EN 410
Energy Management

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Recap

- Basics of Combustion
- 3 Ts to optimize combustion
- Air-Fuel ratio and Excess air
- Air pollutants, types, source, heath effects and elimination techniques

Why steam?

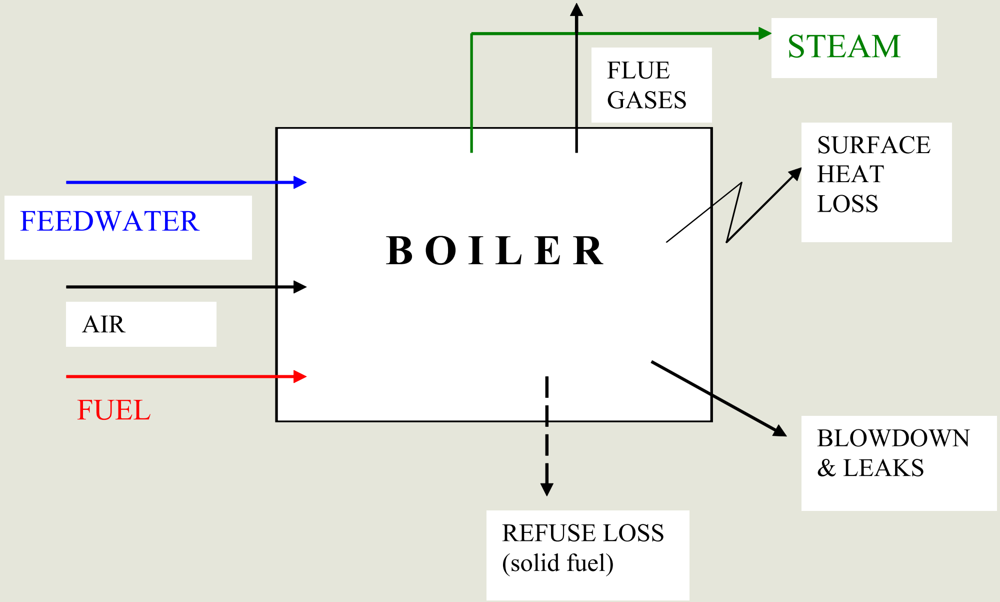
- Used for power generation and as process fluid
- Steam – Commonly used for process heat
- High heat content, easily available, cheap
- High heat transfer coefficient
- Low maintenance
- Steam lines are light-weight
- Steam flows in response to pressure drop; no need for circulating pump

Boiler

According to Indian Boilers Act 2007

“Boilers means a pressure vessel in which stream is generated for use external to itself by application of heat which is wholly or partly under pressure when steam is shut off but does not include a pressure vessel

