THEORY & OBJECTIVE

THERMODYNAMICS APPLICATION

(I.C, RAC & POWER PLANT)

By
Team of
Engineers Academy

- State Engineering Services Examinations.
- Public Sector Examinations.
- JEn (SSC, DMRC & State Level).
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I.C. ENGINE

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1

INTRODUCTION TO INTERNAL COMBUSTION ENGINE

THEORY

1.1 HEAT ENGINES

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and used this energy to produce mechanical work. Heat engines are classified into two broad types :

(a) External combustion engines

(b) Internal combustion engines

1.1.1 External Combustion Engines

In an external combustion engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle, as in the case of a steam engine or a steam turbine plant where the heat of combustion is employed to generate steam which is used in a piston engine or a turbine. Stirling engine is also an external combustion engine.

Advantage of External Combustion Engines :

- Use of cheaper fuels including solid fuels
- High starting torque.

1.1.2 Internal Combustion Engines

In an internal combustion engine, the products of combustion are directly the motive fluid. Petrol, gas, and diesel engines, Wankel engines and open cycle gas turbines are examples of internal combustion engines. Jet engines and rockets are also internal combustion engines.

Advantages of Internal Combustion Engines :

- Greater mechanical simplicity.
- Lower ratio of weight and bulk to output due to absence of auxiliary apparatus like boiler and condenser.
- Lower cost.
- Higher overall efficiency.
- Lesser requirement of water for dissipation of energy through cooling system.

1.2 Engine Components and Basic Engine Nomenclature

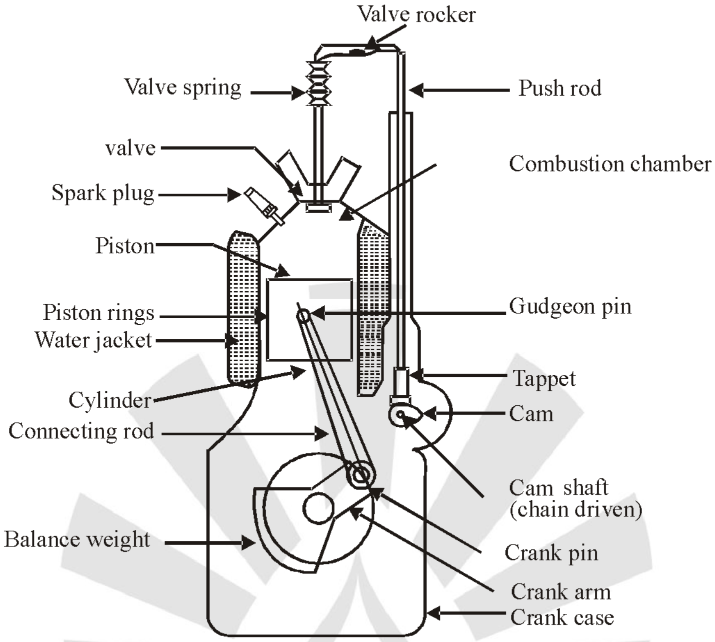


Fig Cross-section of spark-ignition engine

The figure shows the cross-section of a single cylinder spark-ignition internal combustion engine. The cylinder is supported in position by the cylinder block at the top end is covered by cylinder head.

In the cylinder, a piston travels in reciprocating motion. The space enclosed between the upper part of the cylinder and the top of the piston during the combustion process is called the combustion chamber.

(1) Spark Plug : The spark plug supplies the spark that ignites the air/fuel mixture so that combustion can occur. The spark must happen at just the right moment for things to work properly.

(2) Valves : The intake and exhaust valves open at the proper time to let in air and fuel and to let out exhaust. Note that both the valves are closed during compression and combustion so that the combustion chamber is sealed.

(3) Piston : A piston is a cylindrical piece of metal that moves up and down inside the cylinder.

(4) Piston Rings : Piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder.

(5) The Rings Serve Two Purposes

(i) They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.

(ii) They keep oil in the from leaking into the combustion area, where it would be burned and lost. Most cars that "burn oil" and have a quart added every 1,000 miles are burning it because the engine is old and the rings no longer seal things properly.

(6) Connecting Rod : The connecting rod connects the piston to the crankshaft. It can rotate at both ends so that its angle can change as the piston moves and the crankshaft rotates.

(7) Crank Shaft : The crank shaft turns the piston up and down motion into circular motion just like a crank on a jack-in-the-box does.

(8) Sump : The sump surrounds the crankshaft. It contains some amount of oil, which collects in the bottom of the sump (the oil pan.)

- A mixture of air and fuel enters the cylinder through the carburettor in spark-ignition engine via the inlet manifold i.e. the pipe which connects the inlet port of the engine of the air intake.
- In carburettor a throttle is provided to control the mass of mixture entering the combustion chamber. In the cylinder head there are inlet valves for taking the charge in the cylinder and exhaust valves for discharging the products of combustion. A spark plug near the top of the cylinder initiates the combustion.
- The energy of the expanding gas is transmitted by the piston (having piston rings to prevent leakage) through the gudgeon pin to the connecting rod.
- The connecting rod and the crank arm of the crankshaft translate the reciprocating motion of the piston into rotational motion of the crank shaft. The crankshaft is supported in bearings attached to the crankcase.
- The crankcase is the main body of the engine to which the cylinder is attached. The products of the combustion leave through exhaust port and exhaust manifold, both the intake and exhaust valves are operated by the valve mechanism.
- Crankshaft is driven by the crankshaft through timing gears. Lobed cams on the camshaft actuate the push rods and rocker arms for opening the valve against the force of valve springs.

1.3 The Standard Terminology Used in Internal Combustion Engines

(1) Cylinder Bore (D) : The nominal inner diameter of the working cylinder.

(2) Piston Area (A) : The area of a circle of diameter of the working cylinder.

Note : For an engine, in which a piston rod passes through the combustion space, as in a double-acting engine, this area must be reduced by the area of the cross-section of the piston rod

(3) Stroke (L) : The nominal distance through which a working piston moves between two successive reversals of its direction of motion.

(4) Dead Centre : The piston of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).

(5) Bottom Dead Centre (BDC) : Dead centre when the piston is nearest to the crankshaft. In horizontal engines it is also called outer dead centre (ODC).

(6) Top Dead Centre (TDC) : Dead centre when the piston is farthest from the crankshaft. In horizontal engines it is also called inner dead centre (IDC).

(7) Displacement Volume or Piston Swept Volume (Vs) : The nominal volume generated by the working piston when travelling from one dead centre to next one, calculated as the product of piston area and stroke.

$$V_s = A \times L$$

(8) Clearance Volume (Vc) : The nominal volume of the space on the combustion side of the piston at top dead centre.

