Chapter 4.1: Boiler

Short type questions

1.	In the absence of steam flow meter, suggest a method by which steam quantity can be assessed in a boiler. **Ans.** ▪ The feed water flow into the boiler can be used as an effective tool to quantify the steam flow rate from a boiler. ▪ The feed water flow rate also can be quantified either by measuring water flow with the help of water flow meter or by noting the change in level of feed water tank for a specified period of time. Care must be taken to ensure that blowdown is avoided during the trial period.
2.	List out the merits and demerits of direct method of boiler efficiency. **Ans.** Merits • Plant people can evaluate quickly the efficiency of boilers • Requires few parameters for computation • Needs few instruments for monitoring Demerits • 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 • Evaporation ratio and efficiency may mislead, if the steam is highly wet due to water carryover
3.	In the indirect method of boiler efficiency evaluation, list any two additional losses computed for solid fuel fired boilers as compared to liquid and gas fired boilers? **Ans.** • Unburnt losses in fly ash (Carbon) • Unburnt losses in bottom ash (Carbon)
4.	What are the main losses which are not accounted in an indirect method of boiler efficiency testing? **Ans.** • Standby losses • Blow down loss • Soot blower steam • Auxiliary equipment energy consumption
5.	In the absence of data for evaluation of surface heat loss of boiler, what percentage value can be assumed for the following three categories of boilers? a Industrial fire tube / packaged boiler b Industrial water tube boiler c Power station boiler **Ans** a For industrial fire tube / packaged boiler = 1.5 to 2.5% b For industrial water tube boiler = 2 to 3% c For power station boiler = 0.4 to 1%

6.	Define evaporation ratio. **Ans.** Evaporation ratio is the ratio of quantity of steam generation to the quantity of fuel consumption. Evaporation ratio $= \dfrac{\text{Quantity of steam generation}}{\text{Quantity of fuel consumption}}$
7.	State two causes for rise in exit flue gas temperature in a boiler **Ans.** The rise in exist flue gas temperature in a boiler can be due to a. Scale deposit inside the boiler tubes b. Soot deposit on the outer surface of the boiler tube
8.	Write the formula for evaluation of boiler efficiency by direct method. **Ans.** Boiler efficiency,% $= \dfrac{Q \times (H - h) x100}{q \times GCV}$ Where, Q = Steam flow rate in kg/hr h = Enthalpy of fed water kcal/kg H = Steam enthalpy in kcal/kg q = fuel firing rate kg/hr GCV = Gross calorific value of fuel, kcal/kg
9.	List out any four loss components in a heat balance of a boiler. **Ans.** a. Dry flue gas loss b. Surface heat loss c. Loss due to incomplete combustion d. Loss due to hydrogen in fuel
10.	Find out the excess air percentage supplied for a boiler if the theoretical CO_2 is 20.67% and the actual CO_2 measured in the flue gas is 14%. **Ans.** Excess air supplied $= \dfrac{7900 \text{ x } (20.67 - 14)}{14 \text{ x } (100 - 20.67)} = 47.44\%$

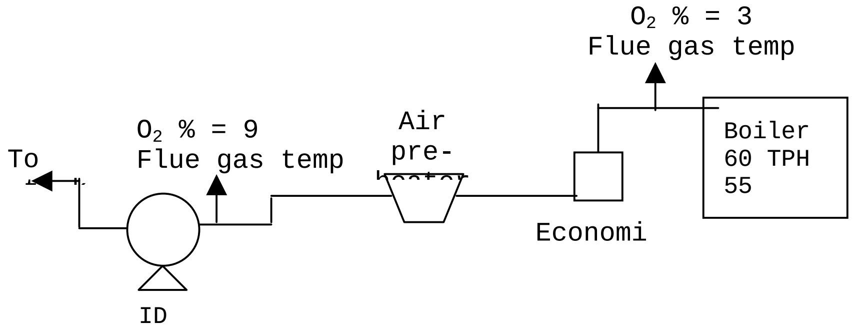
Long type questions

1.	For the evaluation of boiler efficiency by direct method, describe how the heat input can be quantified for the following three cases: • Gaseous fuels • Liquid fuels • Solid fuels **Ans.** For gaseous fuel: A gas meter of the approved type can be used and the measured volume should

