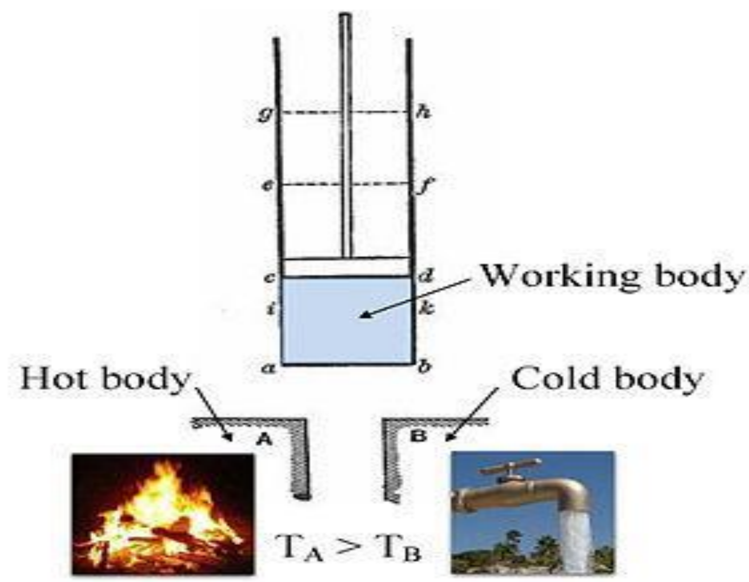
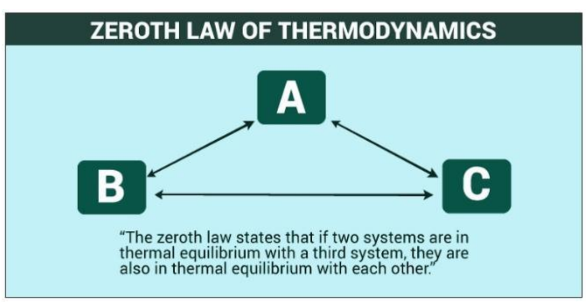
Unit 3

Thermodynamics is the branch of physics that deals with heat and temperature, and their relation to energy, work, radiation, and properties of matter. The behavior of these quantities is governed by the four laws of thermodynamics which convey a quantitative description using measurable macroscopic physical quantities, but may be explained in terms of microscopic constituents by statistical mechanics. Thermodynamics applies to a wide variety of topics in science & engineering, especially physical chemistry, chemical engineering and mechanical engineering, but also in fields as complex as meteorology.



Thermodynamics is principally based on a set of four laws which are universally valid when applied to systems that fall within the constraints implied by each.



Zeroth Law

The zeroth law of thermodynamics states: If two systems are each in thermal equilibrium with a third, they Thermodynamics is principally based on a set of four laws which are universally valid when applied to systems that fall within the constraints implied by each. also in thermal equilibrium with each other.

This statement implies that thermal equilibrium is an equivalence relation on the set of thermodynamic systems under consideration. Systems are said to be in equilibrium if the small, random exchanges between them (e.g. Brownian motion) do not lead to a net change in energy.

First Law

The first law of thermodynamics states: The internal energy of an isolated system is constant.

This law is an expression of the principle of conservation of energy. It states that energy can be transformed (changed from one form to another), but cannot be created or destroyed.

Second Law

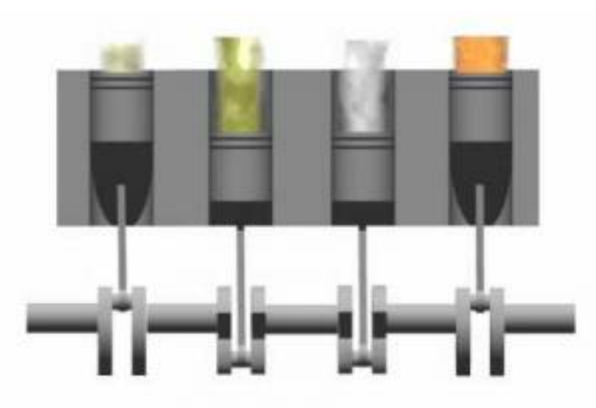
The second law of thermodynamics states: Heat cannot spontaneously flow from a colder location to a hotter location.

This law is an expression of the universal principle of decay observable in nature. The second law is an observation of the fact that over time, differences in temperature, pressure, and chemical potential tend to even out in a physical system that is isolated from the outside world.