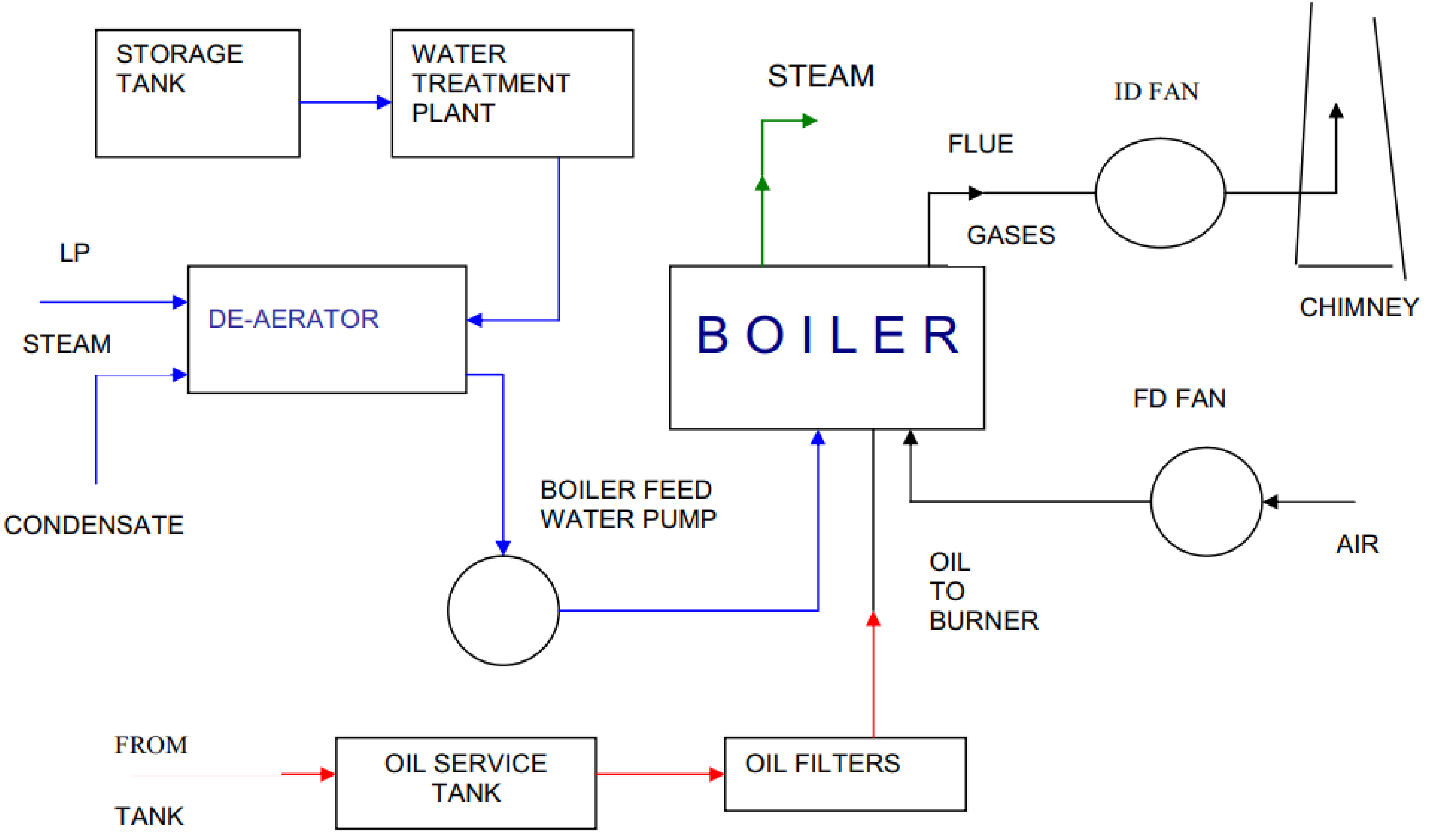
- Capacity less than 25 liters
- < 1kg/cm^2 design gauge pressure
- Water heated below 100°C”



Typical Boiler Specification

Boiler Make & Year : XYZ & 2003
MCR (Maximum Continuous Rating):
10 TPH (F & A 100°C)
Rated Working Pressure :10.54 kg/cm^2(g)
Type of Boiler : 3 Pass Fire tube
Fuel Fired : Fuel Oil

