Mechanical Engineering

Power Plant Engineering

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
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Power Plant Engineering

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CHAPTER 02

Fuels and Combustion

2.1 Introduction

The primary fuels which are burned to release heat and generate steam in boilers are the fossil fuels in the form of coal, fuel oil and natural gas, which represent the remains of plant and animal life that are preserved in the sedimentary rocks.

When more than one type of fuel is simultaneously burned to meet the total heating requirement, the boiler is said to have a combination firing.

2.2 Coal

Coal originated from vegetable matter which grew millions of years ago. Trees and plants falling into water decayed and latter produced peat bogs.

According to geological order of formation, coal may be of the following types.

- Peat — Not regarded as a rank of coal.
- Lignite — **Low rank**
- Sub-bituminous
- Bituminous
- Sub-anthracite
- Anthracite — **High rank**, less volatile, difficult to burn, higher heating value.

These are in the increasing percentage of carbon:

- **Anthracite contains** more than **86% fixed carbon** and less volatile matter, **volatile matter helps in the ignition of coal.** So it is often difficult to burn anthracite.
- **Bituminous** coal is the largest group containing **46–86% of fixed carbon** and **20–40% of volatile matter**. It can be **low volatile**, **medium volatile** and **high volatile**.

Lower the volatility, higher the heating value and less it will smoke:

- **Lignite** is the lowest grade of coal containing moisture as high as 30% and high volatile matter.
- **Peat contains** up to 90% moisture and is not attractive as a utility fuel.

2.3 Coal Analysis

There are two types of coal analysis.

(i) Proximate analysis (ii) Ultimate analysis

2.3.1 Proximate Analysis

The proximate analysis indicates the behaviour of coal when it is heated. When 1 g sample of coal is subjected to a temperature of about 105ºC for a period of 1 hour, the loss in weight of the sample gives the moisture content of the coal.

When 1 g sample of coal is placed in a covered platinum crucible and heated to 950ºC and maintained at that temperature for about 7 min, there is a loss in weight due to the elimination of moisture and volatile matter. Volatile matter consists of hydrogen and certain hydrogen-carbon compounds which can be removed from the coal simply by heating it.

By subjecting 1 g sample of coal in an uncovered crucible to a temperature of about 720ºC until the coal is completely burned, a constant weight is reached, which indicates that there is only ash remaining in the crucible.

- Fixed carbon is the difference between 100% and the sum of the percentages of moisture, ash and volatile matter.
- It is also possible that some of this fixed carbon may include sulphur, nitrogen and oxygen.

  So, **Fixed carbon + Volatile matter + Moisture + Ash = 100%**

  $\Rightarrow$ **$FC + VM + M + A = 100\%$** by mass.

- Lower rank coals (lower fuel ratio) are characterized by a greater oxygen content, that aids ignition and enhances combustibility and flame stability.
- High combustibility improves carbon burnout (reduces carbon carryover) and hence boiler efficiency and for pulverized coal-fired units, this allows the coal to be grind to a coarser size.

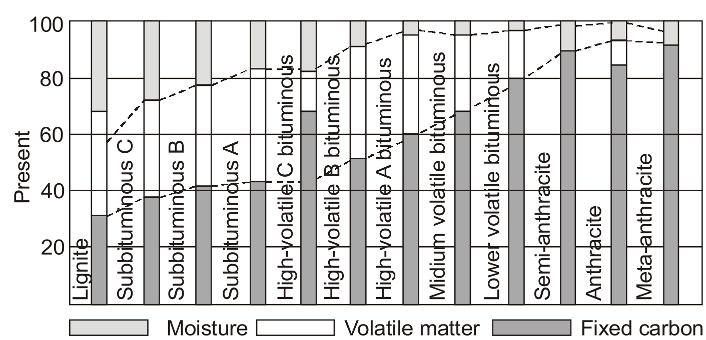


Fig. 2.1

2.3.2 Ultimate Analysis

Ultimate analysis produces the **chemical elements** that comprises the coal substance, together with ash and moisture. The coal substance consists of organic compounds of carbon, hydrogen and oxygen derived from the original vegetable matter. The analysis shows the following components on mass basis:

Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S), Moisture (M) and ash (A) = 100%. or **C + H + O + N + S + M + A = 100%** by mass.

The dry and ash free analysis on combustible basis is obtained by dividing CHON and S by the fraction

$$\left[1-\frac{M+A}{100}\right]$$

2.4 Coal Properties

Swelling Index: Some types of coal during and after release of volatile matter becomes soft and pasty and form agglomerates. These are called **caking coal**.

