

Unit-1 Thermodynamic concept and terminology

* Basic concepts and definitions

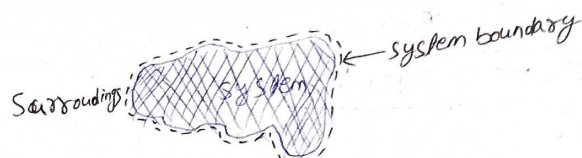
- ⇒ Thermodynamics is the science of energy transfer which deals with the relations among heat, work and properties of systems.
- ⇒ Thermodynamics stems is the Greek words :-
Therme mean heat and dynamis mean power.
- ⇒ It is most efforts to convert heat into power.
(motion)
or energy transformation, including power generation, refrigeration, and relationships among the properties of matter.

* Application areas of thermodynamics

- ⇒ The principles of thermodynamics are playing vital role in designing all the engineering equipments such as:-
 - (i) internal combustion engines
 - (ii) Rockets
 - (iii) Jet engines
 - (iv) fossil-fuelled steam power plants
 - (v) Refrigerators etc.

* Thermodynamic system

- (i) System :- A thermodynamic system is defined as a quantity of matter or a region in space, whose behaviour is being investigated.
- (ii) Surroundings :- Everything external to the system is called surroundings.
- (iii) System boundary :- The system is separated from the surroundings by an imaginary envelop called system boundary. It is either fixed or moving.
- (iv) Universe :- A system and its surroundings together constitute the universe.

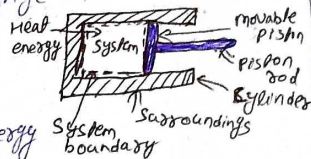


* Types of thermodynamic systems

⇒ There are three types they are:-

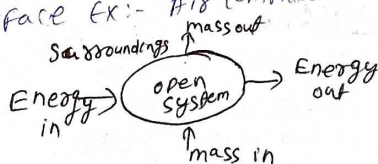
(1) Closed system:- In closed system, attention is -

- focused on a fixed mass.
- ⇒ Energy in the form of heat and work can cross the boundary of the system. But there is no mass flow across the boundary.
- ⇒ Hence, the possibility of change in volume is always there in the closed systems.



(2) Open system:-

- ⇒ In open system, both matter and energy can cross the boundary.
- ⇒ Here, the behaviour of a fixed region in space called control volume is investigated and hence, there may be change in volume.
- ⇒ The surface of the control volume is known as control surface. Ex:- Air compressor and steam turbine.



(3) Isolated system:- A system that exchanges neither energy nor matter with its surroundings is known as an isolated system.

- ⇒ There is no existence of isolated system.
- ⇒ A thermo flask can be approximated to be an isolated system.
- ⇒ A system and its surrounding together can be considered an isolated system.

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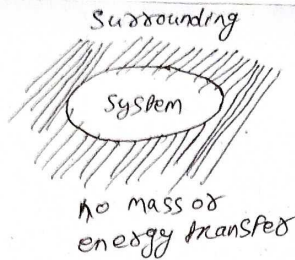
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Thermodynamic Properties :-

⇒ Thermodynamic Properties are classified into two categories :- Intensive Properties and Extensive Properties

(i) Intensive :- Intensive Properties are independent of quantity of matter. Example :- Pressure, Temperature, Density.

(ii) Extensive :-

⇒ These are dependent on the mass of the system. The property value will change with change in mass of the system. Example :- Volume, mass, energy.

⇒ In this properties remaining unchanged such as pressure and temperature are intensive properties. Volume of air will be reduced to half of its initial value. Hence, it is an extensive property.

Thermodynamic State and equilibrium

- ⇒ The condition of the system at any particular moment is known as thermodynamic state.
- ⇒ The word equilibrium ~~means~~ means balance or equal.
- ⇒ Any characteristic of the system is called property of the system.
- ⇒ Any condition of the system.
- ⇒ The state of the system is specified by the property of the system.

⇒ If any one of the property changes the state of the system changes. change in state is called Process

⇒ The equilibrium state of a thermodynamic system is a state that can not be changed without any interaction with its surroundings.

⇒ If a system is balances in following aspects, it is said to be in a state of thermodynamic equilibrium.

⇒ Thermal equilibrium:- A system is said to be in thermal equilibrium if it has same temperature at all parts of the system.

⇒ Mechanical equilibrium:- A system is said to be in mechanical equilibrium if it has same pressure throughout the system.

⇒ Chemical equilibrium:- A system is said to be in chemical equilibrium if it does not undergo any chemical reaction.

⇒ Phase equilibrium:- A system is said to be in phase equilibrium if its mass of each phase is remain constant.

⇒ It is achieve each of satisfy 4 equilibrium exists are thermodynamic equilibrium.

⇒ If any one of the three equilibrium thermal, mechanical chemical equilibrium is absent, the system is not in thermodynamic equilibrium.

* Thermodynamic Process and Cycles:-

⇒ The term process is used to denote a change in the state of a system

→ Reversible process :- If the process is said to be reversible process if it can be reversed in the direction following the same path without leaving any change in the system and surroundings, other wise irreversible.

thermodynamic cycle :-

→ ^{thermodynamic} ~~thermodynamic~~ cycle is a sequence of thermodynamic processes that begin and ends at the same state.

→ it is two types :-
→ Quasistatic process
→ Non-quasistatic process

Quasistatic process

→ If all the intermediate states are equilibrium states, the process is known as quasistatic process. (During the process, the system remains in a state of equilibrium)

→ If it take place infinitely slowly

Non-quasistatic process

→ It is a process in which the intermediate thermodynamic states are not equilibrium states → It is represented by dashed line,

Path :- The line joining the series of states through which the system passes in going from its initial state to final state is called path.

Approach

Macroscopic system :- Any system that is large enough to be observable using our senses are known as a macroscopic system.

Ex:- A gas enclosed in a cylinder.

Microscopic system :- If it is of small dimensions roughly of the size of an atom or a molecule. If the size 10^{-10} meters.

Continuum :- matter can be distributed continuously without any void.

or a continuous distribution of mass within the matter or system with no empty space.

Temperature Name of scale	Freezing point	Boiling point
(1) Celsius	0°	100°
(2) Fahrenheit	32°	212°
(3) Kelvin	273°	373°
(4) Reaumur	0°	80°

* For suppose any scale converted trick formula

$$\frac{\text{Temp.} - \text{Freezing Point}}{\text{Boiling Point} - \text{Freezing Point}} = \text{Constant}$$

$$\Rightarrow \frac{C - 0^\circ}{100 - 0^\circ} = \frac{F - 32^\circ}{212^\circ - 32^\circ} = \frac{K - 273^\circ}{373^\circ - 273^\circ} = \frac{R - 0^\circ}{80^\circ}$$

$$\Rightarrow \frac{C - 0^\circ}{100} = \frac{F - 32}{180} = \frac{K - 273^\circ}{100} = \frac{R - 0^\circ}{80^\circ}$$

$$\Rightarrow \frac{C}{100} = \frac{F - 32}{180} = \frac{K - 273}{100} = \frac{R}{80}$$

$$\Rightarrow \frac{C}{5} = \frac{F - 32}{9} = \frac{K - 273}{5} = \frac{R}{4}$$

Potential energy :- stored form energy due to its position.

Kinetic energy :- It is energy possessed by an object due to its motion.

Zeroth

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Formula

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80-0°

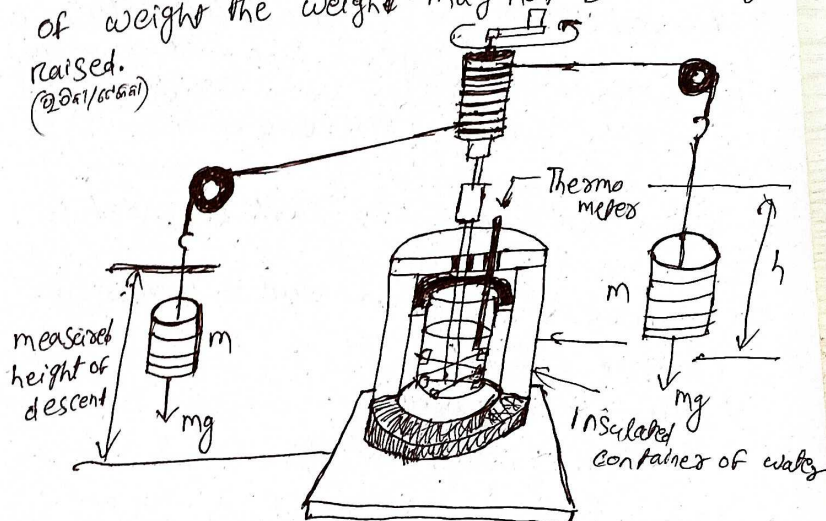
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Zeroth law:- If two bodies are each in thermal equilibrium with ~~some~~ ^a third body, then they are also in equilibrium with each other.
EX:- Thermometers.



