

CHAPTER 3

COMBUSTION CALCULATION

Self Exercise 3

Gaseous propane of 88 kg/hr is burned in a boiler with 10% excess air to produce 1200 kg/hr of steam at 0.1 MPa and 150oC. The percent conversion of the propane is 100%; of the fuel burned, 90% reacts to form CO2 and the balance to form CO. The temperature of combustion air, fuel and water entering the boiler is assumed at 25oC. The flue gas leaves the boiler at 300oC (all the water formed will be vapour). In addition, a substantial amount of heat is also lost through the boiler wall and other uncounted sources.

Calculate the flue gas composition (both dry and wet basis) leaving a boiler.

Calculate the combustion efficiency of a steam boiler

Construct a Sankey diagram showing the heat balance analysis as a percent of heat input.



Combustion Calculation Terminology

1. Combustion Air
2. Theoretical/Stoichiometric Air Requirement
3. Excess Air
4. Mole method of calculation

1. Combustion Air

For all practical purposes, dry air can be assumed to contain 21.0% by vol. of oxygen and 79.0% by vol. of nitrogen so that the molar ratio of N_2/O_2 is 79/21 or 3.76

2. Theoretical or Stoichiometric Air Requirements

The quantity of oxygen theoretically required to ensure complete combustion

As the composition of air is known, the *Theoretical or Stoichiometric Air* can easily be calculated by multiplying the stoichiometric oxygen by the molar ratio of 100/21 i.e. 4.76.

Please correct in the notes page 39

3. Excess Air

In almost all practical combustion systems it is necessary to use more than the stoichiometric amount of air, to ensure complete combustion.

This additional air is referred to as *excess air*, and is denoted as a percentage or fraction over the stoichiometric amount.

3. Excess Air

Excess air is important because it:-

- allows plant performance to be optimized on order that running costs are minimised
- may have a significant influence on pollutant emission, especially NO_x, CO, particulates and soot. Hence formation of these pollutants depends on excess air.
- affect the recorded value of emission due to dilution

Calculation of the Air Requirement for Complete Combustion of Fuel Gases

Example 1

Calculate the theoretical air-gas ratio at MSC of a fuel gas manufactured by the ICI 500 process containing (by volume)

14.8% CO_2
2.7% CO
48.9% H_2
33.6% CH_4

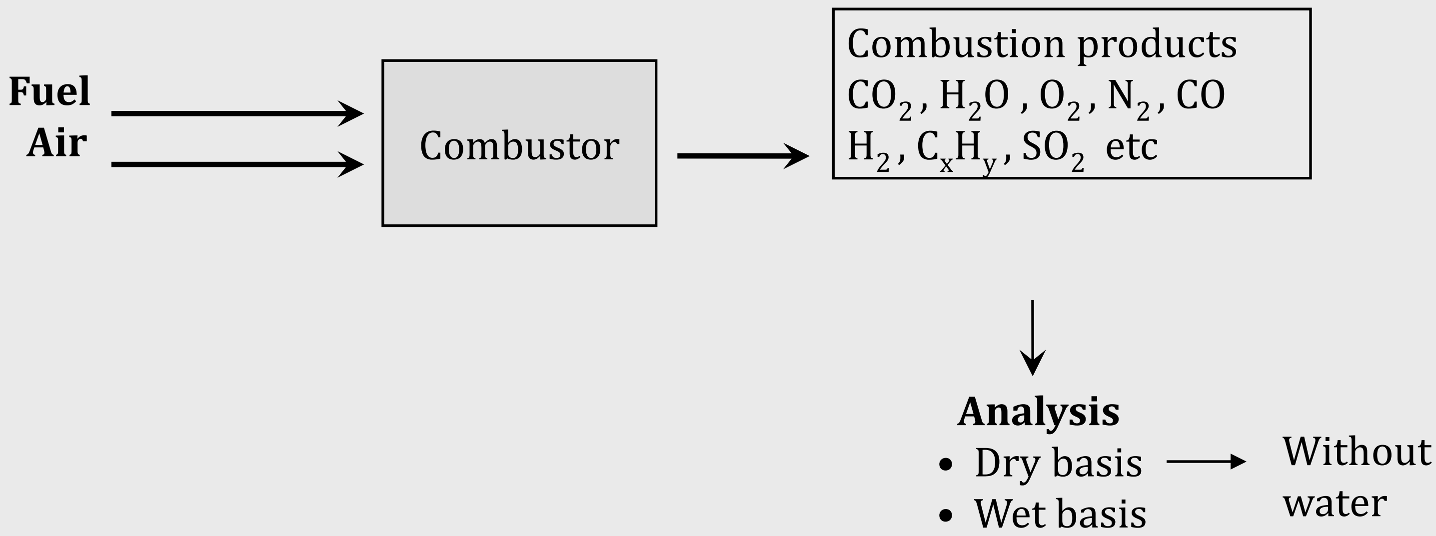
(1) Constituent	(2) Volume fraction	(3) Theoretical O_2 gas ratio	(4) (2) x (3) O_2 required
CO_2 CO H_2 CH_4			

