LECTURE NOTES ON

BASIC MECHANICAL ENGINEERING

2nd SEMESTER

BY

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UNIT-1

THERMODYNAMICS

What is Thermodynamics?

Thermodynamics is a science dealing with Energy and its transformation and its effect on the physical properties of substances.

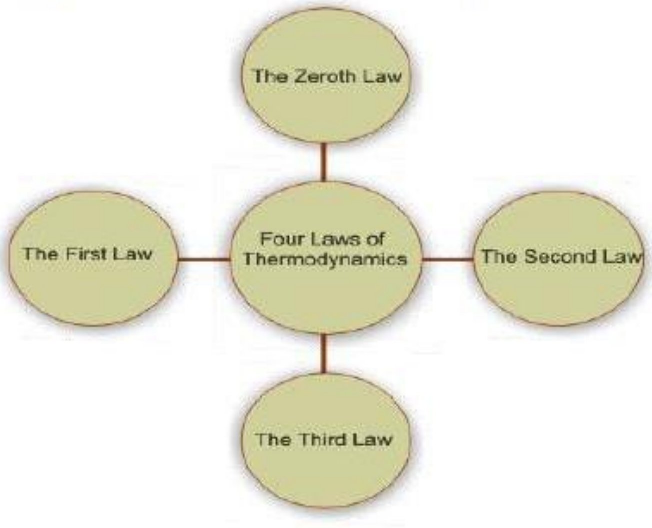
It deals with equilibrium and feasibility of a process.

Deals with the relationship between heat and work and the properties of systems in equilibrium.

Scope of Thermodynamics:

- Steam power plant
- Separation and Liquidfication Plant
- Refrigeration
- Air-conditioning and Heating Devices.
- Internal combustion engine
- Chemical power plants
- Turbines
- Compressors, etc

The principles of thermodynamics are summarized in the form of four thermodynamic laws:



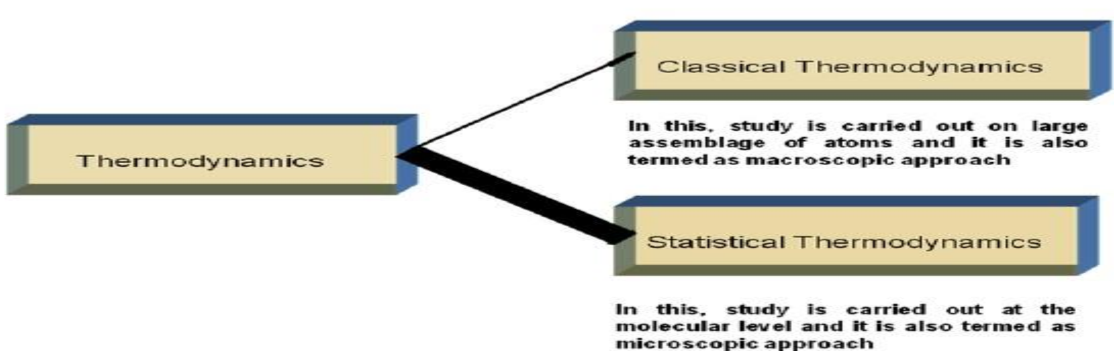
1. **The Zeroth Law** deals with thermal equilibrium and provide same as for measuring temperatures.

2. **The First Law** deals with the conservation of energy and introduces the concept of internal energy.

3. **The Second Law** of thermodynamics provides with the guidelines on the conversion of internal energy of matter into work. It also introduces the concept of entropy.

4. **The Third Law** of thermodynamics defines the absolute zero of entropy. The entropy of a pure crystalline substance at absolute zero temperature is zero.

Different Approaches of Thermodynamics :



Write the difference between Macroscopic and Microscopic approach of Thermodynamics:

Macroscopic Approach	Microscopic Approach
1.Macroscopic approach is known as Classical Thermodynamics.	1. Microscopic approach is known as Statistical Thermodynamics
2. Attention is focussed on a certain quantity of matter without taking into account the events occuring at molecular level.	2. A knowledge of the structure of matter under consideration is essential.
3. Only a few variables are used to describe the state of the matter under consideration.	3. A large no. of variables are required for a complete specification of the state of matter under consideration.
4. The values of the variables used to describe the state of the matter are easily measurable.	4. The variables used to describe the state of matter cannot be measured easily and precisely

Define Thermodynamic System?