(9) Cylinder Volume (V) : The sum of piston swept volume and clearance volume.

$$V = V_S + V_C$$

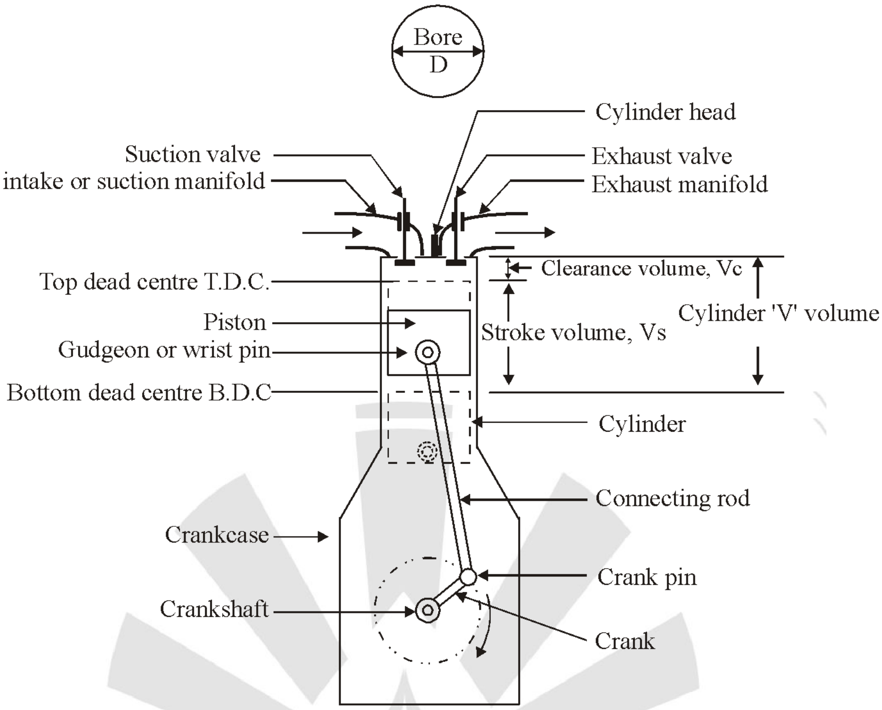


Fig. Important positions and volumes in reciprocating engine

(10) Compression Ratio (CR or r) : The numerical value of the cylinder volume divided by the numerical value of the combustion space volume or clearance volume.

$$\text{Compression ratio} = r = \frac{V}{V_c}$$

1.4 IC Engine Classification

- **Basic engine design :** Reciprocating engines, rotary (Wankel) engines.
- **Working cycle :** Engines working on Otto cycle (spark-ignition or S.I. engines), and engines working on diesel cycle (Compression -ignition or C.I. engines).
- **Number of strokes :** Four-stroke engines and two-stroke engines (both SI and CI engines).
- **Method of cooling :** Water cooled or air cooled.

1.5 Four-Stroke cycle spark-ignition engine

The cycle of operation is completed in four-strokes of the piston or two revolutions of the crankshaft. Each stroke consists of 180° of crankshaft rotation and hence a cycle consists of 720° of crankshaft rotation.

- **Suction Stroke :** Suction stroke 0-1 starts when the piston is at top dead centre and about to move downwards. The inlet valve is open at this time and the exhaust valve is closed. Due to the suction created by the motion of the piston towards bottom dead centre, the charge consisting of fresh air mixed with the fuel is drawn into the cylinder. At the end of the suction stroke the inlet valve closes.
- **Compression Stroke :** The fresh charge taken into the cylinder during suction stroke is compressed by the return stroke of the piston 1-2. During this stroke both inlet and exhaust valves remain closed.

1.8 Table Comparison of Four-Stroke and Two-Stroke Cycle Engines

	Four-stroke cycle	Two-stroke cycle
1.	The cycle is completed in four strokes of the piston or in two revolutions of the crankshaft. Thus, one power stroke is obtained in every two revolutions of the crankshaft.	The cycle is completed in two stroke of the piston or in one revolution of the crankshaft. Thus, one power stroke is obtained in each revolution of the crank-shaft.
2.	Because of the above, turning moment is not so uniform and hence heavier flywheel is needed.	More uniform turning moment and hence lighter flywheel is needed.
3.	Again, because of one power stroke for two revolutions, power produced for same size of engine is small, or for the same power the engine is heavy and bulky.	Because of one power stroke for one revolution, the power produced for same size of engine is more (theoretically twice, actually about 1.3 times), or for the same power the engine is light and compact.
4.	Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lesser rate of wear and tear.	Because of one power stoke in one revolution greater cooling and lubrication requirement. Greater rate of wear and tear.
5.	The four-stroke engine contains valves and valve mechanisms.	Two-stroke engines have no valves but only ports (some two stroke engines are fitted with conventional exhaust valve or reed valve).
6.	Because of the heavy weight and complication of valve mechanism, higher in initial cost.	Because of light weight and simplicity due to the absence of valve mechanism, cheaper in initial cost.
7.	Volumetric efficiency more due to greater time of induction	Volumetric efficiency less due to lesser time for induction.
8.	Thermal efficiency higher, part load efficiency better than two-stroke cycle engine.	Thermal efficiency lower, part load efficiency lesser than four-stoke cycle engine. In two-stroke petrol engines some fuel is exhausted during scavenging.
9.	Used where efficiency is important, in cars, buses, trucks, tractors, industrial engines, aero planes, power generation, etc.	Used were (a) low cost, and (b) compactness and light weight important. Two-stroke (air-cooled) petrol engines used in very small sizes only: lawn movers, scooters, motor cycles, mopeds etc. (lubricating oil mixed with petrol). Two-stroke diesel engines used in very large sizes, more than 60 cm bore, for ship propulsion because of low weight and compactness.

1.9 Table Comparison of SI and CI Engines

Description	SI Engine	CI engine
1. Basic cycle	Based on Otto cycle.	Based on Diesel cycle.
2. Fuel	Petrol (Gasoline). High self-ignition temperature desirable.	Diesel oil. Low self-ignition temperature desirable.
3. Introduction of fuel	Fuel and air introduced as a gaseous mixture in the suction stroke. Carburetor necessary to provide the mixture in the suction stroke. Carburetor necessary to provide the mixture-(except in not so common petrol injection engines). Throttle controls the quantity of mixture introduced.	Fuel is injected directly into combustion chamber at high pressure at the end of compression stroke. Carburetor is eliminated but a high pressure fuel pump and injector necessary. Quantity of fuel regulated in pump.
4. Ignition	Requires an ignition system with spark plug in the combustion chamber.	Self ignition due to high temperature caused by high compression of air, when fuel is injected. Ignition system and spark plug is eliminated.
5. Compression ratio range	6 to 10.5 Upper limit of C.R. fixed by antiknock quality of fuel.	14 to 22. Upper limit of C.R. is limited by the rapidly increasing weight of the engine structure as the compression ratio is further increased.
6. Speed	Higher maximum revolution per minute due to lighter weight.	Maximum r.p.m. lower.
7. Efficiency	Maximum efficiency is lower due to low compression ratio.	Higher maximum efficiency due to higher compression ratio.
8. Weight	Lighter	Heavier due to higher pressures.

1.10 Applications of IC Engines

- **Small Two-Stroke Petrol Engine :** Used where simplicity and low cost of the prime mover are the main considerations.
- **Small Four-Stroke Petrol Engines :** The most important application of small four-stroke petrol engines is in automobiles.
- **Radial Piston Engine in Small Aircraft Propulsion :** The small aircrafts generally use radial four-stroke petrol engines.

  Note : The modern large aircrafts use gas turbine plant as turboprop engine or turbojet engine,
- **Four-Stroke Diesel Engines :** The four-stroke diesel engine is one of the most versatile prime mover. It is manufactured in diameters from 5 cm to 60 cm.