The air requirement for each fuel gas is given by the O_2 requirement x 100/21 thus, The theoretical air-gas ratio = 0.93 x 4.76 = 4.43

Fuel and Flue Gas Composition Calculations

Gravimetric or weight or mass analysis…….. Mass fraction → x_i

Volumetric analysis…….. Mole fraction → y_i



Fuel and Flue Gas Composition Calculations

Conversion of gravimetric analysis to volumetric analysis and vice-versa;

$$x_i = \frac{y_i MW_i}{MW_{mix}}$$

Example 2

The volumetric composition of a sample of gases fuel is the following: H_2 = 50%, CH_4 = 20%, C_2H_4 = 2%, CO_2 = 5%, CO = 16%, N_2 = 7%

1. Determine the molecular weight and the density of the mixture at STP (15^oC & 1 atm) if the total pressure is 1 atm.

2. Determine also the gravimetric composition or composition by weight

* Use Table in Chapter 2 page 19

Dew Point of Flue Gas

The dew point of a gaseous mixture is the temperature at which its water vapour starts condensing, i.e. the temperature at which the saturation pressure of water equals the partial pressure of water vapour in the gaseous mixture.

Dew Point of Flue Gas

To determine the dew point temperature of the products, T_{dp}, the partial pressure of the water vapor is required.

- Dalton's law

$$p_{water} = y_{water} P_T \quad \text{and} \quad y_{water} = \frac{n_{water}}{n_{products}}$$

If the total pressure of the products is assumed to be atmospheric , i.e. 101.325 kPa , then from a steam table, find $T_{d.p} = f(P_{water})$

Example 3

Find the dew point of a flue gas at 150^{o}C being exhausted out of chimney at atmospheric condition. The flue gas composition is

CO_2	13%,
SO_2	0.05%,
O_2	6.75%,
N_2	75%
H_2O	5.2%

Combustion Efficiency

It is an indication of the burner's ability to burn fuel. The amount of unburned fuel, CO and excess air in the exhaust are used to assess a burner's combustion efficiency

$$\eta_{comb} = 100 - uhc_{ineff} - CO_{ineff}$$

$$\eta_{comb} = 100 - 100\left[\frac{(V_{uhc} * CV_{uhc}) + (V_{co} * CV_{co})}{(V_{fuel} CV_{fuel})}\right]$$

Example 3a

Question 3

In class group homework 2

Discuss and prepare the solution of question no 5 page 64

All member must submit

Leader please make sure every member complete the solution and compile before hand in today

Question?

