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S. Y. B.Sc. Semester-4
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UNIT – 5

Internal combustion engine

In an internal combustion engine a fuel is burned within the engine itself & the combusting products serve as the working medium acting for example piston in a cylinder.

Classification of internal combustion engine

There are several classifications according to

Types of fuel used
- Petrol engine
- Diesel engine
- Gas engine

Types of thermo cycles
- Otto cycle
- Diesel cycle

Speed
- low speed
- medium speed
- high speed

Cooling system
- Air cooled
- Water cooled

Type of Ignition
- Spark ignition
- compression ignition

Arrangement of piston
- Vertical
- Inclined
- Horizontal

No. of cylinders
- Single
- Multi cylinders

Types of application
- Stationary
- Automatic
- Aircraft

<u>Comparison of external and internal combustion engine</u>

External Combustion Engine	Internal Combustion Engine
Example steam power plan	Petrol & diesel engine
Working fluid - liquid H_2O which is inert returns back to its original state.	Working fluid- fuel air mixture and don't returns to its original state.
It is a cyclic process, from liquid H_2O steam is produced and returns back in form of liquid.	It is non cyclic process. Air fuel mixture burns and products of Combustion rejected to surroundings.
Efficiency – low	High efficiency

➢ Heat transfer through metal wall is necessary	➢ Heat transfer at high temperature, is necessary because heat is available within the work producing machine
➢ Very large size	➢ Small size
➢ Suitable for stationary application.	➢ Suitable for non-stationary application
➢ It's object to generate power	➢ It's object to generate mechanical energy

The steam power plant

In a steam power plant, the steam is an inert medium to which heat is transferred from burning fuel or from nuclear reactor. It is therefore characterized by large heat transfer surfaces

- For the absorption of heat by large heat transfer surfaces
- For the rejection of heat from the steam at a relatively low temperature in the condenser

The disadvantage is that when heat must be transferred through walls (as through the metal walls of the boiler tubes) the ability of the walls to withstand high temperatures and pressures imposes a limit on the temperature of heat absorption. In an internal combustion engine, on the other hand a fuel is burned within the engine itself and the combustion products serves as the working medium, acting for example on a piston in a cylinder. High temperature are internal and do not involve heat transfer surfaces.

Burning of fuel within the internal combustion engine complicates thermodynamics analysis. Moreover, fuel and air flow steadily into an internal combustion engine and combustion products flow steadily out of it; there is no working medium that undergoes a cyclic process, as does the steam in a steam power plant. However, for making simple analysis one imagine cycle engines with air as the working fluid that are equivalent in performance to actual internal combustion engines. In addition the combustion step is replaced by the addition to the air of an equivalent amount of heat. In each of the following sections, we first present a qualitative description of an internal combustion engine.

Quantitative analysis is then made of an ideal cycle in which air, treated as an ideal gas with constant heat capacities, is the working medium.

The Carnot-engine cycle which is operates reversibly and consists of two isothermal steps connected by two adiabatic steps. In the isothermal step at higher temperature T_H heat $|Q_H|$ is absorbed by the working fluid of the engine, and in the isothermal step at lower temperature T_c , heat $|Q_C|$ is discarded by the fluid. The work produced is $|W| = |Q_H| - |Q_C|$ and the thermal efficiency of tie Carnot engine is

$$\eta = \frac{|W|}{|Q_H|} = 1 - \frac{T_C}{T_H}$$

Clearly, η increases as T_H increases and as T_c decreases. Although the efficiencies of practical heat engines are lowered by irreversibility, it is still true that their efficiencies are increased when the average; temperature at winch heat is absorbed is increased and when the average temperature at which, heat is rejected is decreased.