Boiler System



Performance Evaluation

Boiler Evaporation Ratio

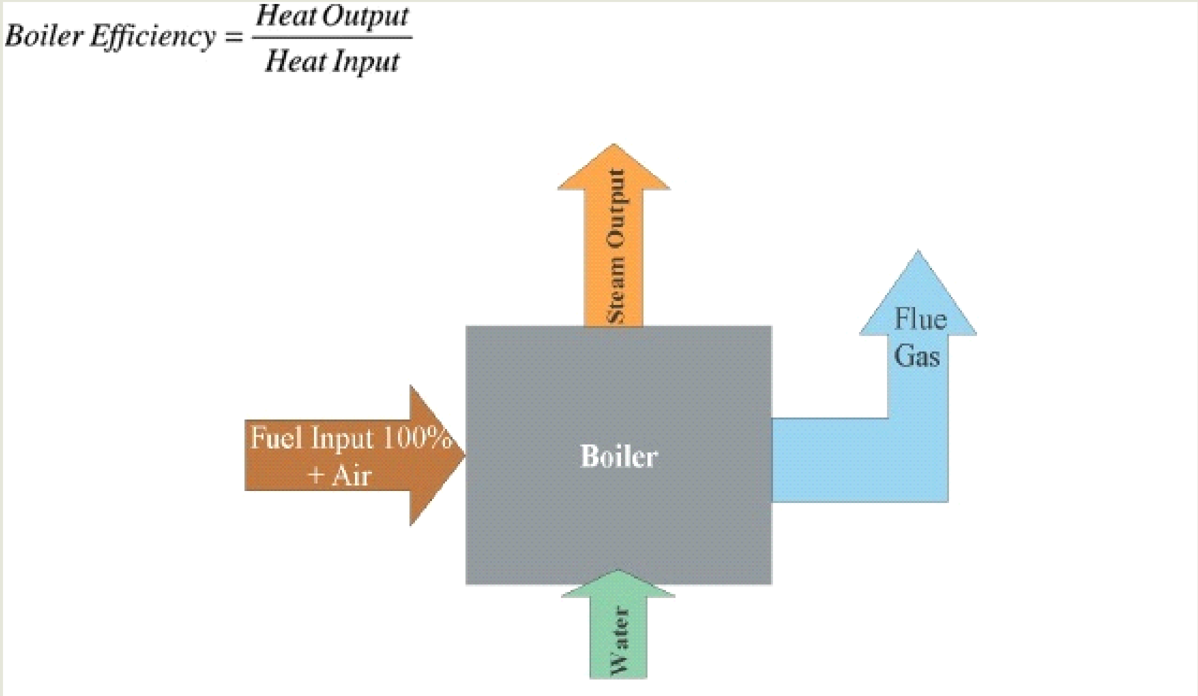
- kilogram of steam generated per kilogram of fuel consumed
- Biomass fired boiler: 2 to 3
- Coal fired boiler: 4 to 5.5
- Oil fired boiler: 13.5 to 14.5
- Gas fired boiler: 11 to 13
- Useful for day to day performance comparison to get an overview of boiler efficiency

Efficiency

- **Standard for Boiler Efficiency Testing**

  (IS 8753, ASME PTC-4-1 and BS845)
- **Direct Method:** energy gain of the working fluid is compared with the energy content of the boiler fuel
- **Indirect Method:** efficiency is calculated based on losses and energy input

Boiler Efficiency – Direct Method



$$\eta_b = \frac{useful \;\; heat}{energy \;\; input}$$

$$= \frac{m_s(h_g - h_{fw})}{m_f(CV) + m_a h_a}$$

Measurement for Direct Method

- Steam flow rate and conditions (p,T)
- Water inlet conditions (T,p)
- Fuel flow rate and composition
- Air flow rate and temperature
- Blowdown should be avoided if it is intermittent blowdown boiler
- Loss should be accounted if it is continues blowdown boiler
- Steady operation

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Boiler Efficiency – Direct Method