Coal that does not cake is called free burning coal. It brakes during combustion exposing large surface area to the air, thus enhancing the combustion process. Caking coals are used to produce coke by heating in a coke oven in the absence of air with the volatile matter driven off. Coal devoid of volatile matter is called coke, which is largely needed in steel plants.

A qualitative method, called the swelling index, has been devised to determine the extent of caking of a coal. **A free burning coal has a high value of Swelling Index; which indicates that it somewhat expands in volume during combustion.**

Grindability: Grindability is often an important criterion for selecting a coal. This property of coal is measured by the standard grindability index, which is inversely proportional to the power required to grind the coal to a specified particle size for burning. Grindability of a standard coal is assumed as 100.

Weatherability: It is a measure of how well coal can be stock piled for long periods of time without crumbling to pieces. Excessive crumbling or weathering of the coal due to climatic conditions may result in small particles of coal which can be dispersed by wind.

Sulphur Content: Sulphur content in coal is combustible and generates some energy by its oxidation to SO_2. Sulphur dioxide is a major source of atmospheric pollution. The operating cost by SO_2 removal equipment is needed to be considered while selecting a coal with high sulphur content.

Heating Value: The heating value or calorific value of coal is a property of fundamental importance. It is the heat transferred when the products of complete combustion of a sample of coal (or other fuel) are cooled to the initial temperature of air and fuel. Two different heating values are cited for coal.

The **Higher Heating Value** (HHV) assumes that the water vapour in the product condenses and thus includes the latent heat of vapourization of the water vapour formed by combustion. The **Lower Heating Value** (LHV) assumes that the water vapour formed by combustion leaves as vapour itself. Hence

$$LHV = HHV - m_w h_{fg} = HHV - 2.395 m_w \text{ MJ/kg}$$

where, m_w is the mass of water vapour formed given by

$$m_w = M + 9H + \gamma_A W_A.$$

where, M and H are the mass fractions of moisture and hydrogen in the coal, γ_A is the specific humidity of atmospheric air and W_A is the actual amount of air supplied per kg of coal.

If the ultimate analysis is known, the HHV of anthracite and bituminous coals can be determined approximately by using Dulong and petit formula as:

$$\text{HHV} = 33.83\,\text{C} + 144.45\left(H - \frac{O}{8}\right) + 9.385 \text{ MJ/kg}$$

Assuming the latent heat of vaporization h_{fg} at the partial pressure of water vapour in the combustion products as 2.395 MJ/kg, the lower heating value of coal is

$$\text{LMV} = \text{HHV} - 2.95 m_w \text{ MJ/kg}$$

Ash Softening Temperature: The ash softening temperature is the temperature at which the ash softens and becomes plastic. This is somewhat below the melting point of ash. For a furnace that would discharge ash in the solid form, a high ash softening temperature would be required.

A stoker furnace must use coal with a high ash softening temperature, otherwise clinkers would be formed. Clinkers, which are large masses of fused ash, cause troubles in discharge and also make combustion inefficient.

Spontaneous Combustion: Combustion of coal takes place rapidly as in a furnace or slowly on a stockpile. If it takes place slowly, there is a degradation or loss of energy content and hence in the value of fuel. The factors which influences spontaneous combustion and which can lead to a big fire are the following:

- Rank of coal, low rank coals are more susceptible because of their higher porosity.
- Amount of surface area exposed to air.
- Ambient temperature, with high solar insolation aiding it.
- Oxygen content of coal.
- Free moisture in coal.

Coal Liquification: The conversion of coal into a liquid fuel requires the addition of hydrogen to coal. Coal has a ratio of hydrogen atoms to carbon atoms of only 0.8 to 1 while in petroleum this ratio is 1.75 to 1. There are three basic modes that have been used to liquify coal. These are:

- hydrogenation
- catalytic conversion
- hydropyrolysis

In the **hydrogenation** process, coal and catalyst are suspended as a slurry, which is reacted with hydrogen ***at high*** pressure and moderate temperature to form liquid hydrocarbons.

In **catalytic conversion** process, a synthesis gas is produced from the coal. The hydrogen and carbon ***monoxide*** in the gas are then combined in the presence of a catalyst to form a liquid hydrocarbon fuel.

In **hydropyrolysis**; coal is heated beyond 450ºC, the fraction of coal volatilized greatly exceeds the volatile matter in coal. The hydrogen entrained pulverized coal is flash pyrolyzed. Upto 50% of the coal can thus be liquefied.