Work:- It is said to be done by the system if the net effect of the system on the surroundings can be converted into raising of weight the weight may not be actually raised.
(2.841/60.641)



Work by the system is positive then work on the system is negative.

~~work~~ note:- Work input and heat output is always positive.

Deca = 10^1
Hecto = 10^2
Kilo = 10^3
Mega = 10^6
Giga = 10^9
Tera = 10^{12}
Peta = 10^{15}
Hexa = 10^{18}

Deci = 10^{-1} $\Rightarrow$ work output
Centi = 10^{-2} and heat input is
Milli = 10^{-3} always negative
Micro = 10^{-6}
Nano = 10^{-9}
Pico = 10^{-12}
Femto = 10^{-15}
Atto = 10^{-18}

Differentiation

⇒ Differentiation is a method used to compute the rate of change of a function of x w.r.t its input x .

⇒ Differentiation refers to the method of finding the derivatives of a function.

Partial Differentiation

⇒ Suppose we have a function $f(x, y)$ which depends on two variables x and y , where x and y are independent of each other. Then we say that the function f partially depends on x and y .

⇒ If we calculate the derivative of f , then that derivative is known as the partial derivative of f .

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⇒ Work and heat are path dependent, so it is path function.

⇒ Properties do not depend on path, so it is point function.

⇒ $dn \rightarrow$ Point function

$\Delta n / dn \rightarrow$ Path function

Energy $\rightarrow$ micro:-
(i) sensible energy
(ii) latent energy
(iii) chemical energy
(iv) nuclear energy
 $\rightarrow$ macro:-
(i) potential energy
(ii) kinetic energy

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⇒ Heat:- It is a method of energy transfer which takes place due to difference in temp.
 $\propto \Delta T$

$\propto \Delta m$
 $Q = C m \Delta T$

here $C \propto$ Proportional
constant.
 $C = \frac{Q}{m \Delta T} = \text{specific heat (kJ)}$

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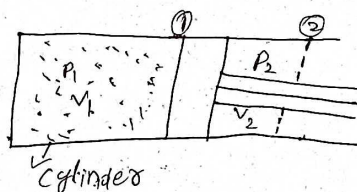
specific heat:- It is the energy required of unit mass of substance by $1K(1^{\circ}C)$

⇒ for non-monatomic gases C_p and C_v increase with temp. but their ratio γ decrease.

$$\frac{C_p}{C_v} = \gamma \text{ gamma}$$

⇒ for monatomic gases C_p , C_v , γ remain constant with temp.

fixed mass energy analysis / closed system analysis:-



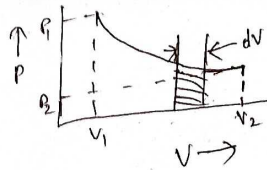
⇒ let the gas in the cylinder be a system having initial pressure (P_1) and (V_1) volume.

⇒ The piston may be moved to a final position having pressure (P_2) and volume (V_2)

⇒ system is in thermodynamic equilibrium both in initial state and final state.

⇒ At any intermediate point there is the pressure (P) and volume (V) which is also in equilibrium state.

⇒ when piston moves a small distance dx and A be the area of piston the force acting on the piston is $F = PA$ and the work done by the gas on the piston is dw



$$W = F \cdot dl$$

$$W = Pa \cdot dl$$

$$W = PdV$$

$$W = \int P dV$$

$$W_{1-2} = \int_{V_1}^{V_2} P dV$$

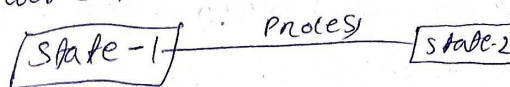
⇒ This equation applicable only when the path is in quasistatic $dW = PdV$
 $W = \int P dV$

Conditions

- ⇒ The system should be closed.
- ⇒ The path ~~should~~ should be in quasistatic.
- ⇒ Area under the curve on P-V diagram represent the work done for a closed system.

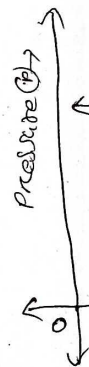
* Transient:-

When work is change with respect to time



* Compression:- It is a process under which volume of the system is gradually reduced, pressure and temperature increase where heat transfer may or may not be possible.

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* Expansion:- It is a process under which volume of a system as its temperature is increased, usually expressed as a fractional change in dimensions per unit temperature change.

$$-\infty < n < \infty$$

$$P r^n = \text{constant}$$

$$n = 0, P V^0 = \text{constant}$$

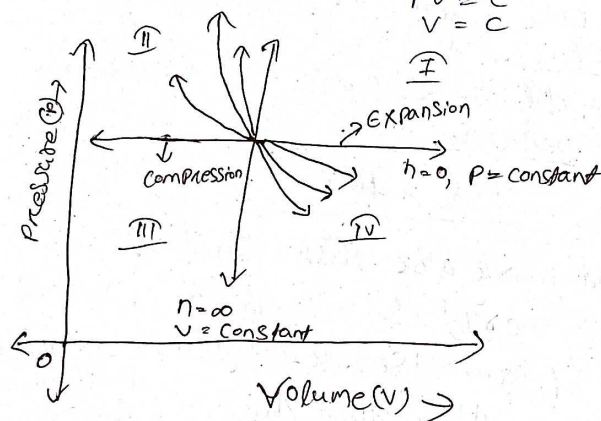
$$P \times 1 = P = \text{constant}$$

$$n = \infty, P V^\infty = C$$

$$V = C$$

$n = \text{polytropic index}$
 $V = \text{adiabatic index}$

the path



adiabatic
 system.

* Example of Isobaric Process:-

⇒ An example of the isobaric process included the boiling of water to steam or the freezing of water to ice.

time

⇒ In the process, a gas either expands or contracts to maintain constant pressure and hence the net amount of work is done by the system or on the system.

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Law of Thermodynamics

⇒ 1st law of thermodynamics :-

It is the law of conservation of energy. ⇒ 1st law
 ⇒ Energy neither be create nor be destroyed.
 ⇒ For a closed system under going a cycle net heat transfer is equal to net work transfer. $\oint \Delta Q = \oint \Delta W$

⇒ It's a quantitative law of energy.
 ⇒ If clockwise cycle is produce work done is in positive.

⇒ If anti-clockwise cycle is work absorb is in negative.

$$\Delta Q = \Delta U + \Delta W$$

* Heat and work are path function.

* Internal energy is a property of system

* Energy of an isolated system is always constant.

$$\Delta Q = \Delta U + \Delta W$$

per isolated system
 $\Delta W = 0$
 $\Delta Q = 0$

$$\Rightarrow \Delta U = 0$$

$$\Rightarrow U = \text{constant}$$

⇒ universe is a isolated system.

Application law of Thermodynamics

(1) Isothermal Process :- It is a thermodynamic process in which the temperature of a system remains constant. $P.V = C$

(2) Isobaric Process :- It is a thermodynamic process in which the pressure of a system remains constant. $\Delta P = 0$

(3) Isoent

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thermodynamics

⇒ joules law
if energy is destroyed in a cycle net work

work done

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system

is always isolated system
 $Q=0$
 $W=0$

dynamic

dynamic system

(3) Isentropic Process :- It is a thermodynamic process in which both adiabatic and reversible. $PV^\gamma = C$ → adiabatic process

⇒ The work transfers of the system are frictionless.

⇒ There is no net heat transfer or net heat transfer zero.

⇒ In this process another name is reversible adiabatic process.

⇒ Mathematically $\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

⇒ This process no change of entropy.