Advantages

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

Disadvantages

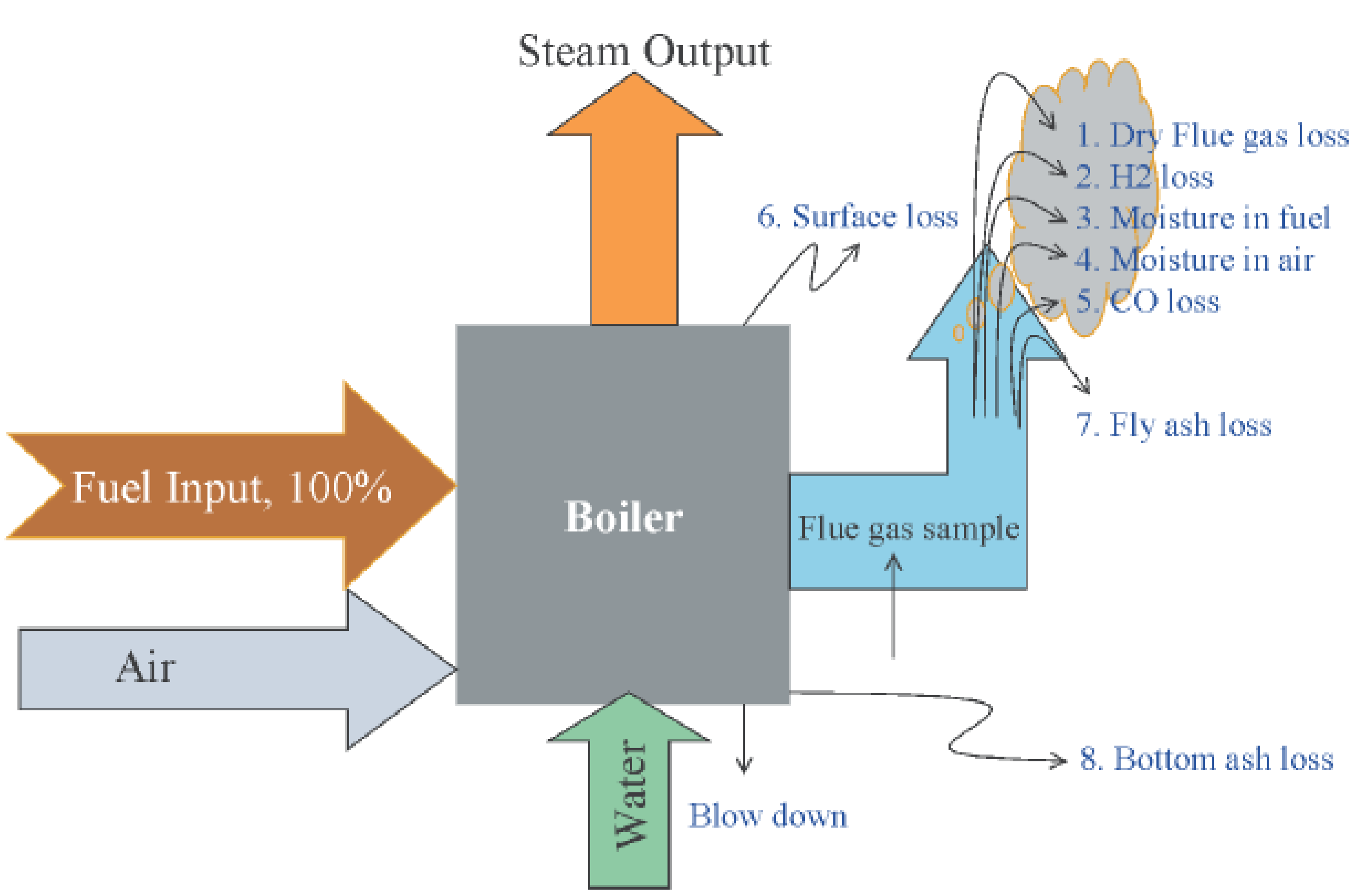
- Does not give clues to the operator as to why efficiency of system is lower
- Does not calculate various losses accountable for various efficiency levels

Problem 1 (Direct method)

- Find out the efficiency and evaporation ration of the boiler by direct method.