Combustion Reaction: The combustible elements in coal and fuel oil are carbon hydrogen and sulphur. The basic equations for complete combustion are:

$$C + O_2 \rightarrow CO_2$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$S + O_2 \rightarrow SO_2$$

When insufficient oxygen is present, the carbon will be burned incompletely with the formation of carbon monoxide.

$$2C + O_2 \rightarrow 2CO$$

In order to burn a fuel completely, four basic conditions must be fulfilled:

- Supply enough air for complete combustion of fuel.
- Secure enough turbulence for thorough mixing of fuel and air.
- Maintain a furnace temperature high enough to ignite the incoming fuel air-mixture.
- Provide a furnace volume large enough to allow time for combustion to be completed.

2.5 Actual Air-Fuel Ratio

The actual amount of air supplied per kg fuel can be ascertained from the measured volumetric composition of combustion products. These methods includes:

- Orsat analyzer
- Haldane apparatus
- Infrared gas analyzer
- Gas chromatograph

Orsat gas analyzer measures the volume or mole fraction of CO_2, CO and O_2 in the dry flue gas. An Orsat analyzer contains three pipettes containing chemical solutions.

The reagents normally used are a **KOH solution to absorb the CO_2 gas**, **Pyrogallol solution to absorb the O_2 gas** and **a cuprous chloride mixture ($CuCl_2$) to absorb the CO gas**.

The remaining unabsorbed gas is nitrogen. Since the sample is collected over water, any water vapour in the flue gas would have condensed during the collection process. The SO_2 gas will react with water in the container. So

$$CO_2 + CO + O_2 + N_2 = 100\% \text{ by volume}$$

The total heat released by complete combustion of 1 kg coal is

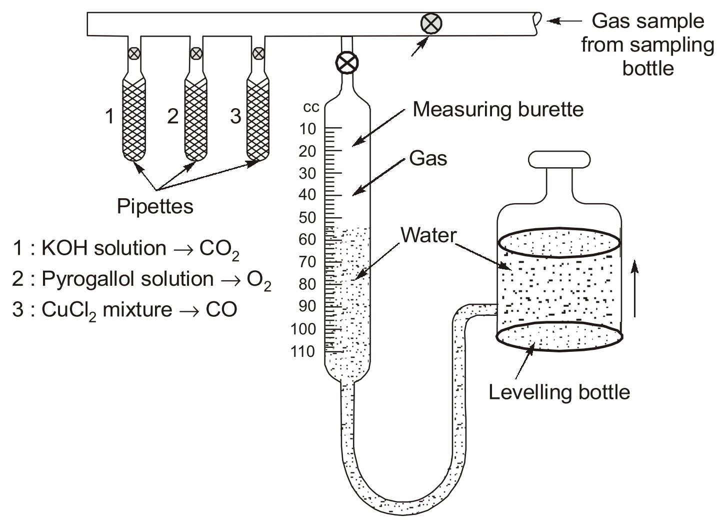


Fig. 2.2 Orsat analyser

$$HHV = 33.837C + 144.45\left(H - \frac{O}{8}\right) + 9.38S \quad \text{MJ/kg}$$

Example 2.1 The exhaust gas composition obtained from a apparatus in a test is as follows: CO_2 = 11%, O_2 = 0.4% and CO = 9%. If the fuel is isooctane (C_8H_{18}) determine the air/fuel ratio of the mixture delivered to the engine. Assume molecular weight of air = 29, H_2 = 2.0 and C = 12.0. Molar ratio of nitrogen to oxygen in air is 3.76.

Solution:

$$xC_8H_{18} + a(O_2 + 3.76\,N_2) \rightarrow 11CO_2 + 9CO + 0.4O_2 + 79.6N_2 + bH_2O$$

C-balance:
$$8x = 11 + 9 = 20$$
$$x = 2.5$$

H-balance:
$$18x = 2b$$
$$18 \times 2.5 = 2b \quad \text{or} \quad b = 22.5$$

O-balance:
$$2a = 22 + 9 + 0.8 + b$$
$$2a = 31.8 + 22.5$$
$$a = 27.15$$

Actual air supplied
$$= \frac{27.15 \times 32}{0.232} = 3744.8 \text{ kg}$$

Air-fuel ratio
$$= \frac{3744.8}{2.5(8 \times 12 + 1 \times 18)} = 13.13$$

2.6 Cooling Limit of Exhaust Gas

At partial pressure, the saturation temperature of water vapour is called the **dew point temperature (DPT)** . Flue gases are cooled in heat exchangers like economiser, air preheater, so as to minimize the loss of exhaust heat through chimney. However, exhaust gases should never be cooled below the dew point temperature.

If cooling is done below DPT, the water vapour condenses into liquid droplets which react with SO_2 or SO_3 to form acid (H_2SO_4), which corrodes the metal surfaces of the ducts through which the flue gas flows. That is the reason, temperature of flue gases leaving the preheater is kept above 160°C.