  Diesel engines have been installed in many cars, particularly taxies. Diesel engines are used in diesel-hydraulic and diesel-electric locomotives. Diesel engines are also used in boats and in ships.
- **Two-Stroke Diesel Engines :** Very high power diesel engines for ship propulsion are generally two-stroke diesel engines. In fact, all engines over 60 cm bore are two-stroke engines.

1.12.3 Mechanical Efficiency (η_m)

The mechanical efficiency of an engine is defined as ratio of brake power (delivered power) to the indicated horsepower (power provided to the piston).

$$\eta_m = \frac{b.p}{i.p.}$$

$$= \frac{\eta_{b.t}}{\eta_{i.t}}$$

or $$\eta_{b.t} = \eta_m \times \eta_{i.t}$$

1.12.4 Volumetric Efficiency (η_v)

The engine output is limited by the maximum amount of air that can be taken in during the suction stroke, because only a certain amount of fuel can be burned effectively with a given quantity of air.

$$\eta_v = \frac{\text{mass of charge actually indicated}}{\text{mass of charge represented by cylinder volume at intake temperature and pressure condition}}$$

$$\eta_v = \frac{\text{charge aspirated per stroke reduced to intake conditions}}{\text{swept volume}} = \frac{V}{V_S}$$

1.12.5 Specific Fuel Consumption (sfc)

Brake specific fuel consumption and indicated specific fuel consumption, abbreviated as bsfc and isfc.

$$\text{bsfc} = \frac{\text{Fuel used in kg/h}}{\text{b.p. in kW}} = \frac{m_f}{\text{b.p.}}\text{kg / kWh}$$

$$\text{isfc} = \frac{\text{Fuel used in kg/h}}{\text{i.p. in kW}} = \frac{m_f}{\text{i.p.}}\text{kg / kWh}$$

1.12.6 Fuel-Air (F/A) or Air-Fuel(A/F) Ratio

This is expressed either as the ratio of the mass of the fuel to that of the air or *vice versa*.

$$\frac{F}{A} = \frac{m_f}{m_a}$$

$$\frac{A}{F} = \frac{\dot{m}_a}{\dot{m}_f}$$

Example :

Distinguish between the swept and clearance volume of a reciprocating engine. Define compression ratio. The engine of the fiat car has four cylinders of 68 mm bore and 75 mm stroke. The compression ratio is 8. Determine the cubic capacity of the engine and the clearance volume of each cylinder.

Solution :

Swept volume of one cylinder is

$$V_s = \frac{\pi}{4}d^2 \times l$$

$$= \frac{\pi}{4}(6.8)2 \times 7.5$$

$$= 272.38 \text{ cm}^3 \text{ (or c.c)}$$

Cubic capacity of the engine

= Total swept volume of all cylinders

= 272.38 × 4 = 1089.5 cm^3 **Ans.**

Compression ratio is

$$r = \frac{V}{V_c}$$

$$= \frac{V_c + V_s}{V_c}$$

$$8 = 1 + \frac{V_s}{V_c}$$

or $$\frac{V_s}{V_c} = r - 1$$

$$\frac{V_s}{V_c} = 8 - 1 = 7$$

Thus, clearance volume of each cylinder is

$$V_c = \frac{V_s}{7}$$

$$= \frac{272.38}{7} = 38.9\text{cm}^3$$

Example :

A diesel engine develops 5 kW. Its indicated thermal efficiency is 30% and mechanical efficiency 57%. Estimate the fuel consumption of engine in (a) kg/hr, (b) liters/hr, (c) indicated specific fuel consumption, and (d) brake specific fuel consumption.

Solution :

Mechanical efficiency, $$\eta_m = \frac{\text{b.p.}}{\text{i.p.}}$$

PRACTICE SHEET

OBJECTIVE QUESTIONS

1. Air standard efficiency of a diesel engine is dependent upon

(a) Cetane number

(b) Compression ratio

(c) Torque

(d) All of these

2. The gas turbine thermal efficiency if compared to diesel cycle

(a) Lower (b) Higher

(c) Same (d) None of these

3. Duration between the time of injection and time of ignition in a diesel engine is called

(a) Lead period

(b) Delay period

(c) Combustion period

(d) Period of compression

4. If gas turbine has its mechanical efficiency compared to I.C. engine then it is

(a) Lower (b) Higher

(c) Same (d) None of these

5. Air standard efficiency of closed gas turbine cycle is represented as

(a) $\eta = 1 - (r_p)^{\gamma - 1}$ (b) $\eta = 1 - \left(\frac{1}{r^p}\right)^{\frac{\gamma-1}{\gamma}}$

(c) $\eta = 1 - \frac{1}{(r_p)^{\gamma+1}}$ (d) $\eta = (r_p)^{\frac{\gamma-1}{\gamma}} - 1$

Where r_P is pressure ratio

6. In I.C. engines, motoring test is conducted to measure

(a) Mean effective pressure

(b) I.H.P.

(c) Friction horse power

(d) B.H.P.

7. With an ideal regenerative, heat exchange the thermal efficiency of gas turbine cycle is

(a) More than work ratio

(b) Equal to work ratio

(c) Less than work ratio

(d) Nothing can be said

8. When steam flows through the fixed blades in reaction turbine

(a) Pressure increases

(b) Velocity increases

(c) Velocity increases and pressure drops

(d) Pressure decreases

9. In a turbine dryness fraction is usually not allowed to fall below

(a) One (b) 0.89

(c) 0.50 (d) 0.77

10. Mean effective pressure can be expressed by dividing the work done by

(a) Total volume (b) Clearance volume

(c) Swept volume (d) None of these

11. In estimation of friction power by Willan's line method, which of the following is assumed constant?

(a) brake thermal efficiency

(b) volumetric efficiency

(c) indicated thermal efficiency

(d) mechanical efficiency

12. Stoichiometric ratio is

(a) Chemically correct air-fuel ratio by weight

(b) Chemically correct air-fuel ratio by volume

(c) Chemically correct air-fuel ratio by moles

(d) Chemically correct air-fuel ratio for maximum efficiency

13. Standard firing order for 6-cylinder S. I. engine is

(a) 1-2-3-4-5-6 (b) 1-3-5-4-2-6

(c) 1-4-2-6-3-5 (d) 1-5-3-2-6-4

55. Knocking behavior in C.I. engine increases
(a) Increased compression ratio
(b) Decreased compression ratio
(c) Increased inlet air temperature
(d) None of these

56. Function of clearance volume in reciprocating air compressors is
(a) Increase the overall efficiency
(b) Accommodate valves in the heat of the compressor
(c) Reduce the work done per kg of air delivered
(d) Create high heat

57. Knocking behaviours in petrol engine increases due to
(a) Increased speed (b) Decreased speed
(c) Rich air-fuel ratio (d) Lean air fuel ratio

58. Piston compression rings are made of
(a) cast iron (b) bronze
(c) aluminium (d) white metal

59. The mechanical efficiency of a single-cylinder four-stroke engine is 80%. The frictional power is estimated t be 20 kW. What is the brake power developed by the engine?
(a) 80 kW (b) 50 kW
(c) 70 kW (d) 75 kW