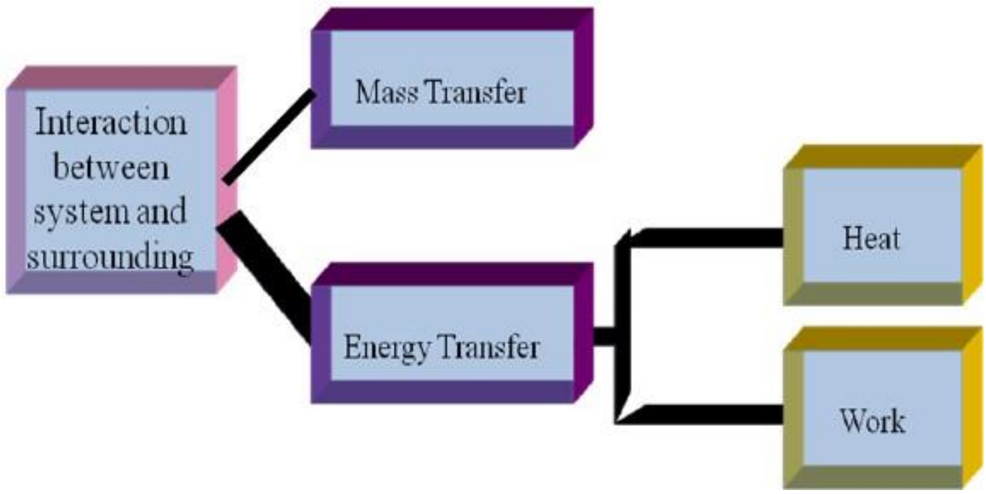
A thermodynamic system is defined as a definite quantity of matter or a region of space within a prescribed boundary upon which attention is focused in the analysis of a problem.

Surrounding: Everything external to the system is Surroundings.

Boundary:

- The surface which separates the system from the surrounding.
- System and surrounding interact through boundary in the form of Heat and Work.
- Boundary can be real(or) imaginary.
- Boundary can be fixed (or) moving.
- System and Surrounding put together is known as **Universe**

Interaction Between System and Surrounding



Based on the type of interaction, the systems are classified as

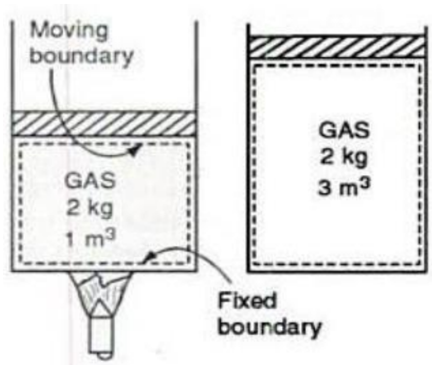
- **CLOSED SYSTEM**

- **OPEN SYSTEM**

- **ISOLATED SYSTEM**

CLOSED SYSTEM (Control Mass): It is a system termed as control mass or fixed mass analysis. There is no mass transfer across the system boundary but energy in the form of Heat or Work can cross the system boundary.

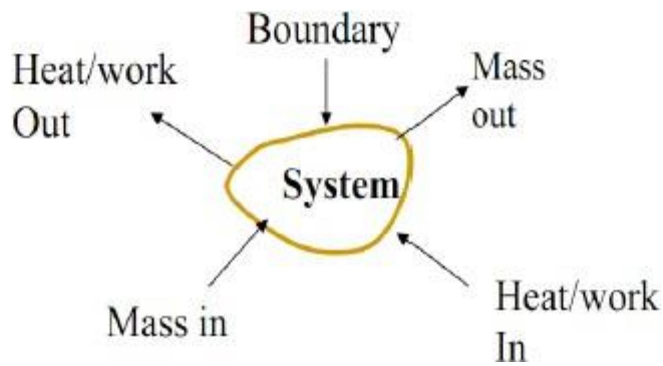
Eg.



Eg. A certain amount of gas enclosed in a cylinder piston arrangement.

Open System(Control Volume): The open system is one in which both mass and energy can cross the boundary of the system.

Open



Open system is also termed as control volume analysis

Write down the concept of Control Volume:

A large engineering problems involve mass flow in and out of a system and therefore, are modeled as control volumes.