Figure1 shows a simple steady-state steady-flow process in which steam generated in a boiler is expanded in an adiabatic turbine to produce work. The discharge stream from the turbine passes to a condenser from which it is pumped adiabatically back to the boiler. The power produced by the turbine is much greater than that required by the pump, and the net power output is equal to the difference between the rate of heat input in the boiler $|Q_H|$ and the rate of heat rejection in the condenser $|Q_C|$.

The property changes of the fluid as it flows through the individual pieces equipment may be shown as lines on a TS diagram, as illustrated in Figure 2. The sequence of lines represents a cycle. Indeed, the particular cycle shown is a carnot cycle. In this idealization, step 1→2 is the isothermal absorption of heat T_H and is represented by a horizontal line on the TS diagram. This vaporization process occurs also at constant pressure and produces saturated-vapor steam from saturated-liquid water. Step 2→3 is a reversible, adiabatic expansion of saturated vapor to a pressure at which $T^{sat} = T_C$. This isentropic expansion process is represented by a vertical line on the TS diagram and produces a wet vapor Step 3 →4 is the isothermal rejection of heat at temperature Tc, and is represented by a horizontal line on the TS diagram. It is a condensation process, but is incomplete. Step 4 →1 takes the cycle back to its origin, producing saturated-liquid water at point 1. It is an isentropic compression process represented by a vertical line on the TS diagram.

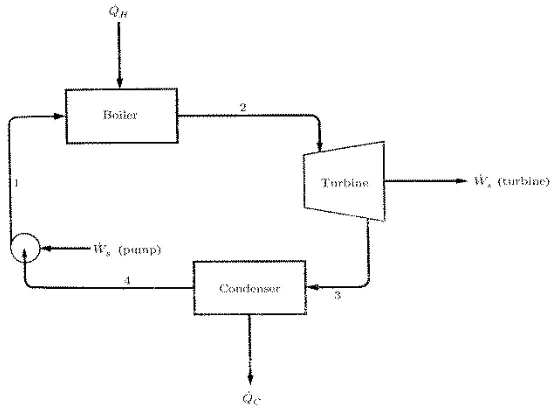

Figure 1: Simple steam power plant.

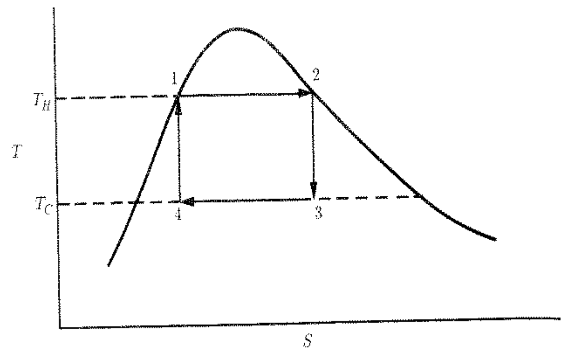

Figure 2: Carnot cycle on a TS diagram.

The thermal efficiency of this cycle is that of a Carnot engine, given by

$$\eta = 1 - \frac{T_C}{T_H}$$

As a reversible cycle, it could serve as a standard of comparison for actual steam power plants. However, severe practical difficulties attend the operation of equipment intended to carry out steps 2→3 and 4 →1. Turbines that take in saturated steam produce an exhaust with high liquid content, which causes severe erosion problems. Even more difficult is the design of a pump that takes in a mixture of liquid and vapor (point 4) and discharges a saturated liquid (point 1).

For these reasons, an alternative model cycle is taken as the standard, at least for fossil-fuel-burning power plants. It is called the Rankine cycle, and differs from the cycle of Figure 2 in two major respects. First, the heating step 1→2 is carried well beyond vaporization, so as to produce a superheated vapor, and second, the cooling step 3→4 brings about complete condensation, yielding saturated liquid to be pumped to the boiler. The Rankine cycle therefore consists of the four steps shown by Figure 8.3, and described as follows:

1 → 2 A constant-pressure heating process in a boiler. The step lies along an isobar (the pressure of the boiler), and consists of three sections: heating of subcooled liquid water to its saturation temperature, vaporization at constant temperature and pressure, and superheating of the vapor to a temperature well above its saturation temperature.