	be corrected for temperature and pressure. A sample of gas can be collected for calorific value determination, but it is usually acceptable to use the calorific value declared by the gas suppliers. For liquid fuel: Heavy fuel oil is very viscous, and this property varies sharply with temperature. The meter, which is usually installed on the combustion appliance, should be regarded as a rough indicator only and, for test purposes, a meter calibrated for the particular oil is to be used and over a realistic range of temperature should be installed. Even better is the use of an accurately calibrated day tank. For solid fuel: The accurate measurement of the flow of coal or other solid fuel is very difficult. The measurement must be based on mass, which means that bulky apparatus must be set up on the boiler-house floor. Samples must be taken and bagged throughout the test, the bags sealed and sent to a laboratory for analysis and calorific value determination. In some more recent boiler houses, the problem has been alleviated by mounting the hoppers over the boilers on calibrated load cells, but these are yet uncommon.
2.	List out the major factors which affect the boiler performance. **Ans.** The various factors affecting the boiler performance are listed below: • Periodical cleaning of boilers • Periodical soot blowing • Proper water treatment programme and blow down control • Draft control • Excess air control • Percentage loading of boiler • Steam generation pressure and temperature • Boiler insulation • Quality of fuel
3.	List out different temperatures to be measured during the boiler (steam generation) audit? **Ans.** The following temperatures should be recorded during the boiler audit: 1. Make-up water 2. Condensate return 3. Feed water to deaerator (after condensate mix) 4. Water entering to economiser 5. Water entering to boiler 6. Flue gas at exist from boiler Flue gas at exist from economiser Flue gas at exist from air pre-heater 7. Air supply to the boiler 8. Air supply to the air heater 9. Steam temperature, where super heater is fitted 10. Temperature of preheated fuel (in case of heavy oils)

Numerical type questions

1. The measured parameters of paper industry boiler is given below:



Fuel analysis

Ash content in fuel	:	8.63%
Moisture in coal	:	31.6%
Carbon content	:	41.65%
Hydrogen content	:	2.0413%
Nitrogen content	:	1.6%
Oxygen content	:	14.48%
GCV of coal	:	3501 kcal/kg

Useful data

Theoretical air requirement	:	4.84 kg/kg of coal
Theoretical CO_2%	:	20.67%
Specific heat of air	:	0.24 kcal/kg °C
Ambient air temp	:	30 °C
Boiler efficiency	:	82%
Coal consumption/per hr	:	12 TPH

i. Estimate the heat loss due to air infiltration.
ii. Estimate heat loss quantity as percentage of fuel input

Ans.

i. Estimation of heat loss:

Excess air percentage level $= \left(\frac{O_2\% \times 100}{21 - O_2\%}\right)$

$= \left(\frac{3 \times 100}{21 - 3}\right)$

At boiler outlet $= \left(\frac{3 \times 100}{21 - 3}\right) = 16.66\ \%$

At ID fan $= \left(\frac{9 \times 100}{21 - 9}\right) = 75\ \%$

Actual air infiltration quantity in the duct $= \left[\left(1 + \frac{75.0}{100}\right) \times 4.84\right] - \left[\left(1 + \frac{16.66}{100}\right) \times 4.84\right]$