Prove $PV^\gamma = C$

$$P \propto \frac{1}{V^\gamma}$$

$$\Rightarrow P \propto \frac{1}{V^\gamma}$$

$$\Rightarrow PV = mRT$$

$$\Rightarrow \frac{PV}{T} = \text{constant}(c)$$

$$\Rightarrow P \cdot V = cT$$

$$\Rightarrow P \cdot V \propto T$$

$$\Rightarrow \frac{1}{V^\gamma} V_1 \propto T$$

$$\Rightarrow V^{1-\gamma} V_1 \propto T$$

$$\Rightarrow V^{1-\gamma} \propto T$$

$$\Rightarrow \frac{V^{1-\gamma}}{T} = C$$

where P = pressure

V = volume

m = mass

T = Temperature

R = Characteristic gas constant

Given

Gas constant

$1-\gamma$

$$\Rightarrow \frac{V_1^{1-\gamma}}{T_1} = \frac{V_2^{1-\gamma}}{T_2}$$

$$\Rightarrow \left(\frac{T_2}{T_1}\right) = \left(\frac{V_2}{V_1}\right)^{1-\gamma}$$

$$= \left(\frac{V_1}{V_2}\right)^{-(1-\gamma)}$$

$$\Rightarrow \left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\Rightarrow P \propto \frac{1}{V^{\frac{1}{\gamma}}} \quad \text{both side power of } \frac{1}{V} \text{ we get}$$

$$\Rightarrow P^{\frac{1}{\gamma}} \propto \left(\frac{1}{V}\right)^{\frac{1}{\gamma}}$$

$$\Rightarrow P^{\frac{1}{\gamma}} \propto \frac{1^{\frac{1}{\gamma}}}{(V)^{\frac{1}{\gamma}}}$$

$$\Rightarrow P^{\frac{1}{\gamma}} \propto \frac{1}{V}$$

$$\Rightarrow \boxed{V \propto \frac{1}{P^{\frac{1}{\gamma}}}}$$

$$\Rightarrow P \cdot V \propto T$$

$$\Rightarrow P \cdot \frac{1}{P^{\frac{1}{\gamma}}} \propto T$$

$$\Rightarrow P^1 \cdot P^{-\frac{1}{\gamma}} \propto T$$

$$\Rightarrow P^{1-\frac{1}{\gamma}} \propto T$$

$$\Rightarrow P^{\frac{\gamma-1}{\gamma}} \propto T$$

$$\Rightarrow \frac{P^{\frac{\gamma-1}{\gamma}}}{T} = C$$

$$\Rightarrow \frac{(P_1)^{\frac{\gamma-1}{\gamma}}}{T_1} = \frac{(P_2)^{\frac{\gamma-1}{\gamma}}}{T_2}$$

$$\Rightarrow \left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Consider (i) P_1 is initial state and (ii) P_2 is final state

$$\therefore \left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

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$$\Rightarrow \frac{P}{V^{\gamma}} = \text{const}$$

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(4) polytropic :- It is a Thermodynamic process which describes the relationship between the pressure and volume of a fluid during expansion or compression.

⇒ This may involve heat transfer, work interaction or both. (heat transfer may or may not take place)

$$\boxed{\Rightarrow PV^n = C}$$

$$\boxed{\Rightarrow 0 \leq n \leq \infty}$$

where ~~$n = \gamma$~~
 $n = \gamma$

(5) Isochoric :- It is a thermodynamic process which the volume of a system remain constant or pressure and temperature change.
 ex:- heating of gas in a closed cylinder.

Ideal Gas :- $PV = mRT$

$$\Rightarrow \frac{PV}{m} = RT$$

$$\Rightarrow \frac{P}{\rho} = RT$$

sign density $\leftarrow \int \Rightarrow \rho$

$$P \cdot V = n \bar{R} T$$

$$= \frac{m}{M} \bar{R} T$$

$$\Rightarrow \frac{m \bar{R}}{M} T = mRT$$

where:-

P = Pressure

V = Volume

m = Given mass of gas

M = molecular mass

R = Characteristic given gas constant

$\bar{R}$ = Universal gas constant

n = no of mole

T = Temperature

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Universal Gas constant value

Gas	molecular weight	C_p (kJ/kgK)	C_v (kJ/kgK)	$R = C_p - C_v$ (kJ/kgK)	$\gamma = \frac{C_p}{C_v}$
Air	28.97	1.005	0.718	0.287	1.4
Oxygen (O ₂)	32	0.920	0.660	0.260	1.4
Nitrogen (N ₂)	28	1.046	0.754	0.298	1.39
Hydrogen (H ₂)	2	14.40	10.40	4.0	1.38
CO	28	1.046	0.754	0.292	1.39
CO ₂	44	0.840	0.650	0.190	1.3
Methane (CH ₄)	16	2.22	1.70	0.520	1.3
SO ₂	64	0.796	0.67	0.126	1.19
Ammonia (NH ₃)	17	-	-	0.488	-
Water	18	-	-	0.462	-

Universal gas constant = $8.31446261815324 \text{ J}$
 molecular mass of air = 28.96 g/mol

Given

~~$P_1 = 5 \text{ bar}$~~

$T_1 = 30^\circ$

$T_1 = 30 + 273 = 303$

$T_2 = 50^\circ$

$T_2 = 50 + 273 = 323$

$P_2 = ?$

~~$\Rightarrow \left(\frac{50}{30}\right) = \left(\frac{n}{5}\right)^{\frac{\gamma-1}{\gamma}}$~~

~~$\Rightarrow 1.06 \text{ K} = \left(\frac{n}{5}\right)^{\frac{1.4-1}{1.4}}$~~

~~$\Rightarrow 1.06 \text{ K} = \left(\frac{n}{5}\right)^{0.28}$~~

$1.06 \text{ K} = \frac{n}{1.56}$

$\Rightarrow (n)^{0.28} = 1.06 \times 1.56$

~~≈ 2.58~~
 ≈ 1.65

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{n}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{323}{303} = \left(\frac{n}{5} \right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow 1.06 = \left(\frac{n}{5} \right)^{0.28}$$

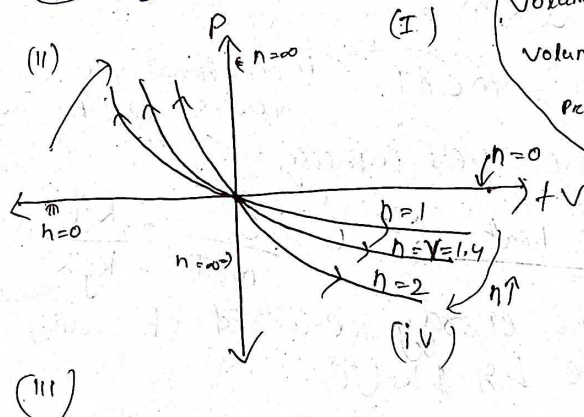
$$\Rightarrow 1.06 = \frac{n}{1.56}$$

$$\Rightarrow 1.06 \times 1.56 = n^{0.28}$$

$$\Rightarrow 1.653 = n^{0.28}$$

$$\Rightarrow P_2 = (1.653)^{\frac{1}{0.28}} = n$$

$$\Rightarrow P_2 = 6.01$$



Volume increase
= Expansion
Volume decrease
= Compression
Pressure constant
horizontal
 $\Rightarrow n=0$
Volume constant
 $\Rightarrow n=\infty$

$PV^n = C$
 $n=0$
 $P=C$
 $n=\infty$
 $n=1$
 $PV=C$

* Internal energy is a property of a system

* 1st law thermodynamics point

⇒ Perpetual motion machine of First time (PMM-I) is impossible.

⇒ The concept of the machine which produces the work continuously without energy observing any energy in any form is called (EMM-I) and it is impossible.

* Heat :-

⇒ Heat transfer is a path function.

⇒ It is a low grade of energy.

⇒ It is a method of energy transfer which takes place due to difference in temp.

⇒ $Q \propto dT$ ⇒ change temp.