2→ 3 Reversible, adiabatic (isentropic) expansion of vapor in a turbine to the pressure of the condenser. The step normally crosses the saturation curve, producing a wet exhaust. However, the superheating accomplished in step1 → 2 shifts the vertical line far enough to the right on Fig. 8.3 that the moisture content is not too large.

3→4 A constant-pressure, constant-temperature process in a condenser to produce saturated liquid at point 4.

4 →1 Reversible, adiabatic (isentropic) pumping of the saturated liquid to the pressure

of the boiler, producing subcooled liquid. The vertical line (whose length is exaggerated in Figure 8.3) is very short, because the temperature rise associated with compression of a liquid is small.

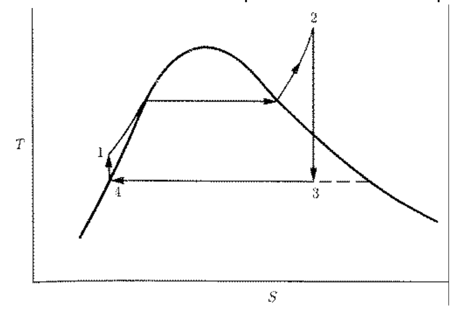

Figure 3: The Rankine cycle.

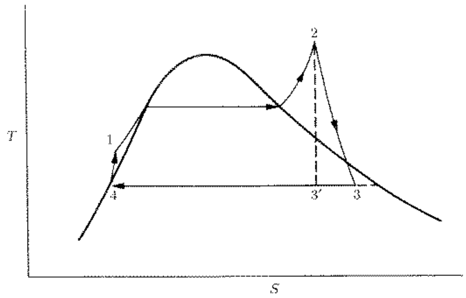

Figure 4 Simple practical power cycle

Power plants can be built to operate on a cycle that departs from the Rankine cycle solely because of the irreversibilities of the work-producing and work-requiring steps. We show in figure 4 the effects of these irreversibilities on steps 2→3 and 4→1. The lines are no longer vertical, but tend in the direction of increasing entropy. The turbine exhaust is normally still wet, but as long as the moisture content is less than about 10 percent, erosion problems are not serious. Slight sub-cooling the condensate in the condenser may occur, but the effect is inconsequential.

The boiler serves to transfer heat from a burning fuel to the cycle, and the condenser transfers heat from the cycle to the surroundings. Neglecting kinetic- and potential-energy changes reduces the energy relations, in equations (a) and (b),

$$\Delta\left(H+\frac{1}{2}u^2+zg\right)m = Q+Ws \qquad \text{...........(a)}$$

$$\Delta H+\frac{\Delta u^2}{2}+g\Delta z = Q+Ws \qquad \text{.........(b)}$$

in either case to

$$Q = m\Delta H \quad \text{............. (1)}$$

and

$$Q = \Delta H \quad \text{............. (2)}$$

Example 1 Steam generated in a power plant at a pressure of 8,600 kPa and temperature of 500°C is fed to a turbine. Exhaust from the turbine enters a condenser at 10 kPa, where it is condensed to saturated liquid, which is then pumped to the boiler.

(a) Determine the thermal efficiency of a Rankine cycle operating at these conditions.
(b) Determine the thermal efficiency of a practical cycle operating at these conditions if the turbine efficiency and pump efficiency are both 0.75.
(c) If the rating of the power cycle of part (b) is 80,000 kW, what is the steam rate and what are the heat-transfer rates in the boiler and condenser?

