable losses include:

- **Stack gas losses (excess air, stack gas temperature)**
- **Losses by unburnt fuel**
- **Blow down losses**
- **Condensate losses**
- **Convection and radiation**

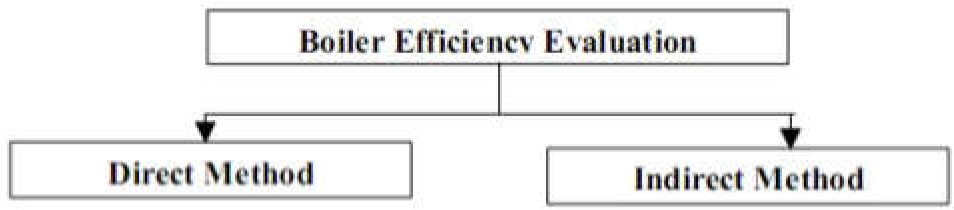
PERFORMANCE EVALUATION OF BOILERS

- The performance parameters of boiler, like efficiency and evaporation ratio reduces with time due to
  - poor combustion,
  - heat transfer surface fouling and
  - poor operation and maintenance.
- Even for a new boiler, reasons such as deteriorating fuel quality, water quality etc. can result in poor boiler performance.
- Boiler efficiency tests help us to find out the deviation of boiler efficiency from the best efficiency and target problem area for corrective action.

Performance Evaluation of Boilers

- Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilised to generate steam.

- There are two methods of assessing boiler efficiency.



Performance Evaluation of Boilers

Direct Method

- This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency.

- This efficiency can be evaluated using the formula

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} \times 100$$

PERFORMANCE EVALUATION OF BOILERS

- Parameters to be monitored for the calculation of boiler efficiency by direct method are :
  - Quantity of steam generated per hour (Q) in kg/hr.
  - Quantity of fuel used per hour (q) in kg/hr.
  - The working pressure (in kg/cm^2) and superheat temperature (^oC), if any
  - The temperature of feed water (^oC)
  - Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel

Performance Evaluation of Boilers

$$Boiler\ Efficiency(\eta)=\frac{Q\,x\,(h_g-h_f)}{q\,x\,GCV}\,x\,100$$

- Where,
  - hg – Enthalpy of saturated steam in kcal/kg of steam
  - hf - Enthalpy of feed water in kcal/kg of water

Direct Method

- Advantages of direct method:
  - Plant people can evaluate quickly the efficiency of boilers
  - Requires few parameters for computation
  - Needs few instruments for monitoring

- Disadvantages of direct method:
  - Does not give clues to the operator as to why efficiency of system is lower
  - Does not calculate various losses accountable for various efficiency levels

Indirect Method

- Indirect method is also called as heat loss method.
- The efficiency can be arrived at, by subtracting the heat loss fractions from 100.
- The principle losses that occur in a boiler are:
  - Loss of heat due to dry fluegas
  - Loss of heat due to moisture in fuel and combustion air
  - Loss of heat due to combustion of hydrogen
  - Loss of heat due to radiation
  - Loss of heat due to unburnt fuel

INDIRECT METHOD

- The data required for calculation of boiler efficiency using indirect method are:
  - Ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content)
  - Percentage of Oxygen or CO_2 in the flue gas
  - Flue gas temperature in ^0C (T_f)
  - Ambient temperature in ^0C (T_a) & humidity of air in kg/kg of dry air.
  - GCV of fuel in kcal/kg
  - Percentage combustible in ash (in case of solid fuels)
  - GCV of ash in kcal/kg (in case of solid fuels)

Indirect Method

i Percentage heat loss due to dry flue gas = $\frac{m\,x\,C_p\,x\,(T_f - T_a)}{GCV\ of\ fuel}\ x\ 100$

- m = mass of dry flue gas in kg/kg of fuel
- Cp = Specific heat of flue gas (0.23 kcal/kg ^{o}C)

INDIRECT METHOD

ii. Percentage heat loss due to evaporation of water formed due to H_2 in fuel

$$= \frac{9 \text{ x } H_2 \text{ x } \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} x \ 100$$

C_p – Specific heat of superheated steam (0.45 kcal/kg ^{0}C)

INDIRECT METHOD

iii. Percentage heat loss due to evaporation of moisture present in fuel

$$= \frac{M \text{ x } \{584 + C_p\,(T_f - T_a)\}}{\text{GCV of fuel}} \; x\ 100$$

Where, M – kg of moisture in 1kg of fuel

C_p – Specific heat of superheated steam (0.45 kcal/kg)^{0}C

INDIRECT METHOD

iv. Percentage heat loss due to moisture present in air

$$= \frac{AAS \; x \; humidity \; factor \; x \; C_p \; x \; (T_f - T_a)}{GCV \text{ of fuel}} \; x \; 100$$

C_p – Specific heat of superheated steam (0.45 kcal/kg ^{0}C)

v. Percentage heat loss due to unburnt in fly ash

$$= \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} \; x \; 100$$

Actual Air Mass Supplied (AAS) per Kg of Fuel=1+Excess Air Supplied (EA) X Theoretical Air

INDIRECT METHOD

vi Percentage heat loss due to unburnt in bottom ash

$$= \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of bottom ash}}{\text{GCV of fuel}} \, x\, 100$$

Indirect Method

vii Percentage heat loss due to radiation and other unaccounted loss

- In a relatively small boiler, with a capacity of 10 MW, the radiation and unaccounted losses could amount to between 1% and 2% of the gross calorific value of the fuel

- while in a 500 MW boiler, values between 0.2% to 1% are typical.