⇒ $Q \propto m$ ⇒ mass

⇒ $Q = mc dT$ → proportionality constant which is specific heat
 ↓
 per unit mass

⇒ mc = Heat capacity

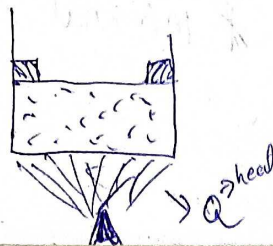
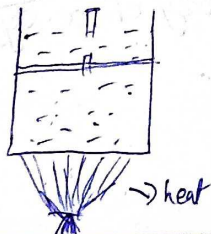
* Specific heat :- $C = \frac{Q}{mdT} = \frac{kJ}{kg \cdot K}$ (unit)

It is the energy required of unit mass substance by $1K$ (1°)

C_P = Specific heat pressure

note
 $C_P > C_V$ always

C_V = Specific heat volume



$1 = \frac{I}{P}$
 $\frac{dQ}{dt} = \frac{dU}{dt} + \frac{dW}{dt}$
 $\frac{dQ}{dt} = \frac{dU}{dt} + \frac{dW}{dt}$
 $\frac{dQ}{dt} = \frac{dU}{dt} + \frac{dW}{dt}$

$\Rightarrow$ ~~CP is more~~ ^{Relationship} ~~than CV~~ because C_p includes both internal energy as well as boundary work, where as C_v includes only internal energy.

$$\Rightarrow C_p - C_v = R$$

$$\Rightarrow \frac{C_p}{C_v} = \gamma$$

$$\Rightarrow \gamma C_v - C_v = R$$

$$\Rightarrow C_v(\gamma - 1) = R$$

$$\Rightarrow C_v = \frac{R}{\gamma - 1}$$

$$\Rightarrow C_p - \frac{C_p}{\gamma} = R$$

$$\Rightarrow C_p \left(1 - \frac{1}{\gamma}\right) = R$$

$$\Rightarrow C_p = \frac{\gamma R}{\gamma - 1}$$

$$C_p \left(\frac{\gamma - 1}{\gamma}\right) = R$$

$$\Rightarrow C_p(\gamma - 1) = \gamma R$$

$$\Rightarrow C_p = \frac{\gamma R}{\gamma - 1}$$

Assignment $\Rightarrow C_p - C_v = R$ derivation (5 mark question)

~~Prove~~ $C_p - C_v = R$... derived

$$dU = m C_v dT \dots (i)$$

$$dQ = m C_p dT \dots (ii)$$

$$dW = P dV \dots (iii)$$

$$dQ = dU + dW \dots (iv) \text{ 1st law of Thermodynamics}$$

Substituting eqn (i), (ii), (iii), (iv) we get

$$m C_p dT = m C_v dT + P dV$$

$$\Rightarrow P dV = m C_p dT - m C_v dT \dots (v)$$

where

Q = heat supply

dU = change in internal energy

W = work done

dV = change in volume of the gas

dT = change in Temperature

for mole of ideal gas the equation is: -

$$P.V. = mRT$$

~~$$P.V. = mRT$$~~

$$\Rightarrow P.dV + V.dP = mRdT$$

$$\Rightarrow P.dV = mRdT - V.dP$$

Pressure is constant, $dp=0$

$$\Rightarrow P.dV = mRdT$$

When put $P.dV$ on eqn (V) we get

~~$$\Rightarrow mC_p dT - mC_v dT = mRdT$$~~

$$\Rightarrow \boxed{C_p - C_v = R} \dots (V_i) \text{ proved}$$

Q $PV = C \Rightarrow P = \frac{C}{V}$

$$W = \int P.dV$$

$$= \int \frac{C}{V} dV$$

$$= C \int \frac{1}{V} dV$$

$$= C \ln(V) \dots$$

$$= P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$$

$$= P_1 V_1 (\ln V_2 - \ln V_1)$$

$$= \boxed{P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)} \dots (Ans)$$

$$\Rightarrow P_1 V_1 = P_2 V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{P_1}{P_2}$$

$$\Rightarrow PV^n = C$$

$$P = \frac{C}{V^n}$$

$$W = \int \frac{C}{V^n} dV$$

$$= C \int \frac{1}{V^n} dV$$

$$= C \int V^{-n} dV$$

$$= C \left[\frac{V^{-n+1}}{-n+1} \right]$$

$$= C \left[\frac{V_2^{-n+1}}{-n+1} - \frac{V_1^{-n+1}}{-n+1} \right]$$

$$= C \left[\frac{V_2^{-n+1}}{-n+1} - \frac{V_1^{-n+1}}{-n+1} \right]$$

$$= \frac{C \cdot V_2^{-n+1}}{-n+1} - \frac{C \cdot V_1^{-n+1}}{-n+1}$$

$$= \frac{P_2 V_2^n \cdot V_2^{-n+1}}{-n+1} - \frac{P_1 V_1^n \cdot V_1^{-n+1}}{-n+1}$$

$$= \frac{P_2 V_2^{n-n+1} - P_1 V_1^{n-n+1}}{-n+1}$$

$$= \frac{P_2 V_2 - P_1 V_1}{-n+1}$$

$$= \frac{-(P_2 V_2 - P_1 V_1)}{-(-n+1)}$$

$$\Rightarrow \frac{-P_2 V_2 + P_1 V_1}{n-1} = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$C = P_1 V_1$$

$$C = P_2 V_2$$

$$C = P_1 V_1^n = P_2 V_2^n$$

$$PV^\gamma = C$$

$$P = \frac{C}{V^\gamma}$$

$$W = \int \frac{C}{V^\gamma} dV$$

$$= C \int \frac{1}{V^\gamma} dV$$

$$= C \int V^{-\gamma} dV$$

$$= C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]$$

$$= C \left[\frac{V_2^{-\gamma+1}}{-\gamma+1} - \frac{V_1^{-\gamma+1}}{-\gamma+1} \right]$$

$$= C \left[\frac{V_2^{-\gamma+1}}{-\gamma+1} - \frac{V_1^{-\gamma+1}}{-\gamma+1} \right]$$

$$= \frac{C \cdot V_2^{-\gamma+1}}{-\gamma+1} - \frac{C \cdot V_1^{-\gamma+1}}{-\gamma+1}$$

$$= \frac{P_2 V_2^\gamma \cdot V_2^{-\gamma+1}}{-\gamma+1} - \frac{P_1 V_1^\gamma \cdot V_1^{-\gamma+1}}{-\gamma+1}$$

$$= \frac{P_2 V_2^{\gamma-\gamma+1} - P_1 V_1^{\gamma-\gamma+1}}{-\gamma+1}$$

$$= \frac{P_2 V_2 - P_1 V_1}{-\gamma+1}$$

$$= \frac{-(P_2 V_2 - P_1 V_1)}{-(-\gamma+1)}$$

$$= \frac{-P_2 V_2 + P_1 V_1}{\gamma-1}$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma-1}$$

worked one

↓

2nd law of Thermodynamics

It is qualitative law of energy.

Source = high temp.

Sink = low temp.

~~Reservoir~~

Thermal Energy Reserver: - (TER)

which add or remove the heat of a Reserver but Temperature is same. is known as (TER)

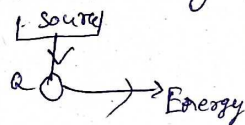
It is two type: - $\rightarrow$ high Reserver

$\rightarrow$ low Reserver

Kelvin Planck: -

It is impossible to develop a cyclic device which produces net work output by exchanging energy with a single reservoir.

The concept a such a device is called PMM-II, has 100% Thermal efficiency as impossible.



Classius Planck

It is impossible to develop a device which transfers heat from lower temp to high. temp. without any external energy input. Such a device will have infinite COP and is impossible.

(Coefficient of Performance) $EPR = \text{Energy Performance ratio}$

C.O.

of

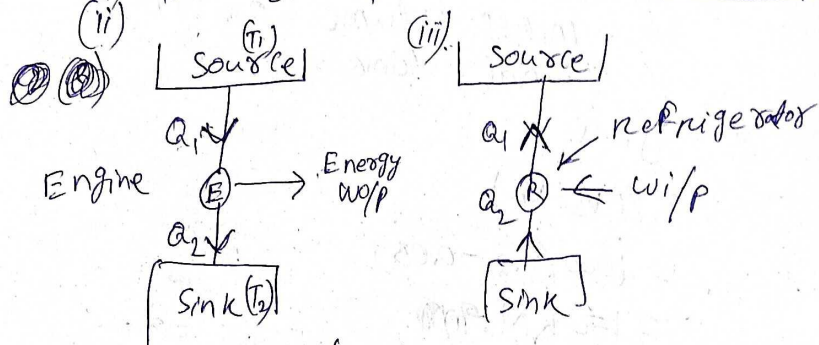
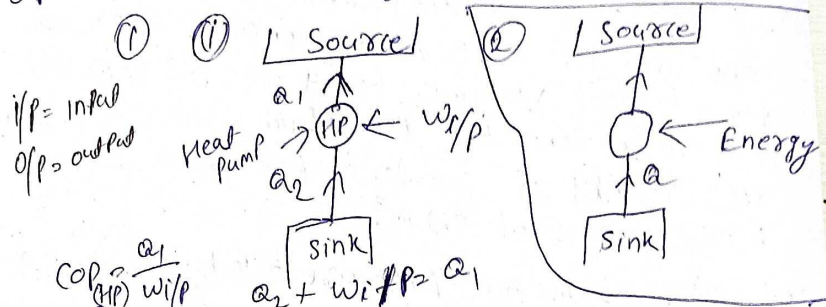
$i/p = 10$

$o/p = 0$

C

⊙

C.O.P.: C.O.P can be defined as the ratio of desired effect energy input.



$$\eta = \frac{O/P}{I/P} = \frac{w/p}{q_1}$$

$$q_2 + w/p = q_1$$

$$C.O.P = \frac{q_2}{w/p}$$

$$q_1 = w + q_2$$

Condition :-

$$COP_{HP} = \frac{q_1}{w/p} = \frac{q_2 + w/p}{w/p}$$

$$= \frac{q_2}{w/p} + 1$$

$$\Rightarrow COP_{HP} = COP_{Ref.} + 1$$

* Temp. limit same or Temp. Ratio same

Assignment 1st Chapter

* A certain working fluid at 10 bar is contained in a piston cylinder arrangement the initial volume being 0.05 m^3 . Calculate the work done by the fluid when it expands reversibly at constant pressure to a final volume of 0.2 m^3 .