2.7 Control of Excess Air

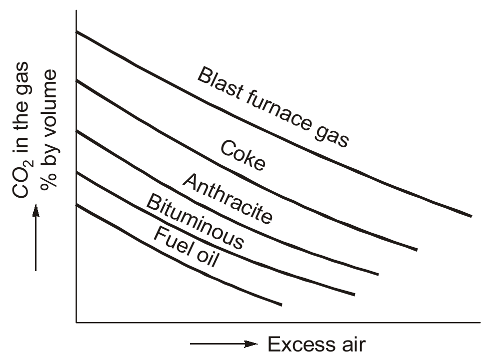


Fig. 2.3

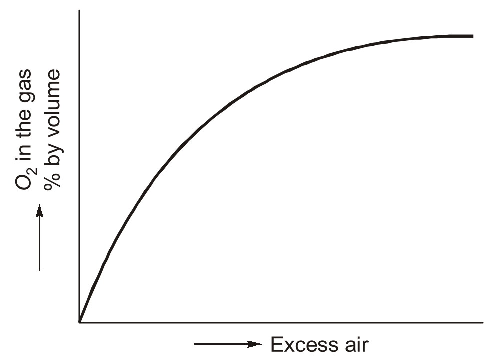


Fig. 2.4

Proper control of the right amount of excess air maintains optimum combustion efficiency. Amount of CO_2 and O_2 in combustion gases are indexes of excess air. The desirable CO_2 level depends on the fuel and the optimum excess air for the furnace. Desirable O_2 values depend much less on the type of fuel. If the measured O_2 content is more than that desired, the air supply is to be reduced. If it is less than the desired, air supply is to be increased.

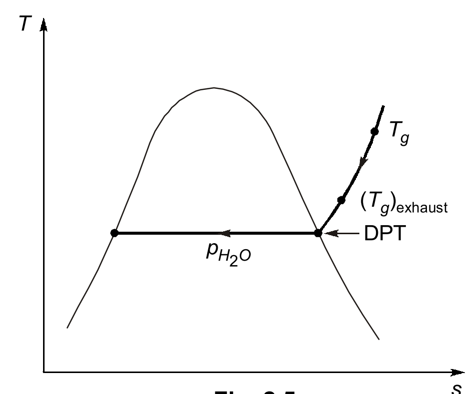


Fig. 2.5

$$\% \text{ excess air} = \frac{O_2 - 0.5CO}{0.264N_2 - (O_2 - 0.5CO)} \times 100$$

where, O_2, CO and N_2 are the volumetric percentages in the dry flue gases. % excess air

$$= 100\left[\frac{CO_2}{(CO_2 + CO)} - 1\right] = 100\left[\frac{O_2 - 0.5CO}{21 - O_2}\right]$$

where, (CO_2)=% CO_2 in the stoichiometric products. All components are in percentage.

Example 2.2 Propane (C_3H_8) is used as a fuel in an engine with 30% excess air. Assuming complete combustion determine the composition of exhaust gases on mass basis. Atomic weights are C = 12, O = 16, N = 14, H = 1. Molar ratio of nitrogen to oxygen is 3.76. [IES : 1994]

Solution:

$$C_3H_8 + x(O_2 + 3.76N_2) \rightarrow aCO_2 + bH_2O + cN_2$$

Carbon balance: $a = 3$

H balance: $8 = 2b$ or $b = 4$

O balance: $2x = 2a + b$

$2x = 2 \times 3 + 4 = 10$ or $x = 5$

N balance: $7.52x = 2c$

$7.52 \times 5 = 2c$ or $c = 18.8$

Now as 30% excess air is used

$$C_3H_8 + 1.3 \times 5\,(O_2 + 3.76\,N_2) = 3CO_2 + 4H_2O + cO_2 + d\,N_2$$

Now again O balance gives us

$$1.3 \times 5 \times 2 = 3 \times 2 + 4 + 2c$$

$\Rightarrow$ $c = 1.5$

again N balance

$$1.3 \times 5 \times 3.76 \times 2 = 2d$$

$$d = 24.44$$

Mass analysis

$$CO_2 = 3 \times 44 = 132 = \frac{132}{936.32} \times 100 = \mathbf{14.09\%}$$

$$H_2O = 4 \times 18 = 72 = \frac{72 \times 100}{936.32} = \mathbf{7.69\%}$$

$$O_2 = 1.5 \times 32 = 48 = \frac{48 \times 100}{936.32} = \mathbf{5.12\%}$$

$$N_2 = 24.44 \times 28 = 684.32 = \frac{684.32 \times 100}{936.32} = \mathbf{73.08\%}$$

2.8 Draught (or Draft) System

The gaseous combustion products in huge quantity have to be removed continuously from the boiler furnace. To produce the required flow of either air or combustion gas, a pressure difference is needed.