Third Law

The third law of thermodynamics states: As the temperature of a system approaches absolute zero, all processes cease and the entropy of the system approaches a minimum value.

This law of thermodynamics is a statistical law of nature regarding entropy and the impossibility of reaching absolute zero of temperature. This law provides an absolute reference point for the determination of entropy.



Otto cycle is a gas power cycle that is used in spark-ignition internal combustion engines (modern petrol engines). This cycle was introduced by Dr. Nikolaus August Otto, a German Engineer.

An Otto cycle consists of four processes:

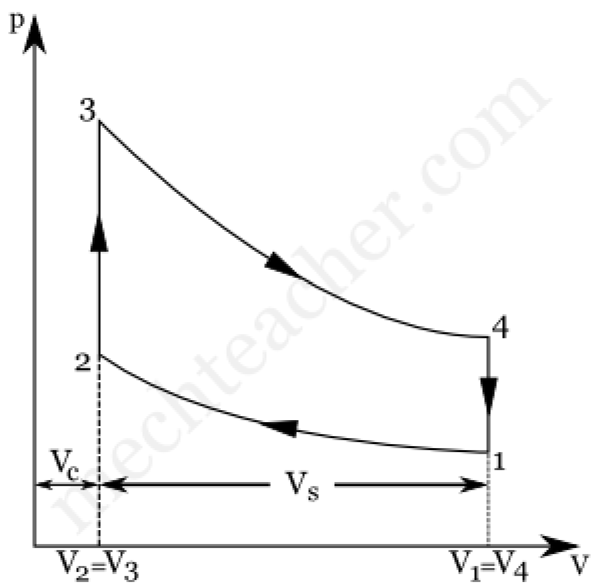
Two isentropic (reversible adiabatic) processes

Two isochoric (constant volume) processes

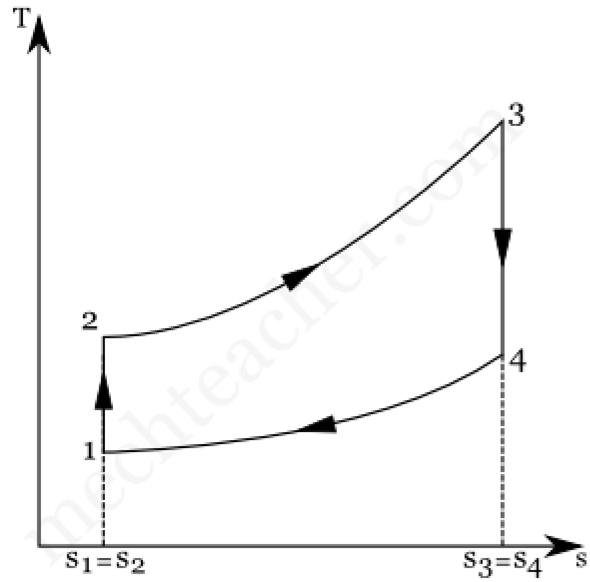
These processes can be easily understood if we understand p-V (Pressure-Volume) and T-s (Temperature-Entropy) diagrams of Otto cycle.

OTTO CYCLE:

p-V Diagram



T-s Diagram



Note:

In the above diagrams,

p → Pressure

V → Volume

T → Temperature

s → Entropy

V_c → Clearance Volume

V_s → Stroke Volume

Processes in Otto Cycle:

As stated earlier, Otto cycle consists of four processes. They are as follows:

Process 1-2: Isentropic compression

In this process, the piston moves from bottom dead centre (BDC) to top dead centre (TDC) position. Air undergoes reversible adiabatic (isentropic) compression. We know that compression is a process in which volume decreases and pressure increases. Hence, in this process, volume of air decreases from V_1 to V_2 and pressure increases from p_1 to p_2. Temperature increases from T_1 to T_2. As this an isentropic process, entropy remains constant (i.e., s_1=s_2). Refer p-V and T-s diagrams for better understanding.

Process 2-3: Constant Volume Heat Addition:

Process 2-3 is isochoric (constant volume) heat addition process. Here, piston remains at top dead centre for a moment. Heat is added at constant volume (V_2 = V_3) from an external heat source. Temperature increases from T_2 to T_3, pressure increases from p_2 to p_3 and entropy increases from s_2 to s_3. (See p-V and T-s diagrams above).