Sol Given :- Initial pressure = 10 bar = 1000 kPa
Initial volume = 0.05 m^3
Final volume = 0.2 m^3

$$W = \int P dV$$

$$= P(V_2 - V_1)$$

$$= 1000(0.2 - 0.05)$$

$$= 150 \text{ kJ}$$

$$= 150 \text{ kJ}$$

$$\begin{array}{r} 1000 \\ \times 0.2 \\ \hline 2000 \\ 0.05 \\ \hline 2000.0 \\ - 200 \\ \hline 1800 \end{array}$$

* A certain fluid is contained in a piston cylinder arrangement. It expands from 0.1 m^3 to 0.5 m^3 according to a law $PV = \text{constant}$. Taking the final pressure as 150 kPa, find the work done by the fluid.

Sol Initial Volume = $0.1 \text{ m}^3 = V_1$

Final Volume = $0.5 \text{ m}^3 = V_2$

Final Pressure = 150 kPa = P_2

$$W = \int P dV$$

$$= P_2 V_2 \ln(V_2/V_1) = 150 \times 0.5 \times \ln(0.5/0.1) = 120.71 \text{ kJ}$$

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* A mass of gas is compressed in a quasi-static process from 100 kPa, 0.3 m³ to 500 kPa, 0.05 m³. Assuming that the pressure and volume are related by $PV^n = C$, find the work done by the gas system.

Sol

$$P_1 = 100 \text{ kPa}$$

$$V_1 = 0.3 \text{ m}^3$$

$$P_2 = 500 \text{ kPa}$$

$$V_2 = 0.05 \text{ m}^3$$

$$W = \int P dV$$

$$= \frac{P_2 V_2 - P_1 V_1}{-n + 1}$$

In this equation all the values are known except the polytropic index n .
Consider the process relation.

$$P_1 V_1^n = P_2 V_2^n$$

$$\left(\frac{V_1}{V_2}\right)^n = \left(\frac{P_2}{P_1}\right)$$

Taking natural log on both sides,

$$n \ln(V_1/V_2) = \ln(P_2/P_1)$$

$$n \ln\left(\frac{V_1}{V_2}\right) = \ln\left(\frac{P_2}{P_1}\right)$$

$$n = \frac{\ln(V_1/V_2)}{\ln(P_2/P_1)}$$

Substituting the numerical values

$$n = \frac{\ln\left(\frac{0.3}{0.05}\right)}{\ln\left(\frac{500}{100}\right)} = 0.898$$

$$W = \frac{500 \times 0.05 - 100 \times 0.3}{1 - 0.898}$$

$$W = -99.019 \text{ kJ}$$

* Figure given below shows a piston cylinder arrangement containing a certain fluid at 300 kPa, 30°C. Diameter of the cylinder is 10 cm and the stiffness of the spring is 200 kN/m. What is the pressure when the gas is heated such that the piston expands by 5 cm. Also compute the work done.

Sol given increase in spring force $df = k \cdot dx$

$$P_1 = 300 \text{ kPa}$$

$$T_1 = 30^\circ\text{C}$$

$$\text{Diameter of the cylinder} = 10 \text{ cm}$$

$$P_2 = ?$$

$$W = ?$$

$$P_2 = P_1 + dP$$

$$= P_1 + \frac{k \cdot dx}{A}$$

$$= 300 + \frac{200 \times 5}{\left(\frac{\pi}{4} \times 0.1^2\right)} \times 10^{-3}$$

$$= 427.3 \text{ kPa}$$

Work done = Area under the straight line 1-2

$$= \frac{P_2 + P_1}{2} \times dV$$

$$= \frac{427.3 + 300}{2} \times \frac{\pi}{4} \times 0.1^2 \times 0.05$$

$$= 0.143 \text{ kJ}$$

$$= 143 \text{ J}$$

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2nd Chapter Problem

Law of Thermodynamics

* During the compression stroke of reciprocating compressor, the work done to the air in the cylinder is 95 kJ/kg and 43 kJ/kg of heat is rejected to the surroundings. Determine the change in internal energy.

Sol Given:- $W = -95 \text{ kJ/kg}$
 $Q = -43 \text{ kJ/kg}$
 $\Delta U = ?$

$$Q = W + \Delta U$$

$$-43 = -95 + \Delta U$$

$$\Delta U = -43 - (-95)$$

$$\Delta U = 52 \text{ kJ/kg}$$

* A closed system undergoes a cycle - comprising of four processes. The heat and work transfer are given in the following table. Prove that tabulated result are consistent with first law of thermodynamic also calculate thermal efficiency of the cycle.

Process	$Q \text{ kJ/min}$	$W \text{ kJ/min}$
1-2	1865	550
2-3	-1735	0
3-4	-950	-279
4-1	1096	0

Sol $\phi dQ = 1865 - 1735 - 950 + 1076$
 $= 276 \text{ kJ/min}$

$\phi dW = 550 - 274$
 $= 276 \text{ kJ/min}$

1st law of thermodynamics is,

$\phi dQ = \phi dW$
 $276 = 276$

Net work done $= 276 \text{ kJ/min}$

Heat supplied $Q_{in} = 1865 + 1076$
 $= 2961 \text{ kJ/min}$

Thermal efficiency $= \frac{W}{Q_{in}}$
 $= \left(\frac{276}{2961} \right) \times 100$
 $= 9.32\%$

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Q/ During a non flow process 5kW Paddle wheel work is supplied while the internal energy of the system increase in one minute by 200kJ. Find the heat transfer when there is no other form of energy transfer.

Given $W = -5 \text{ kJ/s}$

Change in internal energy $= 200 \text{ kJ in one min.}$

$Q = ?$

Sol $Q - W = \Delta E$

$\Delta E = \Delta U$

$Q = W + \Delta U$

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considering a period of one minute

$$W = -5 \times 60 \\ = -300 \text{ kJ}$$

$$\text{Hence, } Q = -300 + 200$$

$$= -100 \text{ kJ}$$

(negative sign indicates that the heat transfer is from the system to the surroundings)

Q one kg of air is heated from 20°C to 105°C .
Find the change of internal energy and change of enthalpy.

assume $C_p = 1.01 \text{ kJ/kgK}$ and

$$C_v = 0.72 \text{ kJ/kgK}$$

Sol.

Given $m = 1 \text{ kg}$

$$T_1 = 20^\circ\text{C}$$

$$T_2 = 105^\circ\text{C}$$

Change of ~~int~~ internal energy,

$$U_2 - U_1 = m \cdot C_v \cdot (T_2 - T_1)$$

$$= 1 \times 0.72 (105 - 20)$$

$$= 61.2 \text{ kJ}$$

Change of enthalpy,

$$H_2 - H_1 = m C_p (T_2 - T_1)$$

$$= 1 \times 1.01 (105 - 20)$$

$$H_2 - H_1 = 85.85 \text{ kJ}$$

* A certain working fluid at 10 bar is contained in a cylinder behind a piston, the initial volume being 0.05 m^3 . Calculate the work done by the fluid when it expands reversibly at constant pressure to a final volume of 0.2 m^3 .