= 8.47 – 5.65 = 2.82 kg/kg of coal

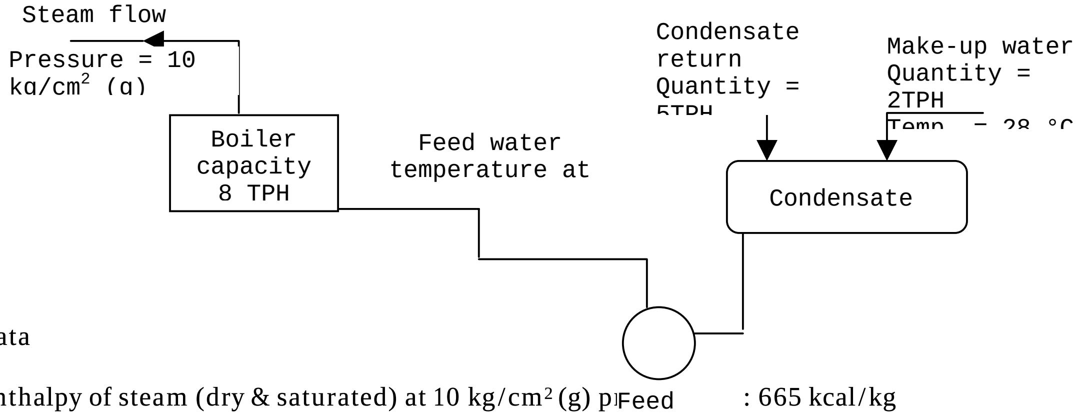
Infiltration air quantity = 2.82 x 12000 = 33,840 kg/h

Heat loss due to infiltrated air : 33840 x 0.24 x (135-30)
: 852768 kcal/h

Heat loss as equivalent to fuel quantity (as coal) : 852768/3501
: 243.6 kg/h

Heat loss as percentage of input fuel : $\frac{243.6}{12000} \times 100 = 2.03\ \%$

2. Analyse the diagram given below and answer the question.



Data

Enthalpy of steam (dry & saturated) at $10\ kg/cm^2$ (g) p	: 665 kcal/kg
Furnace oil consumption	: 600 litres
Specific gravity of furnace oil	: 0.89
Calorific value of FO (GCV)	: 9650 kcal/kg

i. Calculate the boiler efficiency by direct method?
ii. Calculate the water temperature in the condensate tank?
iii. Estimate the fuel loss due to drop in feed water temperature

Ans.

i. Evaluation of boiler efficiency: By direct method

Boiler efficiency (%) : $\frac{Q \times (H - h) \times 100}{q \times GCV}$

Q = Quantity of steam generation per hour	: 7000 kg/h
q = Quantity of fuel used per hour	: 600 x 0.89 = 534 kg/h
GCV = Gross calorific value of the fuel	: 9650 kcal/kg
H = Enthalpy of steam (kcal/kg)	: 665 kcal/kg
h = Enthalpy of feed water	: 42 kcal/kg

Boiler efficiency (η) : $\frac{7000 \times (665 - 42) \times 100}{534 \times 9650}$

: 84.6%

ii. Feed water temperature at condensate tank : $\frac{5000 \times 1 \times 94 + 2000 \times 1 \times 28}{7000 \times 1} = 75.1°C$

Feed water temperature at boiler entrance : 42 °C

iii. To estimate the fuel loss quantity, due to feed water temperature drop:

Fuel consumption at 75°C feed water temperature = $\frac{7000 \times (665 - 75)}{0.846 \times 9650}$

: 505.9 kg/h

FO (litre)	: 505.9/0.89 = 568.4 litre
Furnace oil loss quantity	: 600 – 568.4
	: 31.6 litre/h

3.	Estimate the boiler efficiency by indirect method for the following data.

Type of fuel fired	=	Paddy husk
<u>Paddy Husk composition:</u>		
Moisture	=	10.79%
Mineral Matter	=	16.73%
Carbon	=	33.95%
Hydrogen	=	5.01%
Nitrogen	=	0.91%
Sulphur	=	0.09%
Oxygen	=	32.52%
GCV (Kcal/kg)	=	3568
Cost of Paddy Husk	=	Rs. 1100 / MT
Ambient DBT	=	32 ^{o}C
Boiler parameters on Paddy Husk		
Flue gas temperature	=	190 ^{o}C
CO_2 in flue gas	=	12 %
The losses other than exhaust loss	=	28%

Ans.