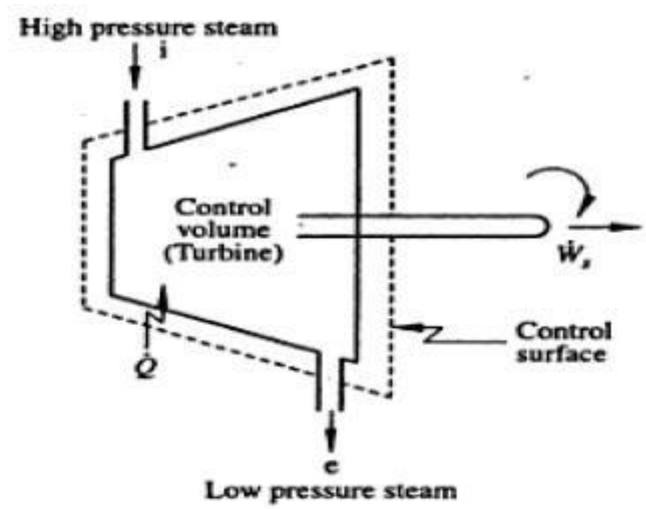
Control volume refers to a definite volume on which attention is focused for energy analysis.

Examples: Nozzles, Diffusers, Turbines, Compressors,

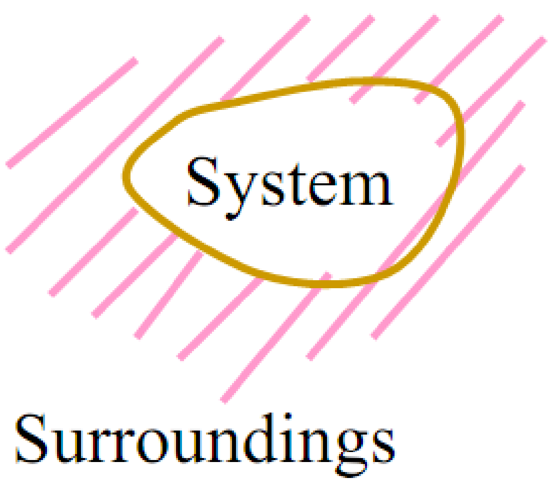
Heat Exchanger, De-super heater, Throttling valves,

I.C engine etc.

Control Surface: The closed surface that surrounds the control volume is called **CONTROL SURFACE.** Mass as well as energy crosses the control surface. Control surface can be real or imaginary.



Isolated System: The isolated system is one in which there is no interaction between the system and the surroundings that neither the mass nor the energy interactions.Therefore it is of fixed mass and energy.

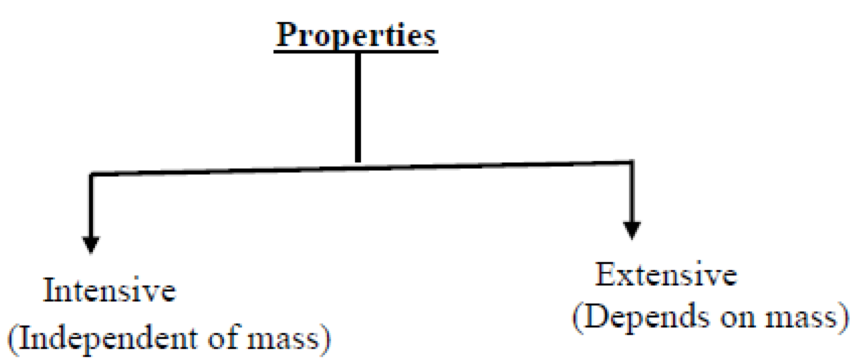


Note:

Mass Transfer	Energy Transfer	Type of System
No	Yes	Closed System
Yes	Yes	Open System
No	No	Isolated System
Yes	No	Impossible

What do you mean by Property?

Any observable characteristics required to describe the conditions or state of a system is known as Thermodynamic property of a system.



Differentiate Intensive and Extensive Property?

Extensive Property	**Intensive Property**
1. Extensive properties are dependent on the mass of a system.	1. Intensive properties are independent of the mass of a system.
2.Extensive properties are additive.	2. Intensive properties are not additive.
3. Its value for an overall system is the sum of its values for the parts into which the system is divided.	3. Its value remains the same whether one considers the whole system or only a part of it.
4.Example:mass(m),volume(V),Energy(E),Enthalpy(H) etc.	4.Example:Pressure(P),Temperature(T),Density etc.
5. Uppercase letters are used for extensive properties except mass.	5. Lowercase letters are used for intensive properties except pressure(P) and temp.(T)

FIRST LAW OF THERMODYNAMICS

- This is based on Law of Conservation of Energy.
- This is also called as First Principle.