In this process,

Heat Supplied = $mC_v(T_3 – T_2)$

where,

m → Mass

C_v → Specific heat at constant volume

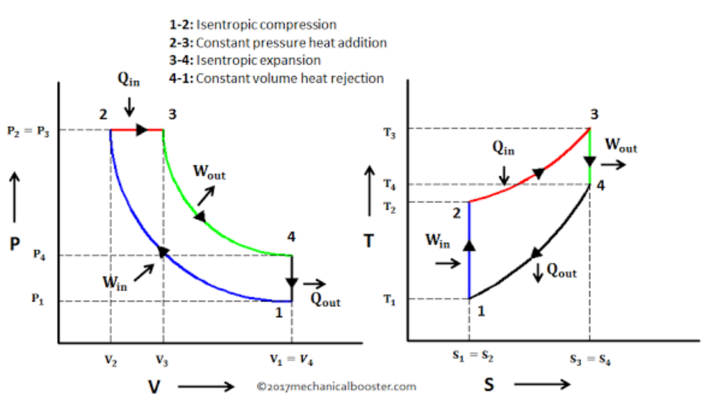
Process 3-4: Isentropic expansion

In this process, air undergoes isentropic (reversible adiabatic) expansion. The piston is pushed from top dead centre (TDC) to bottom dead centre (BDC) position. Here, pressure decreases from p_3 to p_4, volume rises from v_3 to v_4, temperature falls from T_3 to T_4 and entropy remains constant (s_3=s_4). (Refer p-V and T-s diagrams above).

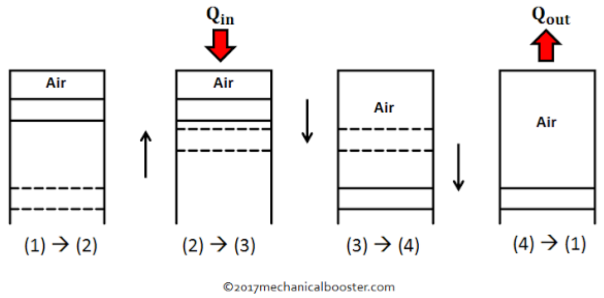
Process 4-1: Constant Volume Heat Rejection

The piston rests at BDC for a moment and heat is rejected at constant volume (V_4=V_1). In this process, pressure falls from p_4 to p_1, temperature decreases from T_4 to T_1 and entropy falls from s_4 to s_1.

DIESEL CYCLE



P-V and T-S Diagram of Diesel Cycle



Piston Position in Diesel Cycle Process

Process 1-2: Isentropic Compression

In this process the piston moves from BDC to TDC and compression of air takes place isentropically. It means that during compression the entropy remains constant and there is no flow of heat out of the cylinder walls (non-conductors) happens. Here the air is compressed so the pressure increases from P1 to P2, volume decreases from V1 to V2, Temperature increases from T1 to T2 and entropy remains constant (i.e. S1 = S2).

Process 2-3: Constant Volume Heat Addition

In this process the, the hot body is kept in contact with the cylinder and heat addition to the air takes place at constant pressure. During this process, the piston rest for a moment at TDC. The pressure remains constant (i.e. P2 = P3), volume increases from V2 to V3, temperature increases from T2 to T3, entropy increases from S2 to S3.

Process 3-4: Isentropic Expansion

In this process, after heat addition, the expansion of air takes place isentropically and work is obtained from the system. The piston moves downward during this process and reaches to BDC. The pressure falls from P3 to P4, Volume increases from V3 to V4, temperature falls from T3 to T4 and entropy remains constant (i.e. S3=S4).

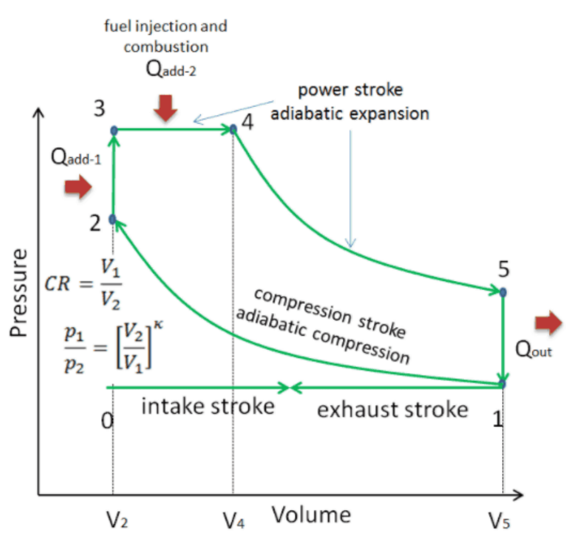
Process 4-1: Constant Volume Heat Rejection