Step – 1 Boiler Efficiency Calculation for Paddy Husk

Find theoretical air requirement

a) Theoretical air required for complete combustion

$$= \frac{(11.6 \text{ x} C) \text{ x } \left\{34.8 \text{ x} \left(H_2 - \left(\frac{O_2}{8}\right)\right)\right\} + (4.35 \text{ x } S)}{100}$$

$$= \frac{(11.6 \text{ x } 33.95) \text{ x } \left\{34.8 \text{ x} \left(5.01 - \left(\frac{32.52}{8}\right)\right)\right\} + (4.35 \text{ x } 0.09)}{100} = 4.27 \text{ kg / kg of paddy husk}$$

Find theoretical CO_2 %

% CO_2 at theoretical condition $(CO_2)_t = \dfrac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C} + \text{Moles of S}}$

Moles of N_2 $= \dfrac{4.27 \times \left(\dfrac{77}{100}\right)}{28} + \left(\dfrac{0.0091}{28}\right) = 0.1178$

% CO_2 at theoretical condition $(CO_2)_t = \dfrac{\left(\dfrac{0.3395}{12}\right)}{0.1178 + \left(\dfrac{0.3395}{12}\right) + \left(\dfrac{0.0009}{32}\right)}$

Max theoretical $(CO_2)_t$ = 19.36 %

To find Excess Air supplied

Actual CO_2 measured in flue gas = 12.0%

b) % Excess air supplied $= \dfrac{7900 \text{ x } [(CO_2)_t - (CO_2)_a}{(CO_2)_a \text{ x } [100 - (CO_2)_t]} = 60.09\ \%$

To find actual mass of air supplied

c) Actual mass of air supplied = {1 + EA/100} x theoretical air

= {1 + 60.09/100} x 4.27

= 6.83 kg/kg of coal

To find actual mass of dry flue gas

Mass of dry flue gas $= \dfrac{0.3395 \times 44}{12} + 0.0091 + \dfrac{6.83 \times 77}{100} + \dfrac{(6.83 - 4.27) \times 23}{100}$

= 7.11 kg / kg of coal

% Heat loss in dry flue gas (L_1) $= \dfrac{m \text{ x } C_P \text{ x } (T_f - T_a)}{\text{GCV of fuel}} \text{ x } 100$

$= \dfrac{7.11 \text{ x } 0.23 \text{ x } (190 - 32)}{3568} \text{ x } 100$

L_1 = 7.24 %

Losses other than exhaust loss = 28%

Total losses = 35.24%

Boiler efficiency = 100 – 35.24 = 64.76%

4. In a process plant a coal fired boiler of 78% efficiency is proposed to be replace with paddy husk fired boiler of 68% efficiency. Calculate the cost savings for changing over to paddy husk.

Calorific value of coal	=	4800 kcalAl / kg
Cost of coal	=	Rs. 2500 / MT
GCV of paddy husk (Kcal/kg)	=	3568
Cost of Paddy Husk	=	Rs. 1100 / MT
Quantity of steam requirement	=	15 TPH
Enthalpy of steam	=	770 kCal / kg
Enthalpy of feed water	=	120 kCal / kg
Annual operating hours of boiler	=	8000 hrs

Ans.

