Paper -4 Energy Performance Assessment for Equipment & Utility Systems

Chapter -1 - Boiler

1. Boiler Efficiency = $\frac{\text{Heat in Steam Output (Kcal)}}{\text{Heat in fuel Input (Kcal)}} = \frac{\text{Quantity of Steam generation}}{\text{Quantity of fuel consumption}}$

2. Boiler Efficiency =

$$\frac{\{\text{Steam flow rate}\left(\frac{kg}{hr}\right)\times\left(\text{Steam enthalpy}\left(\frac{Kcal}{kg}\right)-\text{feed water enthalpy}\left(\frac{Kcal}{kg}\right)\right)\}}{\text{Fuel firing rate}\left(\frac{kg}{hr}\right)\times\text{Grosscalorific Value}\left(\frac{Kcal}{kg}\right)}$$

3. $\eta b = \frac{Q\,(H-h)}{q\times GCV}$

Q = Steam flow rate $\left(\frac{kg}{hr}\right)$

H = Steam enthalpy $\left(\frac{Kcal}{kg}\right)$

h = Feed water enthalpy $\left(\frac{Kcal}{kg}\right)$

q = Fuel firing rate $\left(\frac{kg}{hr}\right)$

GCV = Grosscalorific Value $\left(\frac{Kcal}{kg}\right)$

4. Evaporation Ratio = $\frac{\text{Quantity of steam}\left(\frac{Kcal}{kg}\right)}{\text{Quantity of Fuel}\left(\frac{Kcal}{Kg}\right)} = \frac{Q}{q} = \frac{\eta b\times GCV}{(H-h)}$

5. Efficiency of Boiler α Evaporation Ratio

6. Theoretical air required for combustion = $\frac{\{(11.6 \times C) + 34.8\left(H2 - \left(\frac{O2}{8}\right)\right) + (4.35 \times S)\}}{100}$

= kg/kg of fuel

C, H2, O2, S = Percentage of Carbon, Hydrogen, Oxygen & Sulphur present in the fuel

7. Percentage Excess Air supplied % = $\frac{\{O2\%\}}{21 - O2\%} \times 100$

- O2 measurement is recommended if O2 measurement is not available use CO2 measurement

		$\frac{7900\,x[(CO_2\%)_t - (CO_2\%)_a]}{(CO_2)_a\%\ x\,[100 - (CO_2\%)_t]}$ [from flue gas analysis]
Where, $(CO_2\%)_t$	=	Theoretical CO_2
$(CO_2\%)_a$	=	Actual $CO_2\%$ measured in flue gas
$(CO_2)_t$	=	$\frac{Moles\ of\ C}{Moles\ of\ N_2 + Moles\ of\ C + Moles\ of\ S}$
Moles of N_2	=	$\frac{Wt\ of\ N_2\ in\ theoritical\ air}{Mol.Wt\ of\ N_2} + \frac{Wt\ of\ N_2\ in\ fuel}{Mol.Wt\ of\ N_2}$
Moles of C	=	$\frac{Wt\ of\ C\ in\ fuel}{Molecular\ Wt\ of\ C}$
Moles of S	=	$\frac{Wt\ of\ S\ in\ fuel}{Molecular\ Wt\ of\ S}$

8. Actual mass of Air Supplied /kg of fuel AAS = 1+(EA/100) ×Theoretical air

Indirect Method of Determination of Boiler Efficiency

The various losses in the boiler are

1. Heat Loss due to flue gas (L1)
2. Heat Loss due to Hydrogen in fuel (L2)
3. Heat Loss due to Moisture in fuel (L3)
4. Heat Loss due to Moisture in air (L4)

5. Loss due to Partial combustion of C to CO (L5)
6. Loss due to surface radiation (L6)
7. Unburnt Loss in fly ash (L7)
8. Unburnt Loss in bottom ash (L8)

Boiler Efficiency by Indirect Method= 100 - (L1+L2+L3+L4+L5+L6+L7+L8)

1. Heat Loss due to dry flue gas L1 $= \dfrac{m \times Cp \times (Tf - Ta)}{GCV\ of\ Fuel} \times 100$

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

Cp = Specific heat of flue gas in (kcal/kg)

Tf = Flue gas temperature in (^oC)

Ta = Ambient temperature in (^oC)

Mass of Dry flue gas = CO2 in fuel + SO2 in fuel + N2 in fuel + N2 in Actual mass of air supplied + O2 in flue gas

2. Heat Loss due to hydrogen in fuel L2 $= \dfrac{9H2 \times (584 + \{Cp \times (Tf - Ta)\})}{GCV\ of\ Fuel} \times 100$

H2 = hydrogen present in fuel (kg/kg of fuel)

Cp = specific heat of super-heated steam in (Kcal/kg)

Tf = Flue gas temperature in (^oC)

Ta = Ambient temperature in (^oC)

584 = Latent heat of vaporization in (Kcal/kg)

3. Heat Loss due to Moisture present in fuel L3 $= \dfrac{M \times (584 + \{Cp \times (Tf - Ta)\})}{GCV\ of\ Fuel} \times 100$

M = Moisture in fuel (kg/kg of fuel)

Cp = specific heat of super-heated steam in (Kcal/kg)

Tf = Flue gas temperature in (^{o}C)

Ta = Ambient temperature in (^{o}C)

4. Heat Loss due to Moisture present in air L4 = $\frac{\text{AAS} \times \text{Humidity factor} \times \{\text{Cp} \times (\text{Tf} - \text{Ta})\}}{\text{GCV of Fuel}} \times 100$

AAS = Actual mass of air supplied per kg of fuel

Humidity factor = Kg of water /kg of dry air

Cp = specific heat of super-heated steam in (Kcal/kg)

Tf = Flue gas temperature in (^{o}C)

Ta = Ambient temperature in (^{o}C)

5. Heat Loss due to incomplete combustion L5 = $\frac{\%\text{CO} \times \text{C}}{\%\text{CO} \times \%\text{CO2}} \times \frac{5654}{\text{GCV of fuel}} \times 100$

CO = Volume of CO in flue gas (%) (1% = 10000ppm)

CO2 = Actual volume of CO2 in flue gas (%)

C = Carbon content (kg/kg of fuel)

5654 = Heat loss due partial combustion of carbon (kcal/kg of carbon)

6. Heat Loss due to Radiation & Convection =

For Industrial Fire tube /Packaged boiler = 1.5% to 2.5%

For industrial Water tube boiler = 2 to 3%

For Power station boiler = 0.4% to 1%

Can be calculated using the equation also.

- Note: For Solid Fuels only L7 & L8 applicable

7. Heat Loss due to unburnt in fly ash L7 =

$$\frac{(\text{Total ashcollected /kg of fuelburnt}) \times \text{GCV of flyash}}{\text{GCV of fuel}} \times 100$$

8. Heat Loss due to unburnt in bottom ash =

$$\frac{(\text{Total ashcollected /kg of fuelburnt}) \times \text{GCV of bottom ash}}{\text{GCV of fuel}} \times 100$$

9. $GCV = NCV + \left\{\frac{9H2\% + M\%}{100}\right\} \times 584$