Small pressure difference causing flow of air and gases (in and out) through the boiler is called **draught** (or **draft**).

The function of draught system is basically two-fold:

- To supply to the furnace the required quantity of air for complete combustion of fuel.
- To remove the gaseous products of combustion from the furnace and throw these via chimney or stack to the atmosphere.

2.8.1 Natural Draught

The natural draught is produced by a chimney or a stack. It is caused by the **density difference** between the atmospheric air and the hot gas in the stack. For a chimney of height H meters the draught or pressure difference (N/m^2) produced is given by:

$$\Delta p = gH(\rho_a - \bar{\rho}_g)$$

where, ρ_a = Density of atmospheric air; kg/m^3.

$\bar{\rho}_g$ = Average gas density in the chimney, kg/m^3.

g = Acceleration due to gravity (9.81 m/s^2)

Assuming both air and gas as ideal gases,

$$\Delta p = gH\left[\frac{p_a}{R_aT_a} - \frac{p_g}{R_gT_g}\right]$$

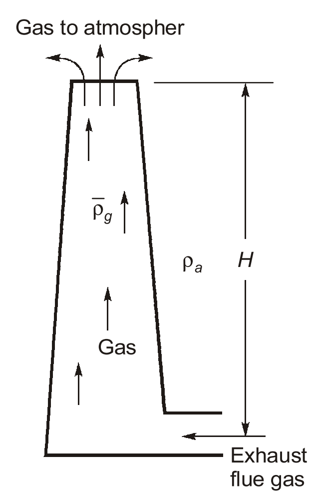


Fig. 2.6

where, $p_a = p_g = 101.325 \text{ kN/m}^2$

$R_a = R_g = 0.287$ kJ/kgK

T_g = average temperature in the chimney, K

$= \dfrac{(T_0 + T_H)}{2}$

T_0 = Gas temperature at inlet to the chimney, K

T_a = Absolute temperature of atmospheric air, K

T_H = Gas temperature at exit from the chimney, K

$$\Delta p = \frac{gHp_a}{R_a}\left[\frac{1}{T_a} - \frac{1}{T_g}\right]$$

Tall and conspicuous from a distance, chimney or stacks are used in all power plants.

In all the modern boilers, the fuel burning rate is high, and so the rate of air supply as well as the rate of flue gas removal is high. There are various heat exchangers like superheaters, reheater, economizer and air preheater on the way to cause large pressure losses for which stacks alone are insufficient, and fans are added for producing mechanical draught. Stacks have thus two functions:

- To assist the fans in overcoming pressure losses.
- To help disperse the gas effluent into the atmosphere at a sufficient height to cause minimum atmosphere pollution.

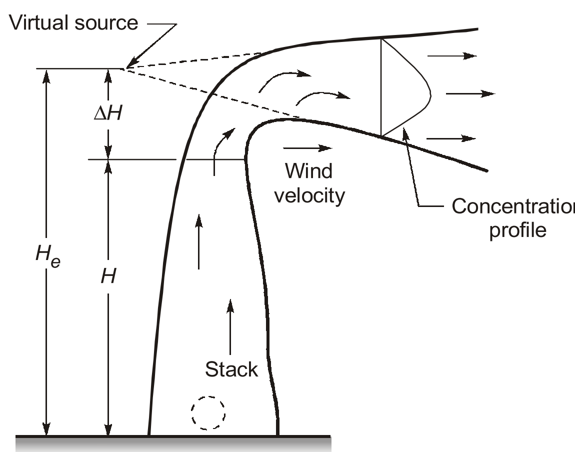


Fig. 2.7

Dispersion of flue gases into the atmosphere is defined as the movement of the flue gases horizontally as well as vertically and their dilution by the atmosphere. The exit velocity of flue gases at stack exit results in a plume rise ΔH above the actual stack. The gases has been in the direction on wind flow. The effective stack height H_e is given by

$$H_e = H + \Delta H$$

2.8.2 Mechanical Draught

Mechanical draught is produced by fans. There are types of fans in use:

- forced draught (FD) fans
- induced draught (ID) fans

When either one is used alone, it should overcome the total air and gas pressure losses within the steam generator.

(a) **Forced draught:** Fans are **installed at inlet to the air preheater**. They **handle cold air**. So they have less maintenance problems, consumes less power (since cold air has less specific volume, and work input per unit mass flow rate is given by mvdp) and therefore the capital and operating costs are lower.