60. The intake charge in a diesel engine consists of
(a) air alone
(b) air + lubricating oil
(c) air + fuel
(d) air + fuel + lubricating oil

61. The cubic capacity of a four-storke SI engine is 250 cc. The oversquare ratio of engine is 1.2 and the clearance volume is 30 cc. What is the compression ratio of the engine?
(a) 8.5 (b) 9
(c) 9.33 (d) 10.33

62. The engine of a car has three cylinder with total displacement of 770 cc. The compression ratio is 8.7. What is the clearance volume of each cylinder?
(a) 34.4 cc (b) 33.33 cc
(c) 32.33 cc (d) 35.2 cc

63. The top of the piston in two stroke engine is
(a) flat (b) slanted
(c) crown shaped (d) convex shaped

64. Thermal efficiency of CI engine is higher than that of SI engine due to
(a) fuel used
(b) higher compression ratio
(c) constant pressure heat addition
(d) none of the above

❑❑❑

ANSWERS AND EXPLANATIONS

1. ***Ans. (b)***
2. ***Ans. (a)***
3. ***Ans. (b)***
4. ***Ans. (a)***
5. ***Ans. (b)***
6. ***Ans. (c)***
7. ***Ans. (c)***
8. ***Ans. (c)***
9. ***Ans. (b)***
10. ***Ans. (c)***
11. ***Ans. (c)***
12. ***Ans. (b)***
13. ***Ans. (c)***
14. ***Ans. (b)***

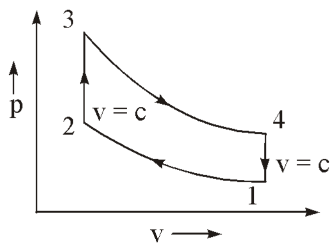
    Ports are mounted instead of valves.
15. ***Ans. (d)***
16. ***Ans. (c)***
17. ***Ans. (a)***

    Advancing the spark timing increases the tendency to preignite
18. ***Ans.* (b)**
19. ***Ans.* (d)**

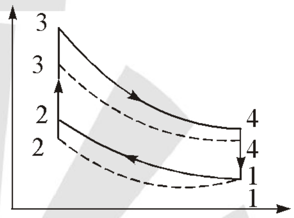
    Diesel engine is compression ignition engine.
20. ***Ans. (a)***
21. ***Ans. (b)***
22. ***Ans. (c)***
23. ***Ans. (b)***
24. ***Ans. (b)***

    As the intake air temperature increases, the tendency of air to mix up with fuel decreases.
25. ***Ans. (b)***

    S. I. engine works on otto cycle.



26. ***Ans. (b)***
27. ***Ans. (a)***
28. ***Ans. (b)***
29. ***Ans. (c)***
30. ***Ans. (b)***
31. ***Ans. (c)***
32. ***Ans. (d)***
33. ***Ans. (c)***



1–2–3–4– with constant specific heat.
1 –2 –3 –4 – with variable specific heat.

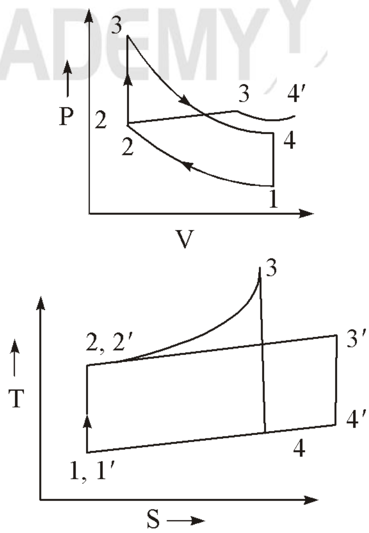
As temperature increases the value of γ decreases.

34. ***Ans. (b)***

    Oxidation of N_2 takes place at high temperature with availability of enough oxygen
35. ***Ans. (d)***
36. ***Ans. (a)***
37. ***Ans. (c)***

    Definition of indicated horse power.
38. ***Ans. (c)***

    In steam turbine the heat of combustion of fuel is first transferred to water to convert it into steam. Then steam is used as working fluid.
39. ***Ans. (b)***



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REFRIGERATION & AIR CONDITIONING

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REFRIGERATING MACHINE AND REVERSED CARNOT CYCLE

THEORY

1.1 INTRODUCTION

Refrigeration is defined as "the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place". It should be kept in mind that refrigeration is not ame as "cooling", even though both the terms imply a decrease in temperature. In general, cooling is a heat transfer process down a temperature gradient, it can be a natural, spontaneous process or an artificial process. However, refrigeration is not a spontaneous process, as it requires expenditure of exergy (or availability). Thus cooling of a hot cup of coffee is a spontaneous cooling process (not a refrigeration process), while converting a glass of water from room temperature to say, a block of ice, is a refrigeration process (non- spontaneous). "All refrigeration processes involve cooling, but all cooling processes need not involve refrigeration".

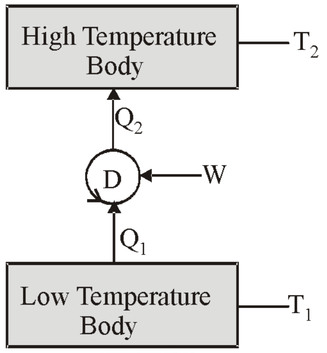
Refrigeration is a much more difficult process than heating, this is in accordance with the second laws of Thermodynamics. This also explains the fact that people knew 'how to heat', much earlier than they learned how to refrigerate'. All practical refrigeration processes involve reducing the temperature of a system from its initial value to the required temperature that is lower than the surroundings, and then maintaining the system at the required low temperature. The second part is necessary due to the reason that once the temperature of a system is reduced, a potential for heat transfer is created between the system and surroundings, and in the absence of a "perfect insulation" heat transfer from the surroundings to the system takes place resulting in increase in system temperature. In addition, the system itself may generate heat (e.g. due to human beings, appliances etc.), which needs to be extracted continuously. Thus in practice refrigeration systems have to first reduce the system temperature and then extract heat from the system at such a rate that the temperature of the system remains low. Theoretically refrigeration can be achieved by several methods. All these methods involve producing temperatures low enough for heat transfer to take place from the system being refrigerated to the system that is producing refrigeration.

1.2 THE SECOND LAW OF THERMODYNAMICS, THE KELVIN-PLANCK STATEMENT AND THE CLAUSIUS STATEMENT

Clausius Statement which is as follows :

Where Q_1 = referigation effect

" It is impossible to construct a device (D) which will operate in a cycle and produce no effect other than the transfer of heat from a low temperature body to a high temperature body"



Schematic representation of a refrigerator/heat pump

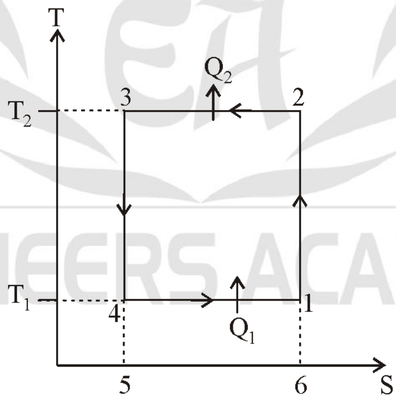
The Clausius statement eliminates the possibility of obtaining refrigeration without doing work. The only alternative is that there must be some work input W. From the first law $W = Q_2 - Q_1$. Accordingly, heat transferred Q_2 is more than heat absorbed Q_1 by the amount of work input W.