For a closed system, undergoing a cycle

Sum of all Work transfers = Sum of all Heat Transfers

$$(W_1+W_2+W_3+\ldots..) = \Sigma(Q_1+Q_2+Q_3+\ldots\ldots\ldots)$$

$$\Sigma(W) = \Sigma(Q)$$

$$\oint dW = \oint dQ$$

For a closed system,undergoing a Process

Whenever heat is absorbed by a system it increases its internal energy and does some work.

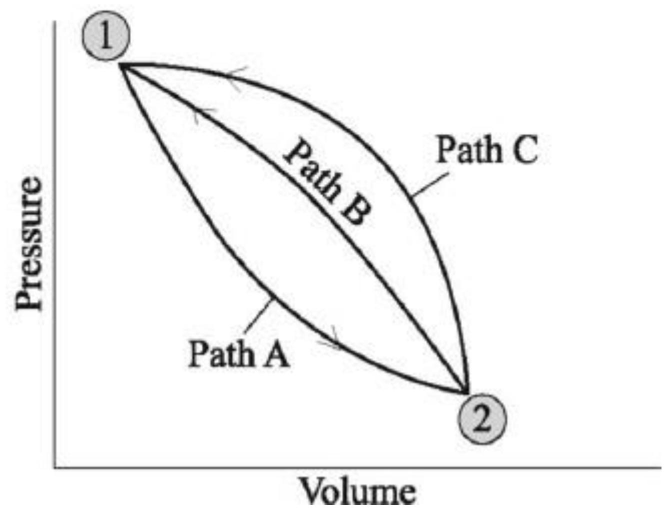
$$Q = \Delta E + W$$

Where Q – heat absorbed by the system

W – Work output from the system

ΔE – Change in Stored Energy of the system

Show that Energy is a property of the system



For path A,

$$Q_A = W_A + \Delta E_A \qquad (1)$$

For path B,

$$Q_B = W_B + \Delta E_B \qquad (2)$$

For path B,

$$Q_C = W_C + \Delta E_C \qquad (3)$$

For Cycle 1-A-2-B-1,

$$W_A + W_B = Q_A + Q_B \qquad (4)$$

$$Q_A - W_A = -(Q_B - W_B)$$

$$\Delta E_A = -\Delta E_B \qquad (A)$$

For Cycle 1-A-2-C-1,

$$W_A + W_C = Q_A + Q_C$$

$$Q_A - W_A = -(Q_C - W_C)$$

$$\Delta E_A = -\Delta E_C \qquad (C)$$

Comparing A and C

$$\Delta E_B = \Delta E_C$$

Enthalpy:

- It is the energy content of the flowing fluid.
- It is defined by the summation of internal energy and flow work.

H = U + PV

<u>Note:</u> For an ideal gas h = u + Pv.

= u + RT

So, h = f(T)

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

is also defined as the change of internal energy of the substance per unit change in temperature at constant volume. C

Define Cp with the help enthalpy and Temperature:

Theamountofheatrequiredtoraisethetemperatureofunitmassofasubstanceby1oCina

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

Reversible constant pressure process.

isalsodefinedasthechangeofinternalenergyofthesubstanceperunitchangein temperature at constant volume. C

Define Cp with the help enthalpy and Temperature:

The amount of heat required to raise the temperature of unit mass of a substance by 1o C in a reversible constant pressure process.

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

C_p is also defined as the change of internal energy of the substance per unit change in temperature at constant pressure.

Application of First law to different Thermodynamic process:

Process	Index=n	Q	$W=\int PdV$	P-V-T Relation
Rev. Const.Vol.	∞	$Q=\Delta U$ $=mC_v(T_2-T_1)$	$W=0$	$\frac{P_1}{T_1}=\frac{P_2}{T_2}$
Rev.Const.pressure	n=0	$Q=\Delta H$ $=mC_p(T_2-T_1)$	$W=P(V_2-V_1)$ $=mR(T_2-T_1)$	$\frac{V_1}{T_1}=\frac{V_2}{T_2}$
Rev. Isothermal	n=1	$Q=W=P_1V_1\ln\left(\frac{V_2}{V_1}\right)$	$W=P_1V_1\ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1=P_2V_2$
Rev.Adiabatic	n=γ	$Q=0$	$W=\frac{P_1V_1-P_2V_2}{\gamma-1}$	$P_1V_1^\gamma=P_2V_2^\gamma$
Rev.Polytropic	n	$Q=\Delta U+W$	$W=\frac{P_1V_1-P_2V_2}{n-1}$	$P_1V_1^n=P_2V_2^n$