THE END

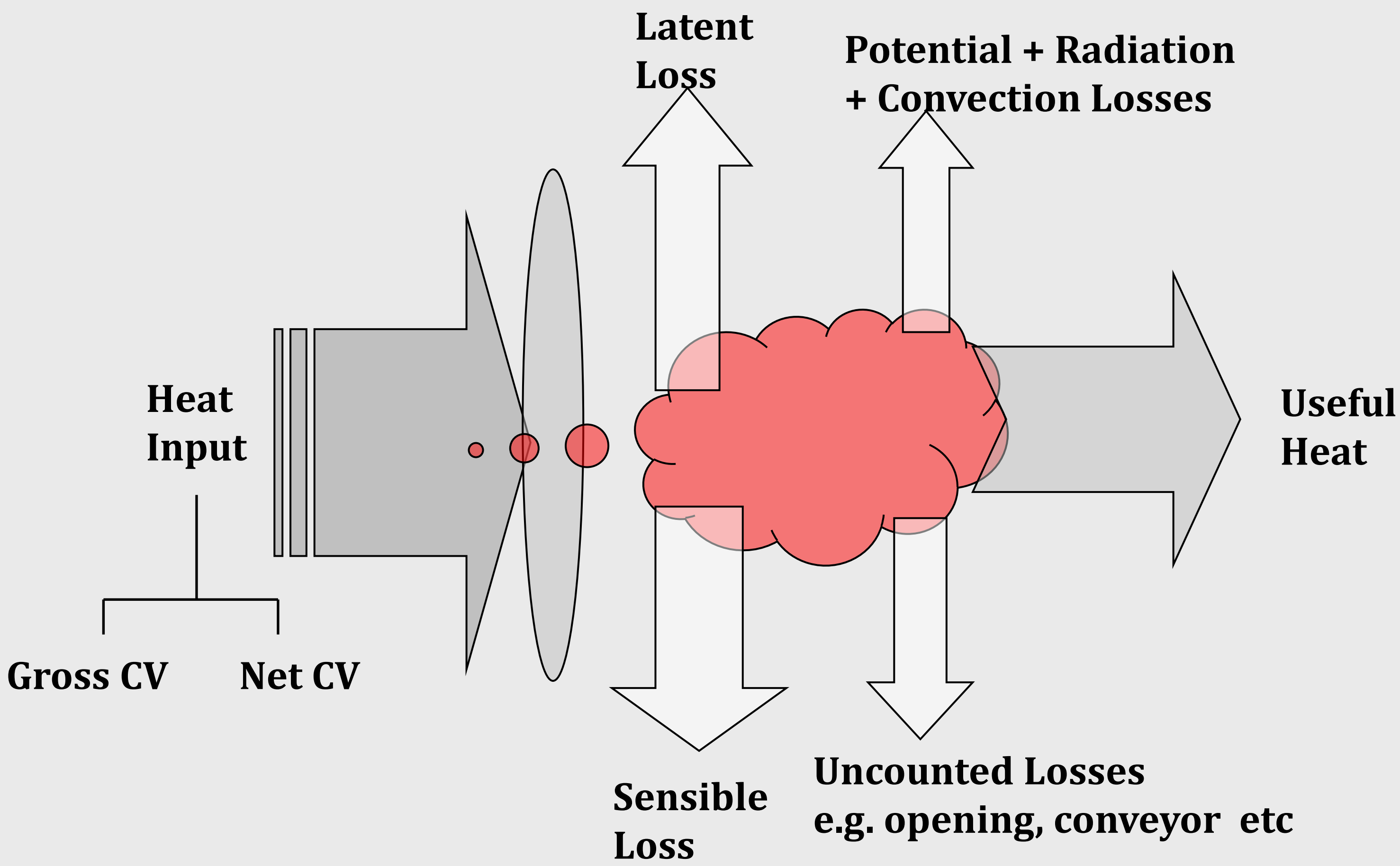
Thank You for the Attention

Heat Loss

Heat loss in the products of combustion is a combination of several parameters;

- Sensible loss i.e. the total enthalpy of the various component gases (CO_2, N_2, O_2, SO_x, NO_x) at the dry flue gas temperature
- Heat losses due to sensible heat of the water vapour, the latent heat at condensation and the sensible heat of liquid water
- Potential losses, i.e. of available heat due to unburnt combustible components

Sankey Diagram



Heat Losses due to the presence of water in flue gas

$$L_{latent} = \Delta H_{sl} + \Delta H_{v} + \Delta H_{sv}$$

$$\Delta H_{sl} = \dot{m}_{H_2 0} C_{pl}(T_{dp} - T_{ref})$$

$$\Delta H_{v} = \dot{m}_{H_2 0} \lambda \text{ ......where } \quad \lambda = f(h_{fg} \ at \ T_{dp})$$

$$\Delta H_{sv} = n_{H_2 0} \int_{T_{dp}}^{T_{flue}} C_p dT$$

Thermal Efficiency

It measures the ability of the exchanger to transfer heat from the combustion process to processing heating medium such as water or steam.

It also accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses.

$$\eta_{\text{thermal}} = \frac{\text{useful heat}}{\text{heat input}}$$

Example 5

Methane is burned with air in a PA Hilton boiler to produce hot water of 55^{o}C. The fuel is fed at a rate of 7 kg/hr at 25^{o}C , the air enters the boiler at a rate of 130 kg/hr at 42.5^{o}C, and the water enters the boiler at a flow rate of 1000 kg/hr at 10^{o}C. The composition of the dry flue gas leaving the boiler at 700^{o}C are found to be 0.9% O_2, 9.7% CO_2, 0.02% CO and the balance N_2