Solution :(a) The turbine operates under the same conditions as the turbine of Example 7.10, where we found

$$(\Delta H)s = -1,274.2 kJkg^{-1}$$

Thus,

$$Ws(isentropic) = (\Delta H)s = -1,274.2 kJkg^{-1}$$

Moreover, we found the enthalpy at the end of isentropic expansion (H'_2 in Example 7.10) to be

$$H'_3 = 2{,}117.4 kJkg^{-1}$$

The thermal efficiency of the cycle is therefore

$$\eta = \frac{|Ws(net)|}{|Q(boiler)|} = \frac{792.4}{2{,}418.6} = 0.3276$$

This is a significant improvement over the value of 0.2961 found in example 1.

Since $Ws(net) = -80{,}000 kJs^{-1}$

$$m = \frac{Ws(net)}{Ws(net)} = \frac{-80{,}000}{-792.4} = 100.96 kgs^{-1}$$

this is the steam rate to the turbine, and with it can calculate the heat-transfer rate in the boiler:

$$Q(boiler) = m\Delta H = (100.96)(2{,}418.6) = 244.2 \times 10^3 \text{ kJ s}^{-1}$$

The heat-transfer rate of the cooling water in the condenser is

$$Q(condenser) = -Q(boiler) - Ws(net)$$

$$= -244.2 \times 10^3 - (-80.0 \times 10^3)$$

$$= -164.2 \times 10^3 \text{ kJs}^{-1}$$

Although the generation rate is higher than was found in example 8.1, the heat-transfer rates in the boiler and condenser are appreciably less, become their functions are partly taken over by the feed water heaters.

The Otto Engine

The most common internal-combustion engine, because of its use in automobiles, is the Otto engine. Its cycle consists of four strokes, and starts with an intake stroke at essentially constant pressure, during which a piston moving outward draws a fuel/air mixture into a cylinder. This is represented by line 0 →1 in figure 5.

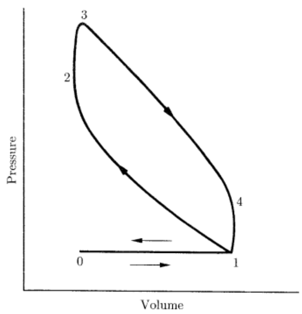

Figure 5: Otto internal combustion – engine cycle

During the second stroke (1→2→3), all valves are closed, and the fuel/air mixture is compressed, approximately adiabatically, along line 1 → 2; the mixture is then ignited, and combustion occurs so rapidly that the volume remains nearly constant while the pressure rises along line 2 → 3. It is during the third stroke (3→4→) that work is produced. The high-temperature, high-pressure products of combustion expand, approximately adiabatically, along line 3→4; the exhaust valve then opens and the pressure falls rapidly at nearly constant volume along line 4 →1. During the fourth or exhaust stroke (line1→0), the piston pushes the remaining combustion gases (except for the contents of the clearance volume) from the cylinder. The volume plotted in the figure is total volume of gas contained in the engine between the piston and the cylinder head.

The effect of increasing the compression ratio, defined as the ratio of the volumes at the beginning and end of the compression stroke, is to increase the efficiency of the engine, i.e., to increase the work produced per unit quantity of fuel.

We demonstrate this for an idealized cycle, called the air-standard cycle, shown in above figure. It consists of two adiabatic and two constant-volume steps, which comprise a heat-engine cycle for which air is the working fluid. In step DA, sufficient heat is absorbed by the air at constant volume to raise its temperature and pressure to the values resulting from combustion in an actual Otto engine. Then the air is expanded adiabatically and reversibly (step AB), cooled at constant volume (step BC), and finally compressed adiabatically and reversibly to the initial state at *D.*

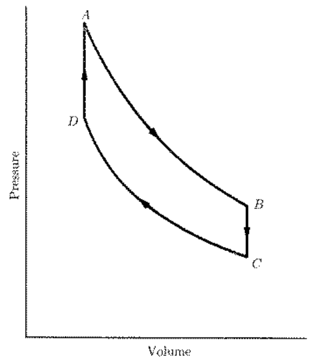

Figure 6: Air-standard Otto cycle.