Type of Boiler	**Coal Fired**
Quantity of steam generated	8 TPH
Steam pressure/ tem	10 bar/180℃
Quantity of Coal consumed	1.8 TPH
Feed water temperature	85 C
GCV of Coal	13388.8 kJ/kg
Enthalpy of saturated steam	2782.36 kJ/kg
Enthalpy of feed water	355.64 kJ/kg

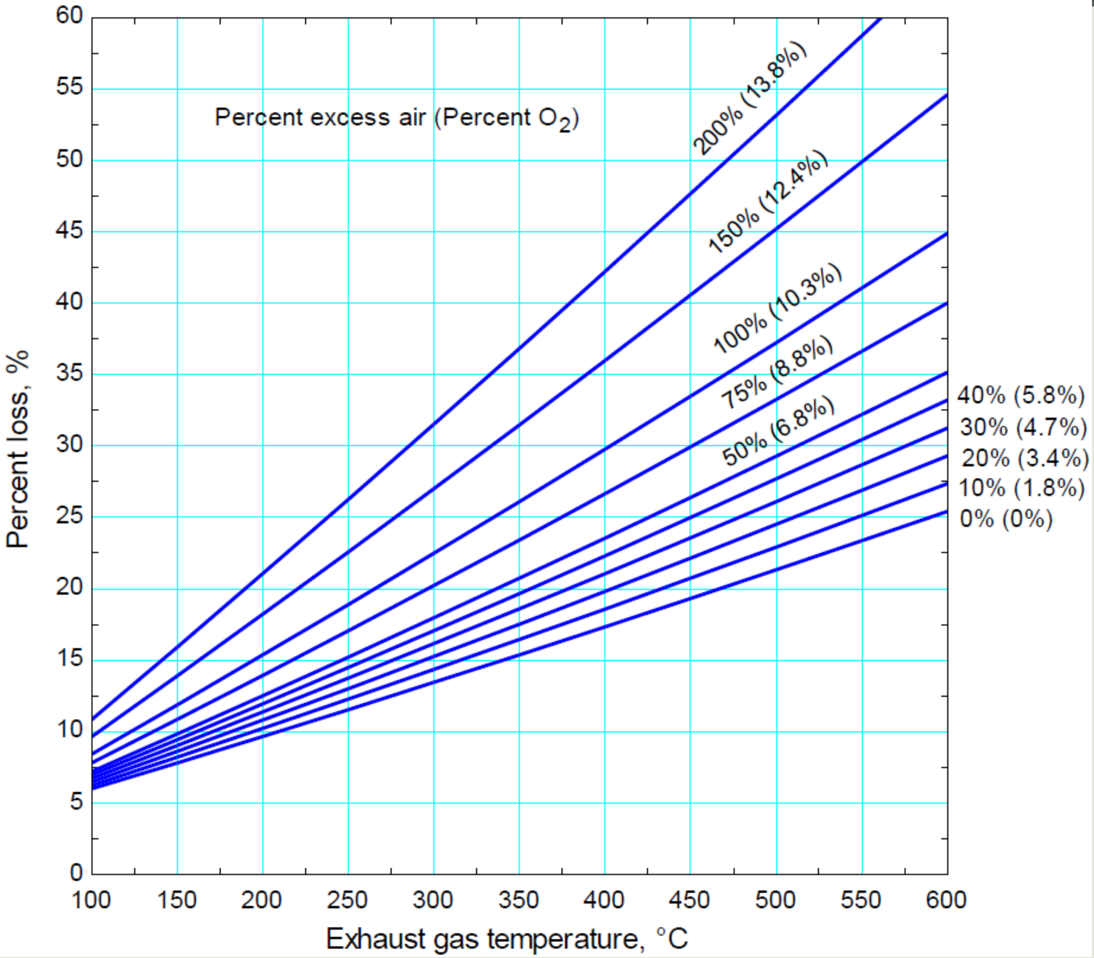
Indirect Method



Flue gas loss

- The greatest fraction of the losses in a boiler is due to energy (enthalpy) of exhaust gases leaving the boiler at a temperature greater than the environment temperature.
- These gases along with the energy they possess are released into the atmosphere.
- Sensible energy represents the amount of energy that could be released from the exhaust gases if they were cooled to the environmental temperature.
- Latent energy represents the heat released when water vapor in the exhaust is condensed at the environment temperature

Flue gas loss



- The fuel is coal with the following composition on a mass basis: 80% C, 5% H_2, 5% O_2, 2% N_2, 0.5% S, and 7.5% ash.
- It has a higher heating value of 36,135 kJ/kg and a lower heating value of 34,945 kJ/kg.