A. For paddy husk fired boiler:

Heat content in the output steam	=	15000 x (770-120)
	=	9750000 kCal / h
Paddy husk requirement	=	9750000 / (3568 x 0.68)
	=	4019 kg / h
Annual operating hours	=	8000
Annual paddy husk consumption	=	4019 x 8000
	=	32152 MT
Annual cost of paddy husk	=	32152 x 1100
	=	Rs. 353.7 lakh

B. For Coal fired boiler

Heat content in the output steam	=	15000 x (770-120)
	=	9750000 kCal / h
Coal requirement	=	9750000 / (4800 x 0.78)
	=	2604 kg / h
Annual operating hours	=	8000
Annual coal consumption	=	2604 x 8000
	=	20832 MT
Annual cost of coal	=	20832 x 2500
	=	Rs. 520.8 lakh

Comparison Table

Sl. No	Particulars	Coal as fuel	Paddy Husk as fuel
1	Boiler efficiency, %	78	68
2	Annual fuel consumption, MT	20832	32152
3	Annual fuel cost, Rs (lakh)	520.8	353.7

Cost savings = Rs. 167.1 lakh (Ans.)

5. Calculate the efficiency of the AFBC boiler by indirect method.

Fuel Analysis (% by mass)

Carbon	:	53.9 %
Hydrogen	:	3.1 %
Nitrogen	:	1.1 %
Sulphur	:	0.3 %
Ash	:	23.8 %
Oxygen	:	10.5 %
Moisture	:	7.3 %
GCV	:	5060 kCal / kg

The boiler operating parameters are given below.

Steam pressure	:	62.0 kg / cm^2
Steam temperature	:	470 ^oC
Actual air supplied	:	8.91 kg/kg of coal
Mass of dry flue gas	:	9.31 kg/kg of coal
Flue gas temperature	:	160 ^oC
CO_2 %	:	14.7
CO ppm	:	325
GCV of bottom ash	:	800 kCal / kg
GCV of fly ash	:	452.5 kCal / kg
Ratio of bottom ash to fly ash		15: 85

Loss due to hydrogen in fuel	=	3.54%
Loss due to moisture in fuel	=	0.93%
Loss due to moisture in air	=	0.2%
Surface heat losses	=	2%

Ans.

To find all losses

1. % Heat loss in dry flue gas (L_1) = $\frac{m \ x \ C_P \ x \ (T_f - T_a)}{GCV \ of \ fuel} \ x \ 100$

$= \frac{9.31 \ x \ 0.23 \ x \ (160 - 32.4)}{5060} \ x \ 100$ L_1

= 5.40 %

2. % Heat loss due to partial conversion of C to CO (L_5)

$= \frac{\%CO \ x \ \%C \ x \ 5744}{[\%CO + (\%CO_2)a] \ x \ GCV of \ fuel} \ x \ 100$

$= \frac{0.0325 \ x \ 0.539 \ x \ 5744}{[0.0325 + 14.7] \ x \ 5060} \ x \ 100$

L_2 = 0.13 %

3. % Heat loss due to unburnt in fly ash % Ash in coal = 23.8

Ratio of bottom ash to fly ash	=	15:85	
GCV of fly ash	=	452.5 Kcal/kg	
Amount of fly ash in 1 kg of coal	=	0.85 x 0.238	= 0.2023 kg
Heat loss in fly ash	=	0.2023 x 452.5	= 91.54 kCal / kg of coal
% heat loss in fly ash L_3	=	91.54 x 100 / 5060	= 1.81 %

4. % Heat loss due to unburnt in bottom ash

GCV of bottom ash	=	800 Kcal/kg	
Amount of bottom ash in 1 kg of coal	=	0.15 x 0.238	= 0.0357 kg
Heat loss in bottom ash	=	0.0357 x 800	= 28.56 kCal/kg of coal
% Heat loss in bottom ash L_4	=	28.56 x 100 / 5060	= 0.56 %

	5. Loss due to hydrogen in fuel L_5=	3.54% (given)
	6. Loss due to moisture in fuel L_6=	0.93% (given)
	7. Loss due to moisture in air L_7 =	0.2% (given)
	8. Surface heat losses L_8 =	2% (given)
	Boiler efficiency by indirect method	= 100 – (L_1+ L_2+ L_3+ L_4+ L_5+ L_6+ L_7+ L_8) = 100-(5.40 + 0.13+ 1.81+ 0.56+ 3.54+0.93+0.2+2) = 100-14.57 = 85.43 %