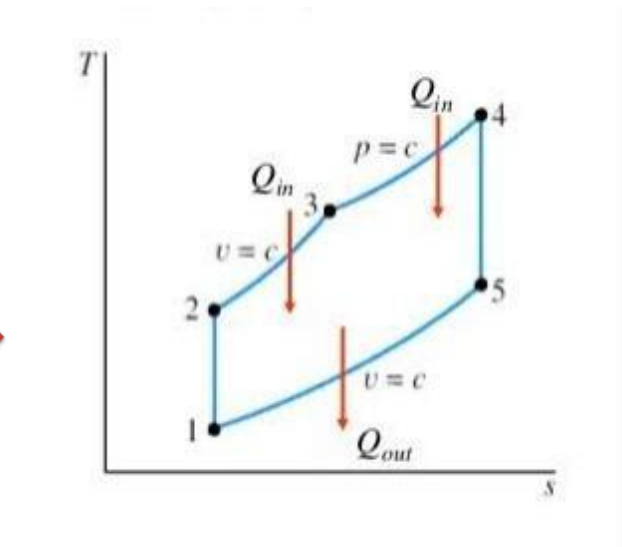
In this process, the piston rest at BDC for a moment and the cold body is brought in contact with the cylinder and the heat rejection takes place at constant volume. The pressure decreases from

P4 to P1, temperature decreases from T4 to T1, entropy decreases from S4 to S1 and volume remains constant (i.e.V4 = V1).

This is the four working process of diesel cycle engine that we have discussed. Now we will discuss how this cycle is implemented in the 4 stroke diesel engine. When this cycle is used in 4 stroke diesel engine than we have 2 extra processes. One is suction process and other one is exhaust
process. For heat addition diesel is used as fuel which burns and adds heat.

DUAL CYCLE.





0 -> 1 Intake Stroke

1 -> 2 Adiabatic Compression

2 -> 3 Volume is Constant (Isochoric)

3 -> 4 Pressure is Constant (Isobaric)

4 -> 5 Adiabatic Expansion

5 -> 1 Volume is Constant (Isochoric)

Q_{in} / Q_{add} is Heat Supplied to the System.

Q_{out} / Q_{rej} is Heat Rejected out of the System.

AIR STANDARD EFFICIENCY OF OTTO CYLE:

● In An Adiabatic Expansion PV^{γ}= Constant ; Where

γ= Specific Heat At Constant Pressure (C_p) / Specific Heat At Constant Volume (C_v)

● Now Considering One kg Of Air Heat Supplied = $C_v(T_3-T_2)$ Heat Rejected During Cycle = $C_v(T_4-T_1)$

Work Done = Heat Supplied - Heat Rejected = $C_v(T_3-T_2)-C_v(T_4-T_1)$ = $C_v[(T_3-T_2)-(T_4-T_1)]$ Air Standard Or Thermal Efficiency Of Otto Cycle = Work Done Heat Supplied = $C_v[(T_3-T_2)-(T_4-T_1)]$ $C_v(T_3-T_2)$ = 1 - $C_v(T_4-T_1)$ $C_v(T_3-T_2)$ = 1 - (T_4-T_1) _____(1)

(T_3-T_2)

Now For Adiabatic Compression ;

$T_2 / T_1 = (V_1 / V_2)^{(\gamma-1)} = r^{(\gamma-1)}$

$T_1 = T_2 / r^{(\gamma-1)}$ _____(2) Where r = Compression Ratio Similarly For Adiabatic Expansion ; $T_3/ T_4 = (V_4 / V_3)^{(\gamma-1)} = r^{(\gamma-1)}$

$T_4 = T_3 / r^{(\gamma-1)}$ _____(3) Putting Values Of 2 & 3 In 1 ;

$\eta = 1 - T_3 / r^{(\gamma-1)} - T_2 / r^{(\gamma-1)}$

$T_3 - T_2$ $\eta = 1 - 1/ r^{(\gamma-1)}$

Also Equation 1 Can Be Written As;

$\eta = 1 - T_1 [T_4 / T_1 -1] / T_2 [T_3 / T_2 - 1]$ ______(4) But ;

$T_2 / T_1 = T_3 / T_4 = r^{(\gamma-1)}$ $T_4 / T_1 = T_3 / T_2$ ______(5)

Putting 5 In 4; $\eta = 1 - T_1 [T_3 / T_2 -1] / T_2 [T_3 / T_2 - 1]$ $\eta = 1 - T_1 / T_2$