If m_f is the fuel burning rate, ν is the specific volume (m^3/kg) of inlet air and Δp_{FD} is the pressure head developed by the fan to overcome all the pressure losses, then the power required to drive the FD fan is:

$$\text{Power input} = \int mvdp = \frac{m_f \times \frac{A}{F} \times \nu_a \times \Delta p}{\eta_{FD}} \text{kW} = \frac{m_f \times \frac{A}{F} \Delta p}{\rho_{air} \times \eta_{FD}} \text{ kW}$$

η_{FD} = Efficiency of forced draught fan and.
A/F = air-fuel ratio

For good reliability, two forced draught fans operating in parallel are normally used, each capable of undertaking at least 60% of full load air flow, when the other is out of service.

The forced draught fan maintains the entire system up to the stack entrance under positive gauge pressure. The furnace is said to be pressurized.

The stack in such situation is shorter and meant only for disposal of flue gases.

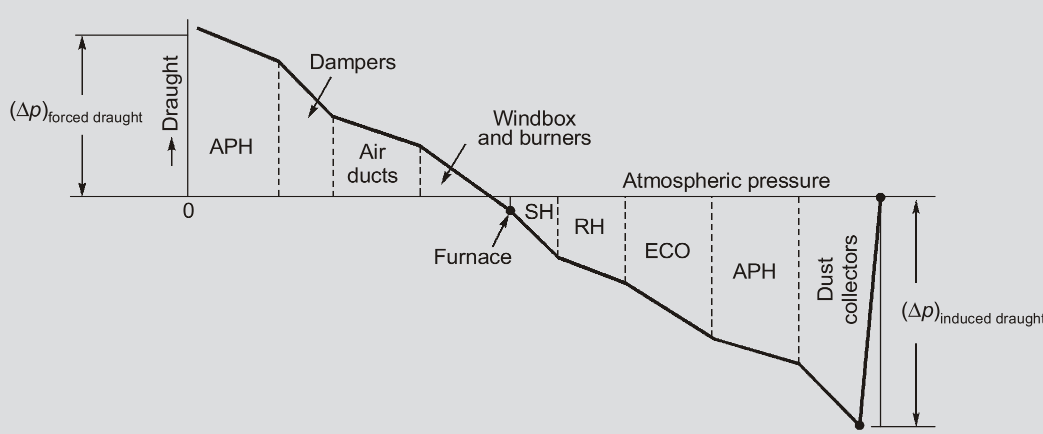
(b) **Induced draught:** Fans are normally located at the **foot of the stack**. They handle **hot combustion gases**. There power requirements are, therefore, greater than forced draught fans. In addition they must cope with corrosive combustion product and fly ash. Induced draught fans are seldom used alone. They discharge essentially at atmospheric pressure and place the system upstream under negative gauge pressure.

If ν_g is the specific volume of the flue gases handled by the ID fan and Δp_{ID} is the pressure head developed, then the power needed to drive the ID fan is

$$\text{Power input} = \int m_g v_g dp = \frac{m_f \times \left(1 + \frac{A}{F}\right) \times \nu_g \times \Delta p_{ID}}{\eta_{ID}} \text{ kW} = \frac{m_f \left(1 + \frac{A}{F}\right) \Delta p_{ID}}{\rho_g \times \eta_{ID}} \text{ kW}$$

NOTE

When both forced and induced draught fans are used in a steam generator, the FD fans push atmospheric air through the air preheater, dampers, various air ducts and burners into the furnace, and ID fans suck out the flue gases through the heat transfer surfaces in the superheaters, reheaters, economiser, gas-side air preheater and dust collectors and discharge into the stack. In such a cases the furnace is said to be operate with balanced draught, meaning that the pressure in it is approximately atmospheric. Actually, it is maintained at a ***slightly negative gauge*** pressure to avoid inward leakage.



2.9 Fans

There are two types of fans viz. **centrifugal and axial**. In the centrifugal fan, the gases are accelerated radially through curved or flat impeller blades from rotor to a spiral or volute casing.

In the axial fan, gases are accelerated parallel to the rotor axis. Axial fans have higher capital costs.

Centrifugal fans have forward curved, flat or backward curved impeller blades.