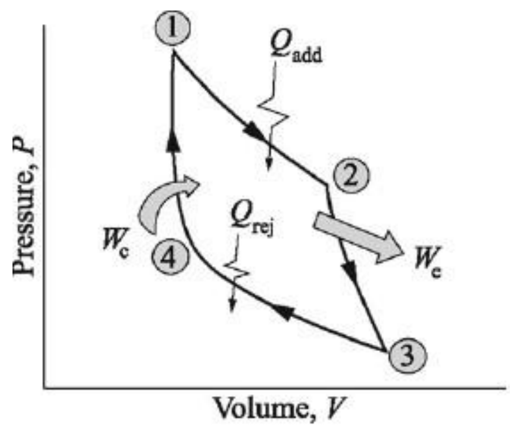
Carnot Cycle: Carnot cycle is a reversible cycle that is composed of four reversible processes, two isothermal and two adiabatic.

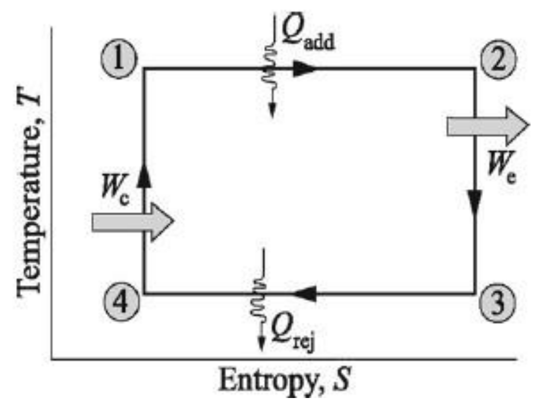
Process 1 - 2 (Reversible Isothermal Heat Addition)

Process 2 – 3 (Reversible Adiabatic Expansion)

Process3–4(Reversible Isothermal Heat Rejection)

Process 4 – 1 (Reversible Adiabatic Compression)





$$\Sigma(Q_{net})_{cycle} = \Sigma(W_{net})_{cycle}$$

$$Q_{add} - Q_{rej} = W_e - W_c$$

$$\eta = \frac{W_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}}$$

$$\boxed{\eta = 1 - \frac{Q_{rej}}{Q_{add}}}$$

From T-S diagram

$$\eta = 1 - \frac{T_2\,(\Delta S)}{T_1\,(\Delta S)}$$

$$\boxed{\eta = 1 - \frac{T_2}{T_1}}$$

Carnot's Theorem :

1. The efficiency of an irreversible heat engine is always less than efficiency of a reversible one operating between the same two reservoirs.

2. The efficiencies of all reversible heat engines operating between the same reservoirs are the same.

Clausius Inequality

The cycle integral of $\frac{\delta Q}{T}$ is always less than or equal to zero.

Mathematically it can be expressed as $\oint \frac{\delta Q}{T} \leq 0$. The equality in the Clausius inequality holds for totally or just reversible cycle and the inequality for the irreversible ones.

Otto cycle:

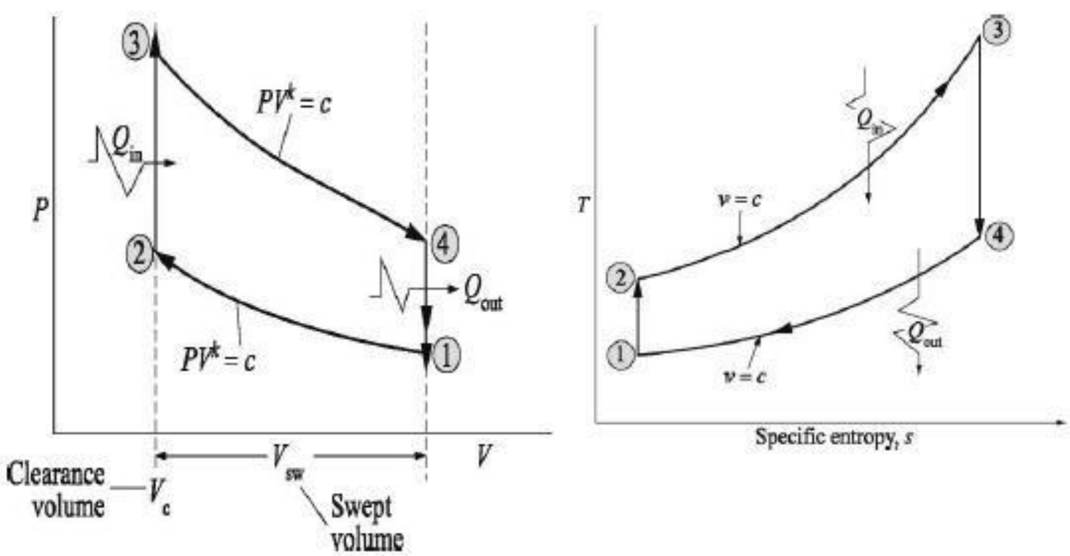
The processes in Otto cycle are

(1–2) Isentropic Compression

(2–3) Constant volume heat addition.