Efficiency of boiler (η) = 100 – (i + ii + iii + iv + v + vi + vii)

Energy Conservation Opportunities

1. Stack Temperature
2. Feed Water Preheating using Economiser
3. Combustion Air Preheat
4. Incomplete Combustion
5. Excess Air Control
6. Radiation and Convection Heat Loss
7. Automatic Blowdown Control
8. Reduction of Scaling and Soot Losses
9. Proper Boiler Scheduling
10. Boiler Replacement

Energy Conservation Opportunities

1. Stack Temperature

- The stack temperature should be as low as possible.
- However, it should not be so low that water vapor in the exhaust condenses on the stack walls.
- This is important in fuels containing significant Sulphur as low temperature can lead to Sulphur dew point corrosion.
- Stack temperatures greater than 200°C indicates potential for recovery of waste heat.
- It also indicate the scaling of heat transfer/recovery equipment and hence the urgency of taking an early shut down for water / flue side cleaning.

ENERGY CONSERVATION OPPORTUNITIES

2. Feed Water Preheating using Economiser

- Typically, the flue gases leaving a modern 3-pass shell boiler are at temperatures of 200 to 300 °C.
- Thus, there is a potential to recover heat from these gases.
- The flue gas exit temperature from a boiler is usually maintained at a minimum of 200 °C, so that the sulphur oxides in the flue gas do not condense and cause corrosion in heat transfer surfaces.
- When a clean fuel such as natural gas, LPG or gas oil is used, the economy of heat recovery must be worked out, as the flue gas temperature may be well below 200°C.

ENERGY CONSERVATION OPPORTUNITIES

2. Feed Water Preheating using Economiser

- The potential for energy saving depends on the type of boiler installed and the fuel used.
- For a typically older model shell boiler, with a flue gas exit temperature of 260°C, an economizer could be used to reduce it to 200°C, increasing the feed water temperature by 15°C.
- Increase in overall thermal efficiency would be in the order of 3%.
- For a modern 3-pass shell boiler firing natural gas with a flue gas exit temperature of 140oC a condensing economizer would reduce the exit temperature to 65°C increasing thermal efficiency by 5%.

ENERGY CONSERVATION OPPORTUNITIES

3. Combustion Air Preheat

- Combustion air preheating is an alternative to feed-water heating.
- In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 °C.
- Most gas and oil burners used in a boiler plant are not designed for high air preheat temperatures.
- Modern burners can withstand much higher combustion air preheat,

Energy Conservation Opportunities

4. Incomplete Combustion

- Incomplete combustion can arise from a shortage of air or poor distribution of fuel.
- It is usually obvious from the colour or smoke, and must be corrected immediately.
- In the case of oil and gas fired systems, CO or smoke (for oil fired systems only) with normal or high excess air indicates burner system problems.
- A more frequent cause of incomplete combustion is the poor mixing of fuel and air at the burner.

ENERGY CONSERVATION OPPORTUNITIES

4. Incomplete Combustion

- With coal firing, unburned carbon can comprise a big loss. It occurs as carbon-in-ash and may amount to more than 2% of the heat supplied to the boiler.

- Non uniform fuel size could be one of the reasons for incomplete combustion.

- In chain grate stokers, large lumps will not burn out completely, while small pieces and fines may block the air passage, thus causing poor air distribution.

ENERGY CONSERVATION OPPORTUNITIES

5. Excess Air Control

- Excess air is required in all practical cases to ensure complete combustion
- The optimum excess air level for maximum boiler efficiency occurs when the sum of the losses due to incomplete combustion and loss due to heat in flue gases is minimum.
- This level varies with furnace design, type of burner, fuel and process variables.
- It can be determined by conducting tests with different air fuel ratios.

ENERGY CONSERVATION OPPORTUNITIES

5. Excess Air Control

- Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.

- Portable oxygen analysers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation.

- Excess air reduction up to 20% is feasible.

ENERGY CONSERVATION OPPORTUNITIES

6. Radiation and Convection Heat Loss

- The external surfaces of a shell boiler are hotter than the surroundings.

- The surfaces thus lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings.

- Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

ENERGY CONSERVATION OPPORTUNITIES

7. Automatic Blowdown Control

- Uncontrolled continuous blowdown is very wasteful.
- Automatic blowdown controls can be installed that sense and respond to boiler water conductivity and pH.
- A 10% blow down in a 15 kg/cm2 boiler results in 3% efficiency loss.

Energy Conservation Opportunities

8. Reduction of Scaling and Soot Losses

- In oil and coal-fired boilers, soot buildup on tubes acts as an insulator against heat transfer.
- Also same result will occur due to scaling on the water side.
- High exit gas temperatures at normal excess air indicate poor heat transfer performance.
- Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits.
- An estimated 1% efficiency loss occurs with every 22°C increase in stack temperature.

ENERGY CONSERVATION OPPORTUNITIES

9. Proper Boiler Scheduling

- Since, the optimum efficiency of boilers occurs at 65-85% of full load,
- it is usually more efficient, on the whole, to operate a fewer number of boilers at higher loads, than to operate a large number at low loads.

Energy Conservation Opportunities

10. Boiler Replacement

- The potential savings from replacing a boiler depend on the anticipated change in overall efficiency.
- Since boiler plants traditionally have a useful life of well over 25 years, replacement must be carefully studied.