Surface heat loss

- Heat transfer losses in boilers are due to boiler surfaces having a temperature higher than the ambient.
- All boilers are supposed to have adequate insulation when they are first installed but the insulation deteriorates with time and use.
- Difficult to estimate
- 1-2% of GCV for 10 MW, 0.2-1% for 500 MW

Blowdown loss

- Impurities in water increase during the operation of a steam boiler.
- These particles also block heat transfer surfaces within the boiler.
- They suspended solid particles collect in the bottom of the boiler.
- These particles are removed periodically by a process called blowdown (or *bottom blowdown).*
- The contaminated steam and condensate are removed by this blowdown process.
- The blowdown process should be optimized to remove the particles effectively without bleeding off excess steam.
- More than necessary blowdown causes significant fuel losses.
- For example, a 5% blowdown at 3.5 bar pressure causes 1% fuel consumption whereas a 10% blowdown at 14 bar causes 3% fuel consumption.

Measurements for In-Direct Method

Instrument	Type	Measurements
Flue gas analyzer	Portable or fixed	% CO_2 , O_2 and CO
Temperature indicator	Thermocouple, liquid in glass	Fuel temperature, flue gas temperature, combustion air temperature, boiler surface temperature, steam temperature
Draft gauge	Manometer, differential pressure	Amount of draft used or available
TDS meter	Conductivity	Boiler water TDS, feed water TDS, make-up water TDS.
Flow meter	As applicable	Steam flow, water flow, fuel flow, air flow

Precautions for Indirect Method

- The efficiency test does not account for:
  - *Standby losses:* losses occur between firing intervals
  - *Blowdown loss*
  - *Soot blower steam*
  - *Auxiliary equipment energy consumption:* energy usage by auxiliary equipment burners, fans, pumps, etc.

Problem 2 (Indirect method) – Furnace Oil Burner

Boiler data

- Fuel firing: 2650 kg/hr
- Surface temperature of boiler: 80 °C
- Surface area of boiler: 90 m^2

Fuel analysis (in %)

- Carbon: 84
- Moisture:0.5
- Hydrogen: 12
- Nitrogen: 0.5
- Sulphur:1.5
- Oxygen: 1.5
- GCV of Coal: 10000 kcal/kg

Flue gas analysis

- V%CO_2 in flue gas: 10.8
- V%O_2 in flue gas: 7.4
- Flue gas temperature: 190 °C

Ambient data

- Ambient temperature: 30 °C
- Humidity: 0.025 kg / kg dry air
- Wind velocity: 3.8 m/s

Flue Gas Heat Loss

$$L_1 = \frac{m \, x \, C_p \, x \, (T_f - T_a)}{GCV \; of \; fuel} \, x \, 100$$

Where,

L_1 = % Heat loss due to dry flue gas

m = Mass of dry flue gas in kg/kg of fuel

= Combustion products from fuel: $CO_2 + SO_2$ + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/Water vapour in the flue gas should not be considered)

C_p = Specific heat of flue gas in kcal/kg

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

m = Total mass of flue gas – Mass of water vapor

= Mass of air flow rate + Mass of fuel rate – (9*Hydrogen content in fuel)- Moisture content in fuel