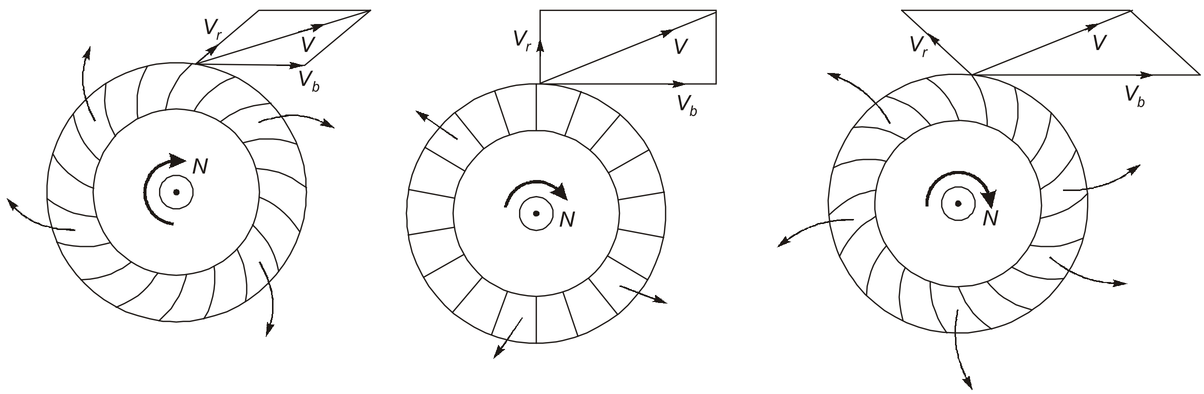


Fig. 2.8

The absolute velocity V is the same in all three cases. **For same V, the blade tip velocity V_b is the highest for the backward curved blades and the lowest for forward curved blades.**

Since $V_b = \frac{\pi DN}{60}$ for same tip diameter D, the rpm N is the highest for backward curved blades and lowest for forward curved blades.

If FD fans should have high V_b so as to rotate at high speed and handle large volume flow of air. Therefore, **centrifugal fans with backward-curved blading are normally used for FD fans.**

The ID fans handle dust laden flue gases and so the blades are subject to erosion by the fly ash. The erosion rate of blades is lower if the blade tip speed V_b is less and fan rotates at lower speeds.

Therefore **centrifugal fans having forward-curved or flat blading are used for ID fans.** Low-speed fans with flat blades are used for particularly dirty or corrosive gases.

In damper control, a damper is used to control the flow of gas by regulating the flow area according to the load. It has the advantage of low capital cost since it needs a simple constant speed induction AC motor. Dampers are usually put on the outside of the fan, although dampers at inlet to the fan are sometimes used.

Inlet dampers consume less power than outlet dampers but are only effective for moderate load changes near full load.

Variable-speed control has the advantage of less power consumption and is the most efficient method for fan control. The effect of speed on fan performance is:

- Volume flow $\propto$ N
- Pressure head $\propto N^2$
- Power input $\propto N^3$

where, N is the rpm of the fan.

The types of drives are:

- Variable-speed steam turbine
- Variable-speed DC motor
- Electronically adjustable motor drive.
- Hydraulic coupling
- Multiple speed AC motor

Primary air fans supply air to dry and transport pulverized coal to the furnace.

Fans are a major source of noise in power plants. To reduce this noise, they are often housed in thick masonry acoustical enclosures or equipped with silencers or both.

Summary

- The calorific value of the fuel is defined as the amount of heat energy liberated by complete combustion of a unit quantity of a fuel. It is also called the heating value. It is measured in kJ/kg or kJ/m^3.
- After the combustion, if the products are cooled to the reactant's temperatures then the water vapour gets condensed and the heat of its vaporisation is recovered. Thus, the calorific value is called the higher calorific value or gross calorific value.
- Fuel is a combustible matter. It consists of bonded chemical energy between its constituent elements. The combustion is an exothermic process, in which the rapid oxidation of fuel takes place with a release of heat energy.
- The lower or net calorific value is the amount of heat released by complete combustion of unit quantity of fuel, when water vapour in the products is in gaseous form.
- The gross or higher calorific value of powdered and liquid fuels is determined at constant volume in the bomb calorimeter, while calorific value of a gaseous fuel is determined by Junker's calorimeter at constant pressure.
- The enthalpy of formation is defined as the enthalpy of a substance at a specified stage due to its chemical composition. During a combustion process, the amount of heat released is called the enthalpy of combustion.
- The Orsat apparatus is used for fuel gas analysis on the volume basis. It uses the chemical absorption technique.
- The air has 23% of oxygen and 77% nitrogen by mass and 21% of oxygen and 79% of nitrogen by volume. The theoretical amount of air that supplies just sufficient oxygen for complete combustion of all elements of the fuel is termed as stoichiometric air required. The air-fuel ratio is defined as the ratio of mass of air to the mass fuel during the combustion process.

Objective Brain Teasers

Q.1 Consider the following statements :
1. Pulverized fuel gives high and controlled burning rate.
2. Insufficient air causes excessive smoking of exhaust.
3. Excess air is provided to control the flue gas temperature.
4. Effect of sulphur in fuel is to give high heat transfer rate.