1.2.1 THE COROLLARIES OF IIND LAW COMPRISING THE CARNOT PRINCIPLE

1. Since a Refrigeration cycle operating reversible between two heat reservoirs has the highest coefficient of performance.
2. All reversible refrigeration cycles have the same COP.

1.3 IDEAL REFRIGERATION CYCLE / HEAT PUMP (BASED ON REVERSED CARNOT CYCLE)

Since a reversed Carnot cycle can be employed as a reversible refrigeration cycle, it would be a measure of maximum possible COP of a refrigerating machine operating between two temperatures T_K of heat rejection and T_0 of refrigeration.



Reversed Carnot Cycle

The cycle consists of two isothermals and two isentropics as follows :

Process 1-2 Isentropic compression, $s_1 = s_2$

Process 2-3 Isothermal heat rejection to the hot reservoir at T_2 = constant

Process 3-4 Isentropic expansion, $s_3 = s_4$

Process 4-1 Isothermal heat absorption from the cold reservoir at T_1 = constant

The areas on the T-s diagram, representing $\int Tds$ give the heat transfers.

PRACTICE SHEET

OBJECTIVE QUESTIONS

1. Which of the following can be called as a refrigeration process?

(a) Cooling of hot ingot from 1000°C to room temperature

(b) Cooling of a pot of water by mixing it with a large block of ice

(c) Cooling of human beings using a ceiling fan

(d) Cooling of a hot cup of coffee by leaving it on a table

2. A carnot refrigeration required 1.5 kW/ton of refrigerant to maintaned a space –30°C then COP

(a) 2.33 (b) 2

(c) 1.33 (d) None of these

3. One ton refrigeration is also equal to

(a) 800 kcal/day (b) 90 kcal/hr

(c) 14 cal/sec (d) 211 kJ/min

4. Food products can be preserved for a longer time at low temperatures because:

(a) At low temperatures the bacterial activity is reduced

(b) Enzymatic activity is increased at low temperatures

(c) Quality of food products improves at low temperatures

(d) All of the above

5. The cold chain is extremely useful as it:

(a) Makes seasonal products available throughout the year

(b) Reduces food spoilage

(c) Balances the prices

(d) All of the above

6. The useful storage life of food products depends on:

(a) Storage temperature

(b) Moisture content in the storage

(c) Condition of food products at the time of storage

(d) All of the above

7. Cold storages can be used for storing:

(a) Live products such as fruits, vegetables only

(b) Dead products such as meat, fish only

(c) Both live and dead products

(d) None of the above

8. Fast freezing of products is done to:

(a) Reduce the cell damage due to ice crystal growth

(b) Reduce energy consumption of refrigeration systems

(c) Reduce bacterial activity

(d) All of the above

9. The higher temperature of the refrigerator 50°C and the lower is – 10°C, while capacity is 20 tons. The coefficient of performance of the system is

(a) 4.10 (b) 5.38

(c) 3.62 (d) 4.38

10. One ton of refrigeration can be defined as

(a) Refrigeration for freezing 1 ton of water into ice

(b) One ton of refrigerant is used at 273 K in 12 hours

(c) Capacity of freezing 1 ton of water from at 0°C in 24 hours

(d) One ton of water which can be converted into ice in 24 hours

11. Products involving fermentation reactions require refrigeration because:

(a) Fermentation process is exothermic

(b) Fermentation process is endothermic

(c) Fermentation has to be done at uncontrolled temperatures

(d) All of the above

12. Supermarket refrigeration requires:

(a) Provision for storing a wide variety of products requiring different conditions

(b) Reliable refrigeration systems due to the high value of the perishable products

(c) Large refrigerant inventory due to long refrigerant tubing

(d) All of the above

13. Refrigeration is required in petrochemical industries to:

(a) Separate gases by fractional distillation

(b) Provide safe environment

(c) Carry out chemical reactions

(d) All of the above

14. Cold treatment of metals is carried out to:

(a) To stabilize precision parts

(b) To improve hardness and wear resistance

(c) To improve ductility

(d) All of the above

15. Refrigeration is used in construction of dams etc to:

(a) Avoid crack development during setting of concrete

(b) Avoid water evaporation

(c) Reduce cost of construction

(d) All of the above

16. Refrigeration is required in remote and rural areas to:

(a) Store fresh and farm produce

(b) Store vaccines in primary health centres

(c) Store milk before it is transported to dairy plants

(d) All of the above

17. Compared to urban areas, in rural areas:

(a) Continuous availability of grid electricity is not ensured

(b) Space is constraint

(c) Refrigeration is not really required

(d) Refrigeration systems cannot be maintained properly

18. Modern electronic equipment require cooling due to:

(a) Dissipation of relatively large amount of heat in small volumes

(b) To prevent erratic behaviour

(c) To improve life

(d) All of the above

19. For refrigerating system work done per kg of air is 30 kcal and heat extracted per kg of air is 45 kcal. Amount of refrigerant used is 10kg. The coefficient of performance of systems i.e.

(a) 6.52 (b) 1.50

(c) 10.56 (d) 0.67

20. COP for refrigerator and heat pump are related as

(a) $COP_h = COP_r - 1$

(b) $COP_h = COP_r$

(c) $COP_h = COP_r + 1$

(d) $COP_h = \frac{1}{COP_r}$

21. A refrigeration machine working on reverse carnot cycle takes out 2kW from a system. While working between temperature limit of 300 K and 200 K. Then the COP and power input are

(a) 2 and 1 kW (b) 1 and 2 kW

(c) 3 and 2 kW (d) None of these

where r is isentropic compression or expansion.

22. The working temperature in evaporator (–30°C) and condenser (32°C), if the actual refrigerator having COP of 0.75 times $(COP)_{max}$. Then power input of a refrigeration capacity of 5 kW

(a) 7 kW (b) 1.7 kW

(c) 2.7 kW (d) 3 kW

23. Centigrade and fahrenheit scale have same value at

(a) –120°C (b) –85°C

(c) –32°C (d) 273°C

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ANSWERS AND EXPLANATIONS

1. ***Ans. (b)***

2. ***Ans. (a)***

Given P_{in} = 1.5 kW ;