Sol $P_1 = 10 \text{ bar} = 1000 \text{ kPa}$
 $V_1 = 0.05 \text{ m}^3$
 $V_2 = 0.2 \text{ m}^3$

$$W = \int P dV$$

$$= P(V_2 - V_1)$$

$$= 1000(0.2 - 0.05)$$

$$= 150 \text{ kJ/m}$$

$$= 150 \text{ kJ}$$

Q Steam having enthalpy 2930.8 kJ/kg , enters a nozzle with a velocity of steam at the exit of the nozzle, if its enthalpy is reduced to 2721.4 kJ/kg .

Sol $\frac{C_2^2 - C_1^2}{2} = h_1 - h_2$

$$= \frac{C_2^2 - 60^2}{1000 \times 2} = 2930.8 - 2721.4$$

$$= C_2^2 - 60^2 = 418800$$

$$\Rightarrow C_2 = \sqrt{418800 + 3600}$$

$$= 649.92 \text{ m/s}$$

$$\Rightarrow C_2 = 650 \text{ m/s}$$

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Q A fluid flowing through a turbine at the rate of 0.75 kg/s . Across the turbine the specific enthalpy drop of the fluid is 580 kJ/kg and it loses 35 kJ/s in the form of heat energy. Determine the power produced by the turbine. Neglect changes in kinetic energy and potential energy.

Sol Given Flow rate, $m = 0.75 \text{ kg/s}$

Enthalpy drop, $h = 580 \text{ kJ/kg}$

Heat rejection, $Q = 35 \text{ kJ/s}$

Neglecting K.E. and P.E. the SFEE becomes

$$Q - W = m(h_2 - h_1)$$

$$35 - W = -0.75(580)$$

$$W = 435 - 35$$

$$W = 400 \text{ kJ/s}$$

Q In a steady flow open system, a fluid substance flows at the rate of 4 kg/s . It enters the system at a pressure of 600 kN/m^2 , a velocity of 220 m/s , internal energy 2200 kJ/kg and specific volume $0.42 \text{ m}^3/\text{kg}$. It leaves the system at a pressure of 150 kN/m^2 , a velocity of 145 m/s , internal energy 1650 kJ/kg and specific volume $1.5 \text{ m}^3/\text{kg}$. During its passage through the system, the substance has a loss by heat transfer of 4 kJ/kg to the surroundings. Determine the power of the system, stating whether it is from or to the system. Neglect any change of

Gravitational potential energy.

Given $m = 4 \text{ kg/s}$

$$C_1 = 220 \text{ m/s}$$

$$h_1 = (P_1 V_1 + u_1) \\ = 600 \times 0.42 + 2200 \\ = 2952 \text{ kJ/kg}$$

$$C_2 = 145$$

$$h_2 = (P_2 V_2 + u_2) \\ = 150 \times 1.5 + 1630 \\ = 1875 \text{ kJ/kg}$$

$$a = 40 \text{ kJ/kg}$$

$$a - W = \left[h_2 - h_1 + \frac{C_2^2 - C_1^2}{2} \right]$$

$$= -40 - W = \left[(1875 - 2952) + \frac{(145^2 - 220^2)}{1000 \times 2} \right]$$

$$= -40 - W = -577 - 13.68$$

$$W = 550.68 \text{ kJ/kg}$$

$$\text{Workdone Per Second} = 550.68 \times 4$$

* A heat engine receives 2202.72 kJ/s of 1500 kg/min and gives an output of 8.2 kW . Determine. (i) The thermal efficiency

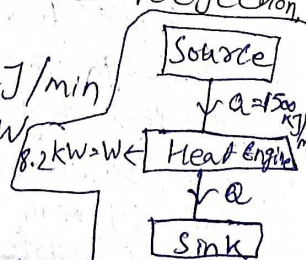
(ii) The rate of heat rejection.

Sol Given data $Q_1 = 1500 \text{ kJ/min}$

$$W = 8.2 \text{ kW}$$

$$Q_1 = 1500 \text{ kJ/min}$$

$$\Rightarrow \frac{1500}{60} = 25 \text{ kJ/s}$$



Thermal efficiency, $\eta = \frac{W}{Q_1}$
 $= \frac{8.2}{25} = 0.328$
 $\eta = 32.8\%$

Rate of heat rejection, $Q_2 = Q_1 - W$
 $= 25 - 8.2$
 $Q_2 = 16.8 \text{ kJ/s}$

Q find the co-efficient of performance and heat transfer rate in the condenser of a refrigerator in kJ/h which has a refrigeration capacity of 12000 kJ/h when power input is 0.75 kW.

Given data :- Refrigeration capacity $Q_2 = 12000 \text{ kJ/h}$

Power Input $W = 0.75 \text{ kW}$
 $= 0.75 \times 60 \times 60 \text{ kJ/h}$
 $W = 2700 \text{ kJ/h}$

Co-efficient of performance
 C.O.P. Refrigerator = $\frac{\text{Heat absorbed at lower temperature}}{\text{Work Input}}$

$= \frac{Q_2}{W} = \frac{12000}{2700}$

C.O.P. = 4.44

1st law = $Q_1 = Q_2 + W$
 $= 12000 + 2700$
 $Q_1 = 14700 \text{ kJ/h}$

1/s
 rate
 3.2 kW

Section

note

1. a = 1500

at 1500

1. a

nk

Problem 3

* A cyclic heat engine is receiving 156000 kJ/hr of heat from a reservoir and produces 15 kW of power. Find the thermal efficiency of the engine. Also calculate heat rejected by the engine to the sink.

Sol Given data

cyclic heat engine.

$$Q = 156000 \text{ kJ/hr} = 156000 \text{ kJ}/3600 \text{ s}$$

$$W = 15 \text{ kW}$$

Thermal efficiency $\eta_{th} = ?$

~~Q_{out}~~ $Q_{out} = \text{Heat rejected} = ?$

$$(a) \quad \eta_{th} = \frac{W}{Q_{in}} = \frac{15}{\left(\frac{156000}{3600}\right)} = 0.346$$

(b) 1st law of thermodynamics:-

$$\sum Q = \sum W$$

$$Q_{in} - Q_{out} = W$$

$$Q_{out} = Q_{in} - W$$

$$= 156000 - 15 \times 3600$$

$$= 10,2000 \text{ kJ/hr}$$

* A refrigerator of COP 3 is to pump 54000 kJ/hr of heat from a cold space into the atmosphere. What is the power required to run the refrigerator. Also find the rate of heat rejected into the atmosphere.

6000

of
heat

Sol Given data

$$C.O.P = 3$$

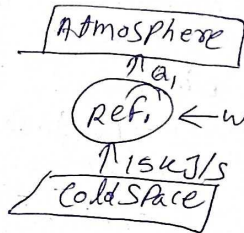
$$Q_2 = 54000 \text{ KJ/hr}$$

$$= \frac{54000 \text{ KJ}}{3600 \text{ s}}$$

$$= 15 \text{ KJ/s}$$

$$W = ?$$

$$Q_1 = ?$$



$$(a) W = \frac{Q_2}{COP} = \frac{15}{3} = 5 \text{ kW}$$

$$(b) Q_1 = W + Q_2$$

$$= 5 + 15 = 20 \text{ KJ/s}$$

Unit-3 Properties Processes of
Perfect Gas Problem

(1) The density of air at NTP is 1.29 kg/m^3
calculate characteristic gas constant for
air.

Given $P = 760 \text{ mm Hg} = 101.325 \text{ kN/m}^2$

$$T = 0 + 273 = 273 \text{ K}$$

$$\text{Density } \rho = m/V = 1.29 \text{ kg/m}^3$$

STP
Standard
Temp. and
Pressure

Conf of air $R = ?$

$$PV = mRT$$

$$P = (m/V)RT$$

$$P = \rho RT$$

$$R = \frac{P}{\rho T}$$

$$= \frac{101.3}{1.29 \times 273}$$

$$= 0.2876 \text{ kJ/kgK}$$

$$R = 0.2876 \text{ kJ/kgK}$$

* A certain perfect gas exerts at 40°C and a pressure of 110.3 kPa if the value of the gas constant is 0.26 kJ/kg K . Find the specific volume.