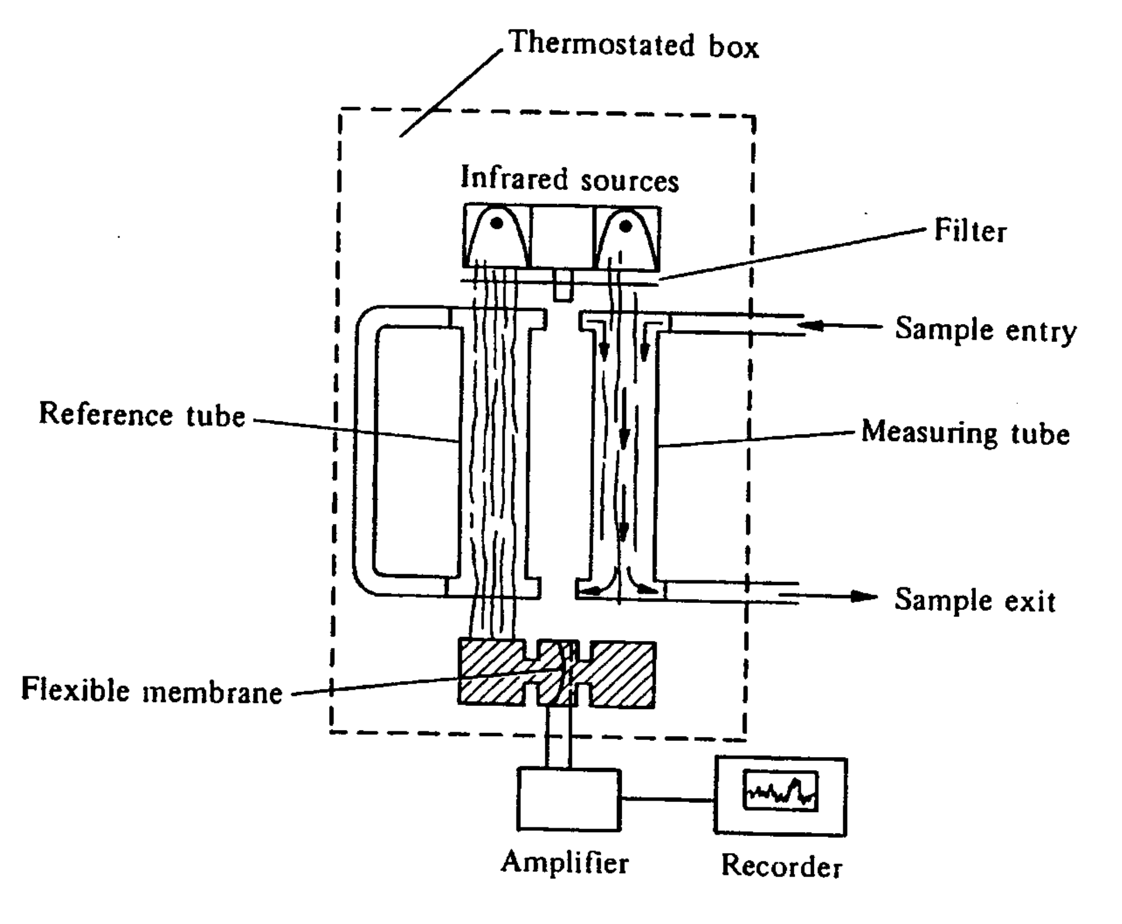
- Sketch a process flow diagram of the above process
- Construct a Sankey diagram showing the percentage of heat available and losses from various sources
- Calculate the combustion and thermal efficiencies of the above process

Analysis of Natural Gas Combustion Product

To determine

i) fuel: air ratio
ii) combustion efficiency
iii) heat content of flue gases for energy balance
iv) thermal efficiency calculations and for measuring the emission of pollutant or toxic gas.