RC = 1 ton = 3.5 kW

Then $COP = \dfrac{3.5}{1.5} = 2.33$

3. ***Ans. (d)***

1TR = 3.5 kW

= 3.5 kJ/sec = 3.5 × 60 kJ/min

= 210 kJ/min

4. ***Ans. (a)***

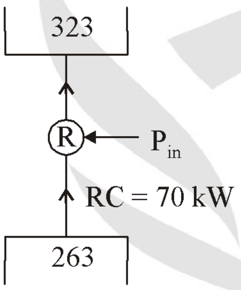
5. ***Ans. (d)***

6. ***Ans. (d)***

7. ***Ans. (c)***

8. ***Ans. (a)***

9. ***Ans. (d)***



$$COP = \frac{263}{323-263} = 4.38$$

10. ***Ans. (c)***

11. ***Ans. (a)***

12. ***Ans. (d)***

13. ***Ans. (a)***

14. ***Ans. (b)***

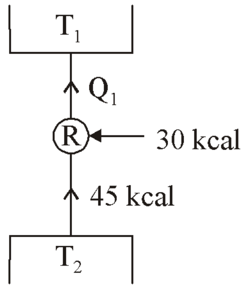
15. ***Ans. (a)***

16. ***Ans. (d)***

17. ***Ans. (a)***

18. ***Ans. (d)***

19. ***Ans. (b)***



$$COP = \frac{45}{30} = 1.5$$

20. ***Ans. (c)***

21. ***Ans. (a)***

$$COP = \frac{T_1}{T_2 - T_1} = \frac{200}{300-200} = 2$$

And $COP = \dfrac{RC}{P_{in}} \Rightarrow P_{in} = \dfrac{2}{2} = 1 \text{ kW}$

22. ***Ans. (a)***

Given T_1 = –30°C = 243 K

T_2 = 32°C = 305 K

$$(COP)_{max} = \frac{T_1}{T_2 - T_1} = \frac{243}{305-243}$$

= 3.91

Again $(COP)_{act.} = 0.75(COP)_{max}$

= 0.75 × 3.91 = 2.94

$= \dfrac{RC}{P_{in}}$

$\Rightarrow \quad P_{in} = \dfrac{5}{2.94} = 1.7 \text{ kW}$

23. ***Ans. (c)***

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THEORY & OBJECTIVE

POWER PLANT

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CONTENTS

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1 STEAM GENERATORS/BOILERS

THEORY

1.1 INTRODUCTION

Steam is mainly required for power generation, process heating and space heating purposes. The capacity of the boilers used for power generation is considerably large compared with other boilers.

Due to the requirements of high efficiency, the steam for power generation is produced at high pressures and in very large quantities.

The boilers generating steam for process heating are generally smaller in size and generate steam at a much lower pressure. A steam generator popularly known as boiler is a closed vessel made of high quality steel in which steam is generated from water by the application of heat. The water receives heat from the hot gases through the heating surfaces of the boiler. The hot gases are formed by burning fuel, may be coal, oil or gas.

In simple, a boiler may be degined as a closed vessel in which steam is produced from water by combustion of fuel.

The main requirements of steam generators or boiler are:

(i) Water must be contained safely

(ii) Steam must be safely delivered in desired condition (as required its pressure, temperature, quality).

1.2 CLASSIFICATION OF BOILERS

1.2.1 According to the relative position of water and hot gases

Fire tube or smoke tube boilers and water tube boilers:

(i) In fire tube boilers, hot gases pass through tubes which are surrounded with water. The Cochran, Lancashire and Locomotive are examples of this type of boilers. Due to their simplicity and because of the small capacity requirements of these boilers are used for producing process steam.

(ii) In water tube boilers, the water circulates through the tubes and hot gases around them. Steam is generated inside the tubes and collected in a cylindrical vessel known as boiler drum found suitable for different capacity and pressure requirements, from process steam to power generation.

2.2.2 According to the axis of shell

The boilers are classified as vertical boilers and horizontal boilers. In vertical steam boilers, the axis of the shell is vertical whereas it is horizontal in case of horizontal steam boilers.

1.2.3 According to the method of the furnace

(i) In externally fired boilers, the furnace is placed outside the boiler shell. The advantage of this type is that the fire place is simple and may be enlarged easily. Water tube boilers are always externally fired.

(ii) In internally fired boilers, the furance is placed inside the boiler shell. Most of the fire tube boilers are of this type.

1.2.4 According to the method of water circulation

Boilers are also classified as natural circulation and forced circulation boilers:

(i) In natural circulation boilers, the water is circulated by natural convection currents which are set up due to the temperature difference.

(ii) In forced circulation boilers, water is circulated with the help of a pump driven by motor. Forced circulation is used mainly in high pressure high capacity boilers.

1.3 BOILER TERMS

The details of the boilers are listed below :

- **Shell :** The shell of the boilers is the main container usually of cylindrical shape, which contains water and steam.
- **Furnace :**A furnace is another important part of the boiler. This may be a grate to burn coal or a burner to atomize and burn liquified fuel. Suitable area and volume should be provided for efficient combustion.
- **Water Flow Path :** Water flow path is the path followed by the water in the boiler (particularly in water tube boiler) during the process of absorption of heat from hot gases and conversion into steam.
- **Gas Flow Path :** The hot gas flow path either in fire tube or in water tube should be arranged in such a way that maximum heat of hot gases should be transferred to the water for steam generation. The boiler efficiency mainly depends upon the gas flow path.
- **Steam Path :** In most of the boilers, the steam is taken out preferably at the top of the shell to avoid water particles being carried with the steam. To reduce the water particles carried by the steam, it is generally taken out through steam separators, in the case of large boilers.
- **Fittings :** The valves and gauges which are necessary for the safety of the boiler, are known as mountings. Water level indicator, safety valve, blow-off cock and fusible plug are some of the mountings.
- **Accessories :** Some equipments like economiser, air preheater and superheater are attached to the boiler to improve its overall efficiency. The economiser and air preheater are used to extract maximum heat from the flue gases and superheater is used to increase the temperature of steam above saturation temperature.

1.4. SELECTION OF A BOILER

While selecting a boiler the following factors should be considered :

1. The working pressure and quality of steam required (i.e., whether wet or dry or super-heated).
2. Steam generation rate.
3. Floor area available.
4. Accessibility for repair and inspection.
5. Comparative intial cost.
6. Erection facilities.

7. The portable load factor.
8. The fuel and water available.
9. Operating and maintenance cost.

1.5. FIRE TUBE BOILERS

Hot flue gases flow through turbines surrounded by water in a shell.

Advantages :

(i) Low initial cost

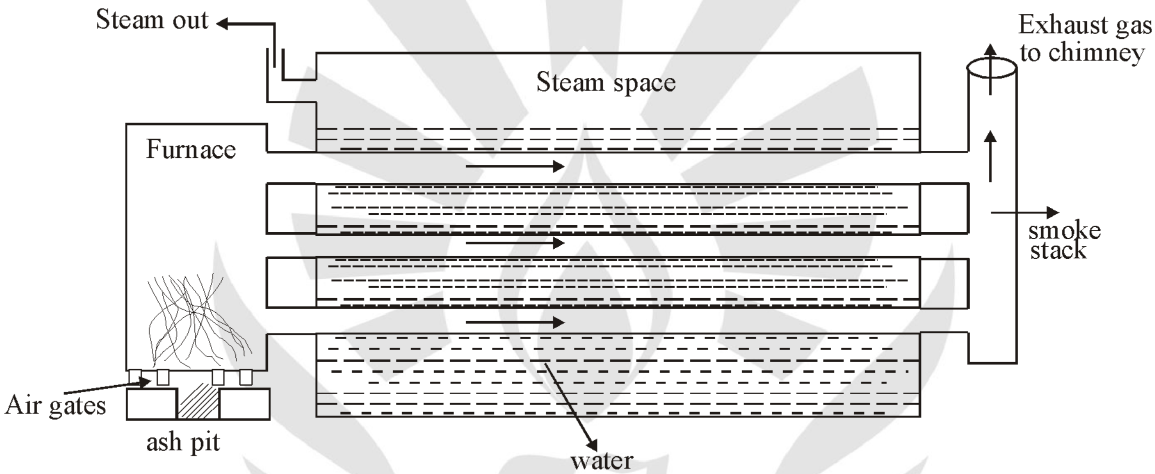
(ii) Reliability in operation.