Sol $P = 110.3 \text{ kPa}$
 $T = 40 + 273 = 313 \text{ K}$
 $R = 0.26 \text{ kJ/kg K}$

Specific Volume $V/m = ?$

$$pV = mRT$$

$$\frac{V}{m} = \frac{RT}{p}$$

$$= \frac{0.26 \times 313}{110.3}$$

$$= 0.738 \text{ m}^3/\text{kg}$$

$$\text{Specific Volume} = 0.738 \text{ m}^3/\text{kg}$$

* For certain ideal gas $R = 0.278 \text{ kJ/kg K}$ and molecular weight $\gamma = 1.25$ determine C_p, C_v

Sol Given $R = 0.278 \text{ kJ/kg K}$

$$\gamma = 1.25$$

$$C_p = ?$$

$$C_v = ?$$

$$M = ?$$

$$C_v = \frac{R}{(\gamma - 1)}$$

$$C_v = \frac{0.278}{1.25 - 1} = 1.112 \text{ kJ/kg K}$$

$$C_v = 1.112 \text{ kJ/kg K}$$

idea
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we know that, $\gamma = \frac{C_p}{C_v}$

$$C_p = \gamma C_v$$
$$= 1.25 \times 1.112$$

$$C_p = 1.4 \text{ kJ/kgK}$$

we know that, $R_u = MR$

$$m = \frac{R_u}{R} = \frac{8.314}{0.278}$$

$$m = 30$$

(1) one kg of a perfect gas occupies a volume of 0.85 m^3 at 15°C and at a constant pressure of 1 bar. The gas is first heated at a const pressure. Find the specific heat at constant volume and constant pressure of the gas. take $\gamma = 1.4$

Ans:- $m = 1 \text{ kg}$
 $V = 0.85 \text{ m}^3$
 $T = 15^\circ\text{C}$
 $= 15 + 273 = 288 \text{ K}$

$$P = 1 \text{ bar}$$
$$= 0.1 \times 10^6 \text{ N/m}^2$$

$$\gamma = \frac{C_p}{C_v} = 1.4$$

$$C_v = ?$$

$$C_p = ?$$

$$C_v = \frac{PV}{MT} = MR$$

where $R = \text{characteristics gas constant}$

$$R = \frac{PV}{mT} = \frac{0.1 \times 10^6 \times 0.85}{1 \times 288} = 295 \text{ J/kgK}$$

Relationship:- $C_v = \frac{R}{\gamma - 1}$

$$= \frac{0.295}{1.4 - 1}$$

$$\Rightarrow C_v = 0.7375 \text{ kJ/kg K}$$

$$C_p = \frac{C_p}{C_v} = 1.4$$

$$\Rightarrow C_p = 1.4 C_v$$

$$= 1.4 \times 0.7375$$

$$\Rightarrow C_p = 1.0325 \text{ kJ/kg K}$$

* A vessel of 2.5 m^3 capacity contains one kg-mole of nitrogen at 100°C . If the gas is ~~cooled~~ cooled to 30°C , calculate final pressure, change in specific internal energy and specific enthalpy take $\gamma = 1.4$ and one kg-mole nitrogen is 28 kg .

Given:- $V_1 = 2.5 \text{ m}^3$

$$T_1 = 100 + 273 = 373 \text{ K}$$

$$T_2 = 30 + 273 = 303 \text{ K}$$

$$1 \text{ kg mole of } \text{N}_2 \text{ gas} = 28 \text{ kg}$$

$$\gamma = 1.4$$

$$P_2 = ?$$

Change in specific internal energy, $du = ?$

Change in specific enthalpy $dh = ?$

$$R = \frac{R_u}{m} = \frac{8.314}{28}$$

$$R = 0.297 \text{ kJ/kgK}$$

$$C_v = \frac{R}{\gamma - 1}$$

$$= \frac{0.297}{1.4 - 1}$$

$$C_v = 0.743 \text{ kJ/kgK}$$

$$C_p = C_v \times \gamma$$

$$= 0.743 \times 1.4$$

$$C_p = 1.04 \text{ kJ/kgK}$$

Final Pressure $\therefore P_2 V_2 = m R T_2$

$$P_2 = \frac{m R T_2}{V_2}$$

$$= \frac{28 \times 0.297 \times 303}{2.5}$$

$$P_2 = 1007.8 \text{ Pa}$$

$$P_2 = 1.008 \text{ kPa}$$

$$du = C_v (T_2 - T_1)$$

$$= 0.743 (100 - 30)$$

$$du = 52.01 \text{ kJ/kg}$$

$$dh = C_p (T_2 - T_1)$$

$$= 1.04 (100 - 30)$$

$$dh = 72.8 \text{ kJ/kg}$$

$$dh = C_p dT$$

$$du = C_v dT$$

$$H = m C_p dT$$

$$U = m C_v dT$$

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* one kg of air is heated in a closed rigid vessel such that its temperature changes from 27°C to 427°C . find the heat transferred and change in internal energy. Assume $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ and $C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$.

Given data:-

$$m = 1 \text{ kg}$$

$$T_1 = 27^{\circ}\text{C} = 27 + 273 = 300 \text{ K}$$

$$T_2 = 427^{\circ}\text{C} = 427 + 273 = 700 \text{ K}$$

$$R = 0.287 \text{ kJ/kg}\cdot\text{K}$$

$$C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$$

$$Q_{1-2} = ?$$

$$U_2 - U_1 = ?$$

$$C_v = C_p - R$$

$$= 1.005 - 0.287$$

$$C_v = 0.718 \text{ kJ/kg}\cdot\text{K}$$

$$\text{Workdone}(W_{1-2}) = 0$$

$$\begin{aligned} \text{Heat transferred, } Q_{1-2} &= m C_v (T_2 - T_1) \\ &= 1 \times 0.718 (700 - 300) \\ &= 0.718 \times 400 \end{aligned}$$

$$Q_{1-2} = 287.2 \text{ kJ}$$

$$\begin{aligned} \text{change in internal energy, } (U_2 - U_1) &= Q_{1-2} \\ &= U_2 - U_1 = 287.2 \text{ kJ} \end{aligned}$$

* A certain gas occupies a space of 0.3 m^3 at a pressure of 2 bar and a temperature of 77°C . It is heated at a constant volume, until the pressure is 7 bar . Determine

- (i) Tem
- (ii) ma
- (iii) Ch
- Assum

Sol Q

L

L

r

Fig. 2

2020

(i) Temperature at the end of the process:-

(ii) mass of the gas;

(iii) Change in internal energy during the process

Assume $C_p = 1.005 \text{ kJ/kgK}$

$C_v = 0.712 \text{ kJ/kgK}$

$R = 287 \text{ J/kgK}$

Sol Given data:- $V_1 = 0.3 \text{ m}^3$

$$P_1 = 2 \text{ bar} = 0.2 \times 10^6 \text{ N/m}^2$$

$$T_1 = 77^\circ\text{C} = 77 + 273 = 350 \text{ K}$$

$$P_2 = 7 \text{ bar} = 0.7 \times 10^6 \text{ N/m}^2$$

$$C_p = 1.005 \text{ kJ/kgK}$$

$$C_v = 0.712 \text{ kJ/kgK}$$

$$R = 287 \text{ J/kgK}$$

$$T_2 = ?$$

$$m = ?$$

Let

$T_2 = \text{Temp. at the end of the process}$

$$\text{Let } \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \frac{P_2 T_1}{P_1} = \frac{0.7 \times 10^6 \times 350}{0.2 \times 10^6}$$

$$T_2 = 1225 \text{ K}$$

$$= 1225 - 273$$

$$= 952^\circ\text{C}$$

mass of the gas

Let $m = \text{mass of the gas}$

$$P V_1 = m R T_1$$

$$m = \frac{P V_1}{R T_1} = \frac{0.2 \times 10^6 \times 0.3}{287 \times 350} = 0.597 \text{ kg}$$

change in internal energy

$$\begin{aligned} dU &= U_2 - U_1 \\ &= mC_v(T_2 - T_1) \\ &= 0.597 \times 0.712 (1225 - 350) \\ dU &= 372 \text{ kJ} \end{aligned}$$

* During a constant pressure process, the internal energy of one kg of a system increases by 28.5 kJ and enthalpy increases by 44.3 kJ. The pressure is maintained at 620 kN/m².

(i) what is the work which accompanies this process?

(ii) If the initial volume is 0.793 m³, what is the final volume?