Which of these statements are correct?
(a) 3 and 4 (b) 2 and 3
(c) 1 and 2 (d) 1 and 4

Q.2 In steam generators, a stoker acts as one of the following devices. What is this device?
(a) Air preheating device
(b) Steam superheating device
(c) Air superheating device
(d) Fuel feeding device

Q.3 For maximum discharge the draught in mm of H_2O is given by (H = height of chimney. T = chimney gas temperature, T_1 = atmosphere temperature)
(a) $h = 176.5\dfrac{H}{T}$
(b) $h = 176.5\dfrac{H}{T_1}$
(c) $h = 176.5\dfrac{T}{H}$
(d) $h = 176.5\dfrac{T_1}{H}$

Q.4 A chimney of height 40 m has mean flue gas temperature of 327°C. The temperature of outside air is 30°C. The air-fuel ratio is 14.3. Draught produced in mm of water column is
(a) 20.26 mm H_2O
(b) 21.42 mm H_2O
(c) 23.26 mm H_2O
(d) 24.61 mm H_2O

Q.5 The higher calorific value of fuel occurs when water vapour
(a) present in products of combustion is condensed to the initial temperature of the fuel
(b) present in products of combustion is not condensed to the initial temperature of the fuel
(c) is not formed during combustion of a fuel
(d) is formed during combustion of a fuel

Q.6 Consider the following statements:
The difference between higher and lower heating values of the fuels is due to
1. heat carried by steam from the moisture content of fuel.
2. sensible heat carried away by the fuel gases.
3. heat carried away by steam from the combustion of hydrogen in the fuel.
4. heat lost by radiation.

Which of these statements is/are correct?
(a) 2, 3 and 4
(b) 1 and 2
(c) 3 only
(d) 1, 2, 3 and 4

Q.7 The expression for stoichiometric air required for combustion of coal having C, H, O and S is
(a) $4.32\left(2.67C + H - \dfrac{O}{8} + S\right)$
(b) $4.32\left(2.67C + 8H + S - \dfrac{O}{8}\right)$
(c) $2.67C + 8\left(H + \dfrac{O}{8}\right) + S$
(d) $2.67C + 8\left(H - \dfrac{O}{8}\right) + S$

Answers

1. (c)	2. (d)	3. (b)	4. (b)	5. (a)
6. (c)	7. (a)			

Hints and Explanations:

1. (c)
- Excess air is provided for complete combustion.
- Smoke is formed due to formation of carbon mono oxide.

3. (b)
Mass of hot gases flowing through the chimney,

$$\dot{m}_g = \rho_g A V_g$$

$$\rho_g = \frac{C_1}{T_g}$$

$$V_g = C\sqrt{2gH_g} \quad (C_1 \text{ \& } C \text{ are constant})$$

H_g = Hot column gas in m.

$$\dot{m}_g = AC_2\sqrt{2gH\left[\frac{m}{m+1}\frac{T_g}{T_a} - 1\right]} \times \frac{1}{T_g}$$

Maximum discharge is a function of T_g

$$\therefore \frac{d\dot{m}_g}{dT_g} = 0 = -\frac{m}{m+1}\frac{1}{T_a T_g^2} + \frac{2}{T_g^3}$$

$$\therefore \frac{T_g}{T_a} = 2\left(\frac{m+1}{m}\right)$$

The draught in mm of water column,

$$h = \frac{353H}{T_a}\left[1 - \frac{m+1}{m}\frac{T_a}{T_g}\right] = \frac{353H}{T_a}\left[1 - \frac{1}{2}\right]$$

$$\therefore \quad h = \frac{176.5H}{T_a}$$

T_a = Atmospheric temperature

T_g = Chimney gas temperature

4. (b)

$$h = 353H\left[\frac{1}{T_1} - \left(\frac{m+1}{m}\right)\frac{1}{T_2}\right]$$

$$= 353 \times 40\left[\frac{1}{303} - \frac{14.3+1}{14.3} \times \frac{1}{600}\right]$$

$$= 21.42 \text{ mm } H_2O$$

6. (c)

The difference between higher and lower heating values of the fuels is due to heat carried away by steam (i.e., latent heat from the combustion of hydrogen in the fuel).

Student's Assignments

Q.1 The volumetric analysis of flue gases obtained from the combustion of an unknown hydrocarbon fuel is CO_2 = 12.1%, CO = 0.5%, O_2 = 3.2% and N_2 = 84.2%. Determine the excess air supplied at percentage of theoretical air.

[Ans. 15%]

Q.2 The ultimate analysis of a sample of petrol was C-85.5% and H-14.5%. The analyse of the dry products gave 14% of CO_2 and some O_2. Calculate the A/F ratio supplied to the engine and the mixture strength.

[Ans. 15.72/1 : 94%]

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