(iii) Less draught required.

(iv) Quick response to load changes.

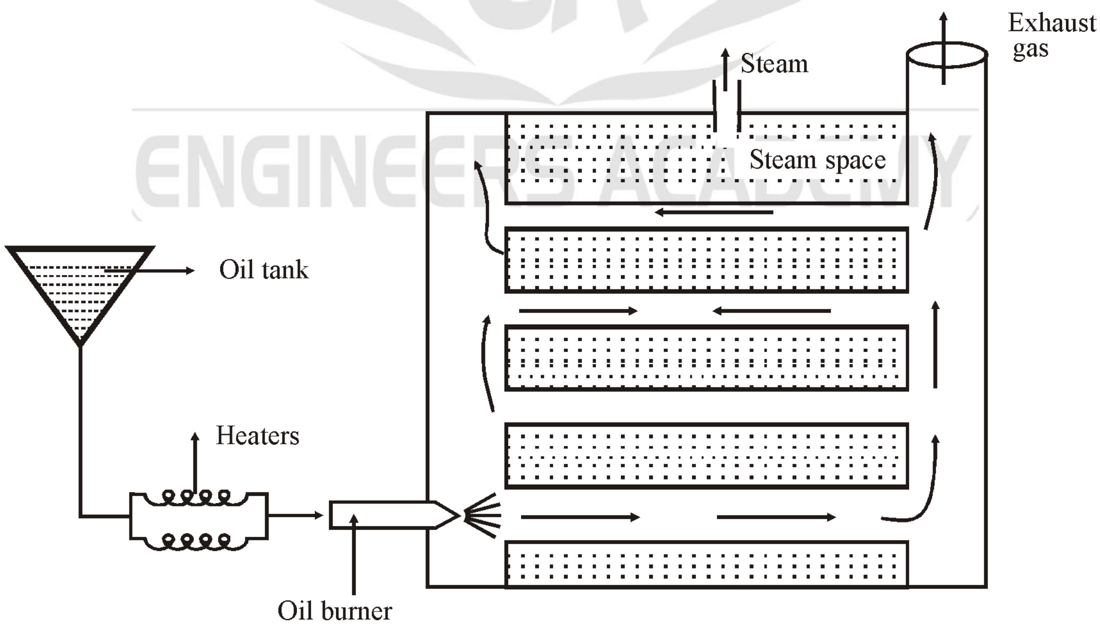
These boilers may be :

(i) Externally fired (Furnace outside the boiler shell)



Fire Tube Boiler

(ii) Internally fired (Furnace intside the boiler shell)



1.6 DIFFERENT TYPE OF FIRE TUBE BOILER

- Simple vertical boiler
- Cochran boiler
- Cronish boiler
- Lancashire boiler
- Locomotive boiler
- Scotch boiler.

1.6.1 Simple vertical boiler

It consists of a cylinderical shell, the greater portion of which is full of water (which surrounds the fire box also) and remaining is the steam space. At the bottom of the fire box is greate on which fuel is burnt and the ah from it falls in the ash pit.

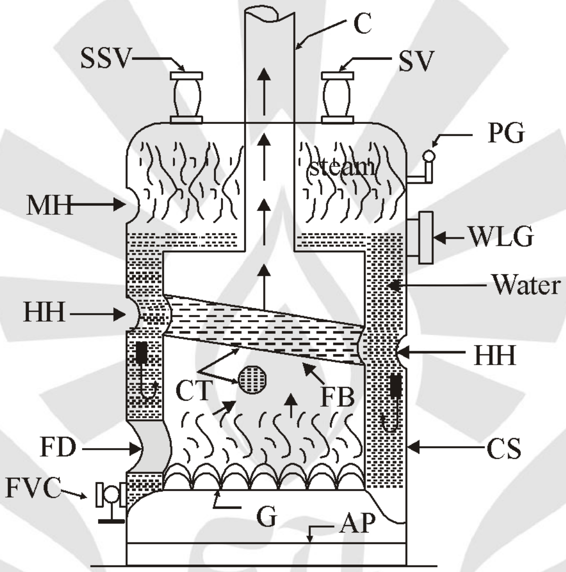


Fig. : Simple vertical boiler

CS	=	Cylindrical shell	C	=	Chimeny	MH	=	Man hole
HH	=	Hand hole	CT	=	Cross tubes	FD	=	Fire door
G	=	Grate	FB	=	Fire box	PG	=	Pressure gauge
AP	=	Ash pit	SV	=	Safety valve	SSV	=	Steam stop valve
WLG	=	Water level gauge	FCV	=	Feed check valve			

The fire box is provided with two cross tubes. This increases the heating surface and the circulation of water. The corrss tubes are fitted inclined. This ensures efficient circulation of water. At the ends of each cross tube are provided hand holes to give access for cleaning these tubes. The combustion gases after heating the water and thus converting it into steam escape to the atmosphere through the chimney. Man hole, is provided to clean the interior of the boiler and exterior of the combustion chamber and chimney.

1.6.2 Cochran boiler

- Multi-tubular vertical fire tube boiler having horizontal fire tubes.
- The heating surface has been increased by means of a number of fire tubes.
- Occupies comparatively less floor area and is very compact.
- Well suited for small capacity requirements.

- Dome shaped furnace causes hot gases to deflect back & unburnt fuel also gets deflected back.
- The spherical top and spherical shape of fire-box are the special features of this boiler. These shapes require least material for the volume. The hemi spherical crown of the boiler shell gives maximum strength to withstand the pressure of the steam inside the boiler. The hemispherical crown of the fire box is advantageous for resisting intense heat. This shape is also advantageous for the absorption of the radiant heat from the furnace.
- Coal or oil can be used as fuel in this boiler. If oil is used as fuel, no grate is provided but the bottom of the furnace is lined with the fire bricks. Oil burners are fitted at a suitable location below the fire door.
- The outstanding freatures of this boiler are listed below.