The thermal efficiency η of the air-standard cycle shown in above figure 6 is simply

$$\eta = \frac{-Ws(net)}{Q_{DA}} = \frac{Q_{DA} + Q_{BC}}{Q_{DA}} \quad ....(3)$$

For 1 mol of air with constant heat capacities,

$$Q_{DA} = Cv(T_A - T_D)$$

$$Q_{BC} = Cv(T_C - T_B)$$

Substituting these expressions in Equation (3) gives

$$\eta = \frac{Cv(T_A - T_D) - Cv(T_B - T_C)}{Cv(T_A - T_D)}$$

or

$$\eta = 1 - \frac{T_B - T_C}{T_A - T_D} \quad ....(4)$$

The thermal efficiency is also related in a simple way to the compression ratio r = Vc/Vd We replace each temperature in Equation (4) by an appropriate group PV/R, the ideal-gas equation. Thus

$$T_B = \frac{P_B V_B}{R} = \frac{P_B V_C}{R}$$

$$T_C = \frac{P_C V_C}{R}$$

$$T_D = \frac{P_D V_D}{R}$$

Substituting into Equation (4) leads to

$$\eta = 1 - \frac{V_C}{V_D}\left(\frac{P_B - P_C}{P_A - P_D}\right) = 1 - r\left(\frac{P_B - P_C}{P_A - P_D}\right) \quad \text{............. (5)}$$

For the two adiabatic, reversible steps, we have PV^{γ} = const. Hence

$$P_A V_D^{\gamma} = P_B V_C^{\gamma}$$ (Since $V_D = V_A$ and $V_C = V_B$)

$$P_C V_C^{\gamma} = P_D V_D^{\gamma}$$

These expressions are combined to eliminate the volumes:

$$\frac{P_B}{P_C} = \frac{P_A}{P_D}$$

Also

$$\frac{P_C}{P_D} = \left(\frac{V_D}{V_C}\right)^{\gamma} = \left(\frac{1}{r}\right)^{\gamma}$$

These equations transform Equation (5) as follows:

$$\eta = 1 - r\frac{\left(P_B - P_C - 1\right)P_C}{\left(P_A / P_D - 1\right)P_D} = 1 - r\frac{P_C}{P_D}$$

Or

$$\eta = 1 - r\left(\frac{1}{r}\right)^{\gamma} = 1 - \left(\frac{1}{r}\right)^{\gamma - 1} \quad \text{............. (6)}$$

This equation shows that the thermal efficiency increases rapidly with the compression ratio r at low values of r, but more slowly at high compression ratios. This agrees with the results of actual tests on Otto engines.

The Diesel Engine

The Diesel engine differs from the Otto engine primarily in that the temperate at the end of compression is sufficiently high that combustion is initiated spontaneously. This higher temperature results because of a higher compression ratio that carries the compression step to a higher pressure. The fuel is not injected until end of the compression step, and then is added slowly enough that the combustion process occurs at approximately constant pressure.

For the same compression ratio, the Otto engine has a higher efficiency than the Diesel engine. However, pre-ignition limits the compression ratio attainable in the Otto engine. The Diesel engine therefore operates at higher compression ratios and consequently at higher efficiencies.

Difference between petrol engine and Diesel engine

Petrol engine	Diesel engine
➢ Fuel - Petrol	➢ Diesel
➢ Working cycle - Otto cycle(const vol.)	➢ Diesel cycle (const press)
➢ Operation ratio - Low (5 to 10)	➢ High (11 to 22)
➢ Require ignition-external source of power	➢ It do not required external source

➢ Engine - Compact and less strong	➢ Huge in size & more stronger
➢ Cost – Low	➢ High
➢ Operation life - Short	➢ Long
➢ Pre-ignition - Possible	➢ Not possible
➢ Efficiency - 25 to 30%	➢ Up to 45%
➢ Application - Light duty	➢ Heavy duty