(3–4) Isentropic Expansion.

(4–1) Constant volume heat rejection.



Efficiency of Otto Cycle

$$\eta_{Otto} = \frac{W_{net}}{Heat\ Supplied}$$

$$Wnet = W_{3-4} - W_{2-1}$$

$$W_{3-4} = C_v(T_3 - T_4) = C_v\ T_3\left(1 - \frac{1}{r_k^{\gamma-1}}\right)$$

$$W_{2-1} = C_v\ (T_2 - T_1) = C_v\ T_1(1 - r_k^{\gamma-1})$$

$$W_{net} = C_p\left(1 - \frac{1}{r_k^{\gamma-1}}\right)\ T_3 - T_1\ r_k^{\gamma-1}$$

$$\boxed{\eta_{otto} = \left[1 - \frac{1}{r_k^{\gamma-1}}\right]}$$

$$\text{Work ratio} = \frac{W_{net}}{W_{turbine}} = 1 - \left[\frac{T_1}{T_3}\right] r_k^{(\gamma-1)}$$

Diesel cycle

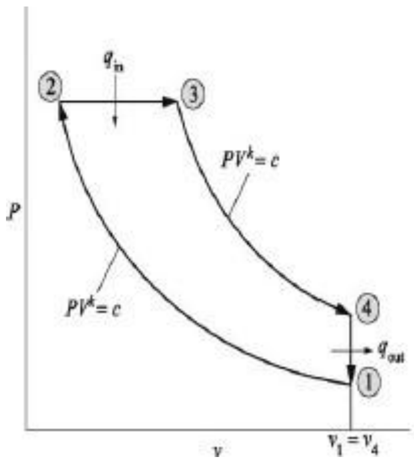
The processes in Diesel cycle are:

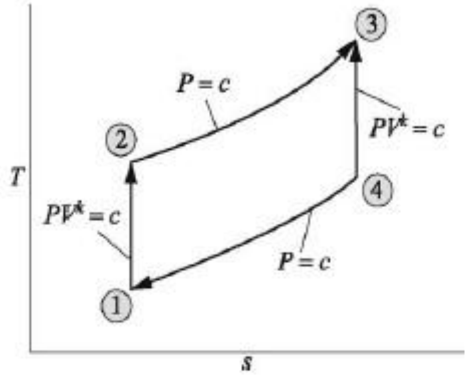
(1–2) Isentropic Compression

(2–3) Constant pressure heat addition.

(3–4) Isentropic Expansion.

(4–1) Constant volume heat rejection.





Efficiency of Diesel cycle

$$\eta_{Diesel} = \frac{W_{net}}{Heat\ Supplied} = \frac{q_{in} - q_{out}}{q_{in}}$$

Now $q_{in} = c_p(T_3 - T_2)$ and $q_{out} = c_v(T_4 - T_1)$

Hence $\eta_{th} = \dfrac{c_p(T_3 - T_2) - c_v(T_4 - T_1)}{c_p(T_3 - T_2)}$

$$= 1 - \frac{(T_4 - T_1)}{\gamma((T_3 - T_2))} = 1 - \frac{T_1\left[\dfrac{T_4}{T_1} - 1\right]}{\gamma T_2\left[\dfrac{T_3}{T_2} - 1\right]}$$

Now $\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma-1} = \left(\frac{1}{r_c}\right)^{\gamma-1}$

Also since $p_3 = p_2$, hence $\frac{T_3}{T_2} = \frac{v_3}{v_2} = \rho$

where ρ is the cut-off ratio.

Again since $v_4 = v_1$, $\frac{T_4}{T_1} = \frac{p_4}{p_1} = \rho^{\gamma}$

Substituting the values of $\frac{T_1}{T_2}$, $\frac{T_3}{T_2}$, and $\frac{T_4}{T_1}$, the value of thermal efficiency

$$\eta_{th} = 1 - \left(\frac{1}{r_c}\right)^{\gamma-1}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$$