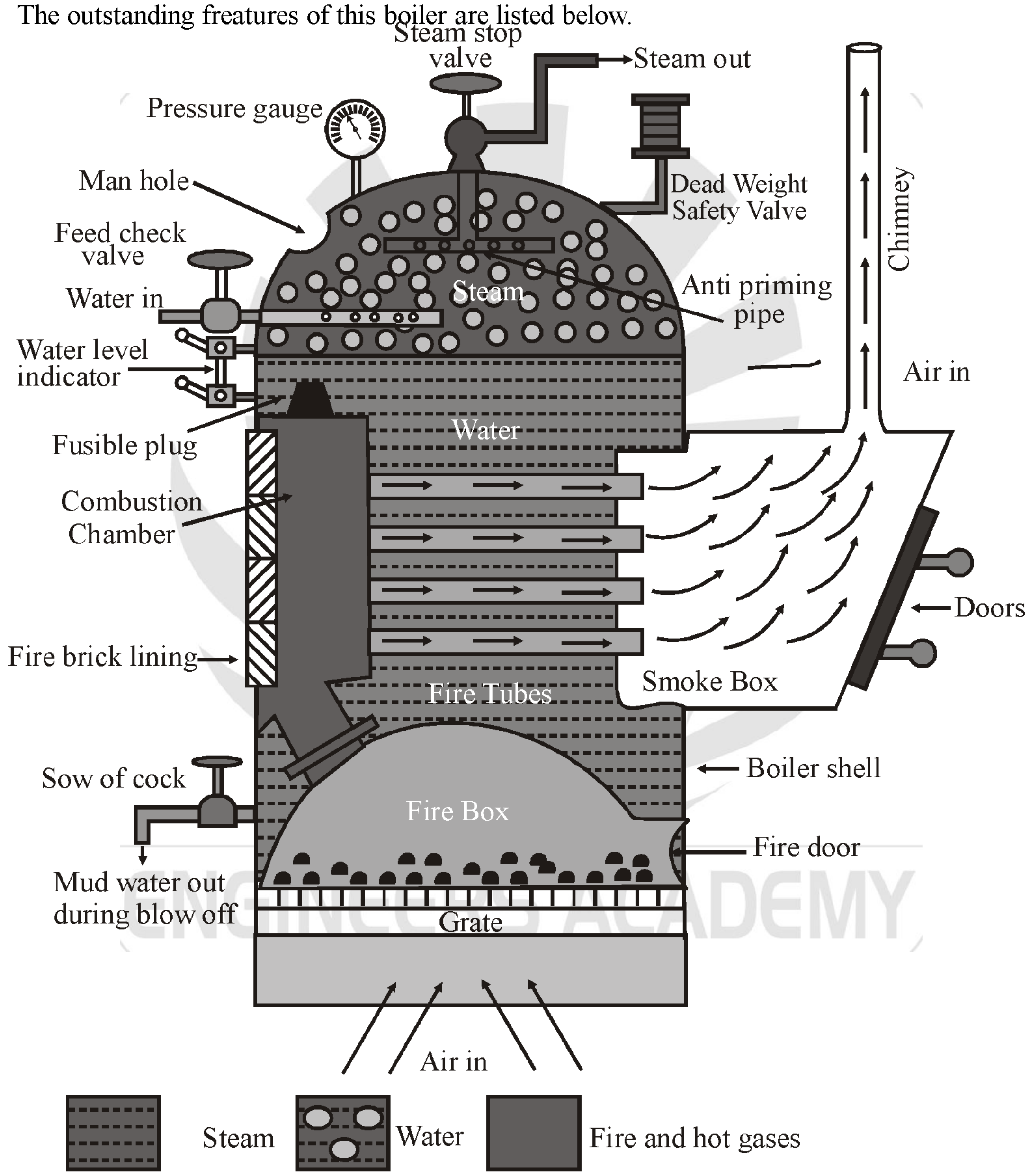


Fig. : Cochran boiler

Advantages :

1. It is very compact and requires minimum floor area.
2. Any type of fuel can be used with this boiler.

PRACTICE SHEET

OBJECTIVE QUESTIONS

1. Match **List-I** (Type of boiler) and **List-II** (Classification of boiler) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Babcock and Wilcox	**1.** Forced circulation
B. Lancashire	**2.** Fire tube
C. La-mont	**3.** Water tube
D. Cochran	**4.** Vertical

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	3	4	1
(c)	3	2	1	4
(d)	2	4	1	3

2. In forced circulation boilers, about 90% of water is recirculated without evaporation. The circulation ratio is

(a) 0.1 (b) 0.9

(c) 9 (d) 10

3. Consider the following

1. Increasing evaporation rate using convection heat transfer from hot gases.

2. Increasing evaporation rate using radiation.

3. Protecting the refractory walls of the furnace.

4. Increasing water circulation rate.

The main reasons for providing water wall enclosure in high pressure boiler furances would include

(a) 2 and 3 (b) 1 and 3

(c) 1, 2 and 4 (d) 2 and 3

4. Consider the following components:

1. Radiation evaporator.

2. Economizers.

3. Radiation superheater.

4. Convection superheater.

In the case of Benson boiler, the correct sequence of the entry of water through these components is:

(a) 1, 2, 3, 4 (b) 1, 2, 4, 3

(c) 2, 1, 3, 4 (d) 2, 1, 4, 3

5. Coal fired power plant boilers manufactured in India generally use:

(a) pulverized fuel combustion

(b) fluidized bed combustion

(c) circulating fluidized bed combustion

(d) moving stoker firing system

6. Once-through boilers will not have

(a) Drums, headers and pumps

(b) Drums, steam separators and pumps

(c) Drums, headers and steam separators

(d) Drums, headers and pumps

7. Match **List-I** (Name of boiler) with **List-II** (Special features) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Lancashire	**1.** High pressure water tube
B. Cornish	**2.** Horizontal double fire tube
C. La-Mont	**3.** Vertical multiple fire tube
D. Cochran	**4.** Low pressure inclined water tube
	5. Horizontal single fire tube

Codes:

	A	B	C	D
(a)	2	5	1	3
(b)	2	4	3	1
(c)	1	5	2	3
(d)	5	4	1	3

ANSWERS AND EXPLANATIONS

1. *Ans. (c)*

Fire tube boilers:
(i) Locomotive boiler (Horizontal boiler)
(ii) lancashire boiler
(iii) Scotch marine boiler
(iv) Cochran boiler (verticale boiler)

Water tube boilers:
(i) Babcox-wilcox boiler
(ii) Lamont boiler (high pressure boiler)
(iii) Benson boiler (High pressure boiler)

2. *Ans. (d)*

3. *Ans. (a)*

Heat transfer to water wall is predominately by radiation.

$$\boxed{E = \varepsilon\sigma AT^4}$$

4. *Ans. (d)*

5. *Ans. (a)*

Coal fired power plant boilers manufactured in india generally use pulverized fuel combustion.

6. *Ans. (c)*

7. *Ans. (a)*

8. *Ans. (d)*

Benson Boiler is a typical high pressure, water tube, forced circulated once through boiler. This boiler does not have any drum.

9. *Ans. (a)*

Forced circulation is required because at high pressure the density difference between steam and water is very less.

10. *Ans. (c)*

NTPC-Talcher (Orissa) plant has sub-critical once-through boiler.

11. *Ans. (c)*

Mass of feed water = 205 kg/hr

Mass of coal = 23 kg/hr

Calorific value of coal = 2050 kJ/kg

Net enthalpy rise = 145 kJ/kg of water

Total enthalpy rise = 145 × 205

Net heat supplied by the coal = 23 × 2050

Boiler efficiency $\boxed{\frac{145 \times 205}{23 \times 2050} = 60\%}$

12. *Ans. (d)*

13. *Ans. (a)*

14. *Ans. (a)*

Heat utilized = 220 × 150 = 33000kJ/hr.

Heat supplied by fuel

= 25 × 2150 = 53750 kJ /hr.

Boiler efficiency

$$= \frac{\text{heat utilized}}{\text{heat supplied by fuel}} = \frac{33000}{53750} = 0.61$$

= 61%

15. *Ans. (c)*

16. *Ans. (c)*

17. *Ans. (d)*

18. *Ans. (d)*

19. *Ans. (c)*

20. *Ans. (c)*

21. *Ans. (a)*

22. *Ans. (b)*

23. *Ans. (b)*

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