Infra Red

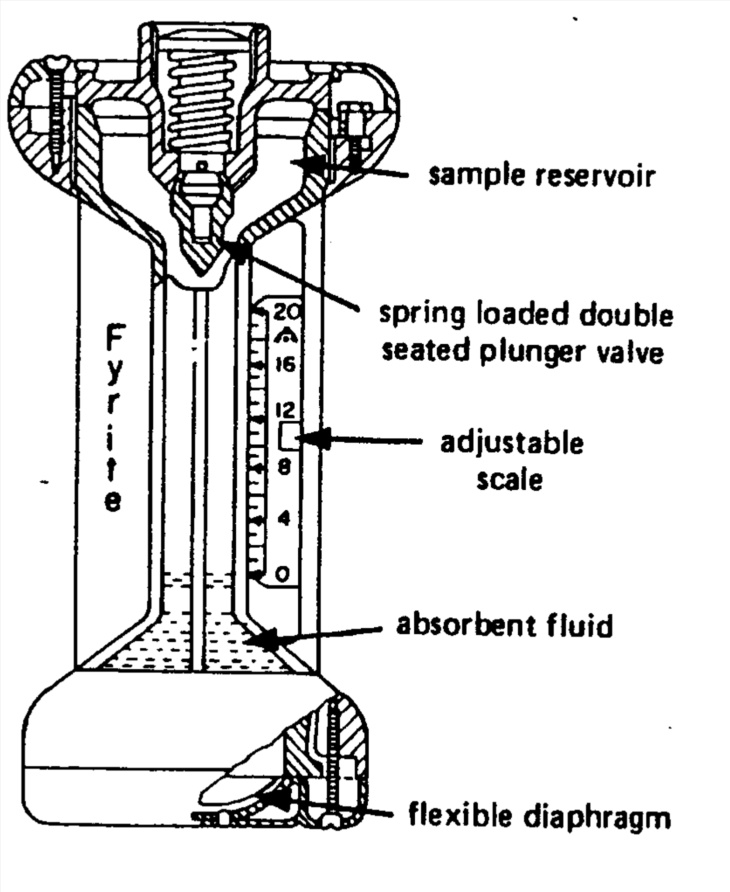


Thermostated box
Infrared sources
Filter
Sample entry
Reference tube
Measuring tube
Sample exit
Flexible membrane
Amplifier
Recorder

Infra Red

- Consist 2 platinum element – one is passivated and the other one is catalyst coated
- The heat of combustion heats the catalytic filament, thus increasing its electrical resistance.
- This in turn unbalances a bridge circuit which produces a measurable voltage change.
- This voltage change is amplified and made proportional to the total concentration of combustible gases present.
- The output signal usually is calibrated in percent of CO or CO_2.
- High accuracy
- Not suitable for field testing

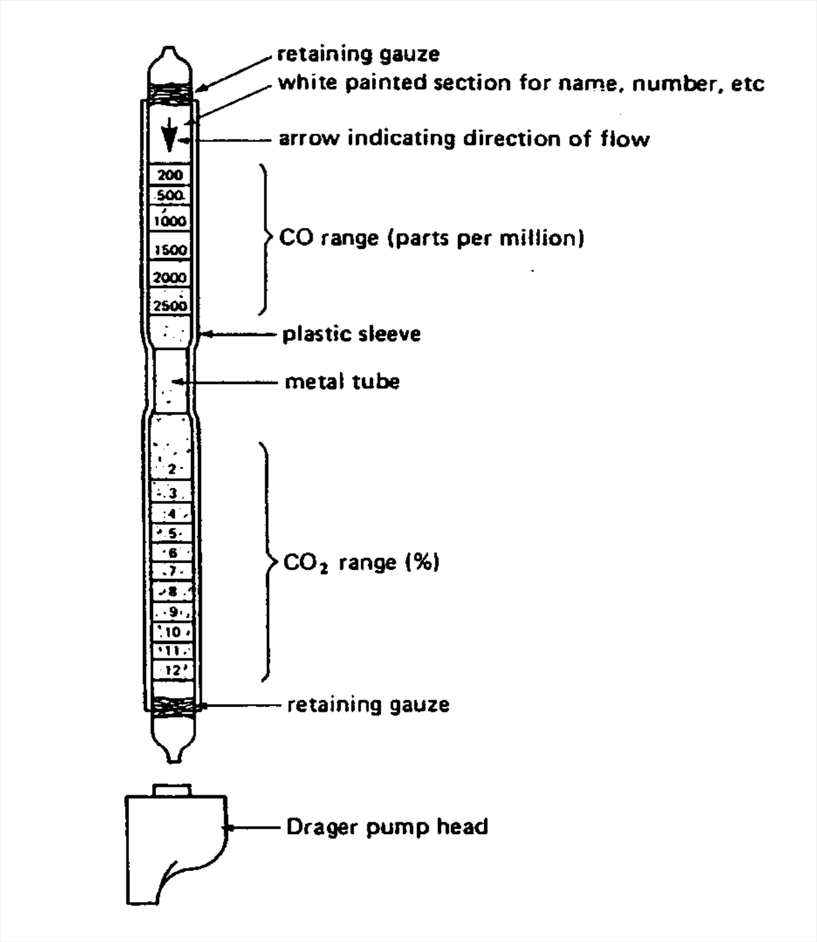
Fyrite Analyzer



Fyrite Analyzer

- turning the tube upside down and noting the change in liquid level when it is returned to the upright position
- Several inversions are necessary until a constant reading
- is easy to operate

Draeger Tube Analyzer



Draeger Tube Analyzer

- used for detecting carbon monoxide, carbon dioxide, oxides of nitrogen and excess oxygen in the products of combustion from appliances and furnaces.

- The concentration of the constituent gas is obtained from the length of discolouration of the absorbent chemical within the graduated tube.

- Simple and portable

- Suitable for both usage for field and laboratory testing

Question?

THE END

Thank You for the Attention