Cp = 0.24 kcal/kg

Mass flow rate of air

- Theoretical air
- Excess air
- Actual mass of supplied air

$C + O_2 \rightarrow CO_2$ + 8084 kcal/kg of carbon burnt

$H_2 + 1/2\ O_2 \rightarrow H_2O$ + 28922 kcal/kg of H_2

$S + O_2 \rightarrow SO_2$ + 2224 kcal/kg of S

b) % Excess Air supplied (EA)	=	$\frac{O_2\%}{21 - O_{2\%}} x100$ [from flue gas analysis]
		Normally O_2 measurement is recommended. If O_2 measurement is not available, use CO_2 measurement
		$\frac{7900 x [(CO_2\%)_t - (CO_2\%)_a]}{(CO_2)_a\% \; x \; [100 - (CO_2\%)_t]}$ [from flue gas analysis]

Heat Loss due to the formation of water

The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to steam and this carries away heat in the form of its latent heat.

$$L_2 = \frac{9 \times H_2 \times \{584 + C_p\,(T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

Where

H_2 = kg of hydrogen present in fuel on 1 kg basis

C_p = Specific heat of superheated steam in kcal/kg °C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

584 = Latent heat corresponding to partial pressure of water vapour in kcal/kg

Cp = 0.45 kcal/kg

Heat Loss due to Moisture in Fuel

$$L_3 = \frac{M \times \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

where

M = kg of moisture in fuel in 1 kg basis

C_p = Specific heat of superheated steam in kcal/kg °C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

584 = Latent heat corresponding to partial pressure of water vapour in kcal/kg

C_p = 0.45 kcal/kg

Heat Loss due to Moisture in Air

$$L_4 = \frac{AAS \ x \ humidity \ factor \ x \ C_p \ x \ (T_f - T_a)}{\text{GCV of fuel}} \ x \ 100$$

where

AAS	=	Actual mass of air supplied per kg of fuel
Humidity factor	=	kg of water/kg of dry air
C_p	=	Specific heat of superheated steam in kcal/kg°C
T_f	=	Flue gas temperature in °C
T_a	=	Ambient temperature in °C (dry bulb)

Cp = 0.45 kcal/kg

Surface heat loss

- Difficult to estimate
- Assumed based on type and size of boiler

➢ Industrial fire tube boiler – 1.5 to 2.5 %

➢ Industrial water tube boiler – 2 to 3 %

➢ Power station boiler – 0.4 to 1%

$$L_6 = 0.548 \times [(T_s / 55.55)^4 - (T_a / 55.55)^4] + 1.957 \times (T_s - T_a)^{1.25} \times \text{sq.rt of } [(196.85\, V_m + 68.9) / 68.9]$$

where

L_6 = Radiation loss in W/m^2

V_m = Wind velocity in m/s

T_s = Surface temperature (K)

T_a = Ambient temperature (K)

Heat Loss due to Incomplete Combustion

$$L_5 = \frac{\%CO \ x \ C}{\%CO + \%CO_2} \ x \ \frac{5654^*}{GCV \ of \ fuel} \ x \ 100$$

L_5	=	% Heat loss due to partial conversion of C to CO
CO	=	Volume of CO in flue gas (%) (1% = 10000 ppm)
CO_2	=	Actual Volume of CO_2 in flue gas (%)
C	=	Carbon content kg / kg of fuel

* Heat loss due to partial combustion of carbon, kcal/kg of Carbon.

$C + O_2 \rightarrow CO_2$ + 8084 kcal/kg of Carbon
$2C + O_2 \rightarrow 2\,CO$ + 2430 kcal/kg of Carbon
$2H_2 + O_2 \rightarrow 2H_2O$ + 28,922 kcal/kg of Hydrogen
$S + O_2 \rightarrow SO_2$ + 2,224 kcal/kg of Sulphur

Heat Loss due to unburnt fuel

7. Heat loss due to unburnt in fly ash (%):

$$L_7 = \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} \; x\ 100$$

8. Heat loss due to unburnt in bottom ash (%)

$$L_8 = \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of bottom ash}}{\text{GCV of fuel}} \; x\ 100$$

Boiler efficiency

Indirect efficiency = 100 – Losses