~~Sol~~ Given $P = P_1 = P_2 = 620 \text{ kN/m}^2$

$$m = 1 \text{ kg}$$

$$U_2 - U_1 = 28.5 \text{ kJ}$$

$$H_2 - H_1 = 44.3 \text{ kJ}$$

$$V_1 = 0.793 \text{ m}^3$$

$$W_{1-2} = ?$$

$$V_2 = ?$$

Solution

for constant pressure process,
Heat added (Q_{1-2}) = change in enthalpy ($H_2 - H_1$)
 $= 44.3 \text{ kJ}$

1st law thermodynamics $W_{1-2} = Q_{1-2} - (U_2 - U_1)$
 $= 44.3 - 28.5$
 $= 15.8 \text{ kJ}$

work done $w_{1-2} = P(V_2 - V_1)$
 $15.8 = 620(V_2 - 0.793)$

final Volume, $V_2 = 0.82 \text{ m}^3$

* A gas whose pressure, volume and temperature are 5 bar, 0.23 m^3 and 185°C respectively has its state changed at constant pressure until its temp. becomes 70°C . Determine (i) the work done, (ii) change in internal energy and (iii) the heat transferred during the process
 $R = 290 \text{ J/kgK}$; $C_p = 1.005 \text{ kJ/kgK}$.

Given $P_1 = 5 \text{ bar} = 500 \text{ kN/m}^2$

$V_1 = 0.23 \text{ m}^3$

$t_1 = 185^\circ\text{C}$

$T_1 = 185 + 273 = 458 \text{ K}$

$P_1 = P_2 = 500 \text{ kN/m}^2$

$t_2 \rightarrow 70^\circ\text{C} = 70 + 273 = 343 \text{ K}$

$R = 290 \text{ J/kgK} = 0.29 \text{ kJ/kgK}$

$C_p = 1.005 \text{ kJ/kgK}$

$W = ?$

$\Delta U = ?$

$Q = ?$

~~Q~~ $P_1 V_1 = m R T_1$

$m = \frac{P_1 V_1}{R T_1} = \frac{500 \times 0.23}{0.29 \times 458}$

$m = 0.8658 \text{ kg}$

~~Q = ?~~

$$C_v = C_p - R$$

$$= 1.005 - 0.29$$

$$C_v = 0.715 \text{ kJ/kgK}$$

(i) work done, $W = P(V_2 - V_1)$

$$= mR(T_2 - T_1)$$

$$W = 0.8658 \times 0.29 \times [343 - 458]$$

$$= -28.8744 \text{ kNm}$$

$$W = -28.8744 \text{ kJ}$$

The negative sign indicates that work is done on the gas.

(ii) Change in internal energy

$$\Delta U = mC_v(T_2 - T_1)$$

$$= 0.8658 \times 0.715 \times (343 - 458)$$

$$\Delta U = -71.19 \text{ kJ} \quad \left(\begin{array}{l} \text{Indicates of -ve sign} \\ \text{loss of internal} \\ \text{energy} \end{array} \right)$$

(iii) Heat transferred

$$Q = W + \Delta U$$

$$Q = -28.8744 - 71.19$$

$$Q = -100.0644 \text{ kJ} \quad \left(\begin{array}{l} \text{-ve sign indicates} \\ \text{rejected from} \\ \text{the gas} \end{array} \right)$$

(3) Given data

$$C_p = 0.984 \text{ kJ/kgK}$$

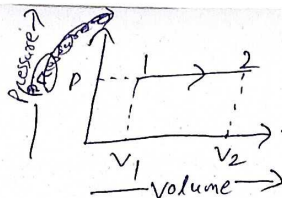
$$C_v = 0.728 \text{ kJ/kgK}$$

$$m = 1 \text{ kg}$$

$$T_1 = 25^\circ\text{C} = 25 + 273 = 298 \text{ K}$$

$$T_2 = 200^\circ\text{C} = 200 + 273 = 473 \text{ K}$$

$$\begin{aligned}
 R &= ? \\
 \gamma &= ? \\
 Q &= ? \\
 W &= ? \\
 dU &= ?
 \end{aligned}$$



$$\begin{aligned}
 R &= C_p - C_v \\
 &= 0.984 - 0.728 \\
 &= 0.256 \text{ kJ/kgK}
 \end{aligned}$$

$$\gamma = \frac{C_p}{C_v} = \frac{0.984}{0.728}$$

$$\gamma = 1.35$$

$$\begin{aligned}
 Q &= m C_p (T_2 - T_1) \\
 &= 1 \times 0.984 (473 - 298)
 \end{aligned}$$

$$Q = 172.2 \text{ kJ}$$

$$W = P(V_2 - V_1) = m R (T_2 - T_1)$$

$$= 1 \times 0.256 (473 - 298)$$

$$W = 44.8 \text{ kJ}$$

$$dU = U_2 - U_1 = m C_v (T_2 - T_1)$$

$$= 1 \times 0.728 (473 - 298)$$

$$dU = 127.4 \text{ kJ}$$

* A piston cylinder arrangement of 75mm diameter and 150mm stroke contains 0.001kg air at 15°C. Calculate the work required to compress the air isothermally to a pressure of 700kN/m². Neglect clearance volume. Take $C_p = 1.005 \text{ kJ/kgK}$, $C_v = 0.718 \text{ kJ/kgK}$

$d = 75 \text{ mm} = 0.075 \text{ m}$
 $l = 150 \text{ mm} = 0.15 \text{ m}$
 $m = 0.001 \text{ kg}$
 $T_1 = 15^\circ \text{C} = 15 + 273 = 288 \text{ K}$
 $P_2 = 700 \text{ kN/m}^2$
 $C_p = 1.005 \text{ kJ/kg K}$
 $C_v = 0.718 \text{ kJ/kg K}$
 $W = ?$

Sol:- $T_1 = T_2 = T$

$R = C_p - C_v$

$= 1.005 - 0.718$

$R = 0.287 \text{ kJ/kg K}$

Initial Volume of air (V_1) = cylinder volume

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

$= \frac{\pi}{4} \times (0.075)^2 \times 0.15$

$V_1 = 0.662 \times 10^{-3} \text{ m}^3$

$P_1 V_1 = m R T_1$

$P_1 = \frac{m R T_1}{V_1} = \frac{0.001 \times 0.287 \times 288}{0.662 \times 10^{-3}}$

$P_1 = 125.3 \text{ kN/m}^2$

Compression work

$W = -P_1 V_1 \log_e \left(\frac{V_1}{V_2} \right)$

$= -P_1 V_1 \log_e \left(\frac{P_2}{P_1} \right)$

$= -125.3 \times 0.662 \times 10^{-3} \times \log_e \left(\frac{700}{125.3} \right)$

$= +0.142 \text{ kJ}$

* 0.1 m
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P

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J

* 0.1 m^3 of air at a pressure of 1.5 bar is expanded isothermally to 0.5 m^3 . Calculate the final pressure of the gas and heat supplied during the process.

Given $V_1 = 0.1 \text{ m}^3$

$$P_1 = 1.5 \text{ bar} = 1.5 \times 100 = 150 \text{ kN/m}^2$$

$$V_2 = 0.5 \text{ m}^3$$

$$P_2 = ?$$

$$Q_1 = ?$$

$$PV = C$$

$$P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$= \frac{150 \times 0.1}{0.5} = \frac{15}{0.5}$$

$$P_2 = 30 \text{ kN/m}^2$$

$$\begin{aligned} \text{work done } W &= P_1 V_1 \log_e \left(\frac{V_2}{V_1} \right) \\ &= 150 \times 0.1 \log_e \left(\frac{0.5}{0.1} \right) \\ &= 24.115 \text{ kJ} \end{aligned}$$

Heat Supplied is equal to work done

$$\text{Heat Supplied } Q = W = 24.115 \text{ kJ}$$

* 0.25 kg of air at a pressure of 1 bar occupies a volume of 0.3 m^3 . If this air expands isothermally to a volume of 0.9 m^3 .

- Determine :-
- (i) The initial temperature
 - (ii) The final temperature
 - (iii) External work done
 - (iv) Change in internal energy

(V) = Heat absorbed by the air
Assume $R = 0.29 \text{ kJ/kgK}$.

Given :- $m = 0.25 \text{ kg}$

$$P_1 = 1 \text{ bar} = 100 \text{ kN/m}^2$$

$$V_1 = 0.3 \text{ m}^3$$

$$T_2 = T_1$$

$$V_2 = 0.9 \text{ m}^3$$

$$R = 0.29 \text{ kJ/kgK}$$

$$T_1 = ?$$

$$T_2 = ?$$

$$W = ?$$

$$\Delta U = ?$$

$$Q = ?$$

$$ds = ?$$

$$\text{Initial Temperature, } T_1 = \frac{P_1 V_1}{mR}$$

$$T_1 = \frac{P_1 V_1}{mR}$$

$$= \frac{100 \times 0.3}{0.25 \times 0.29}$$

$$T_1 = 413.79 \text{ K}$$

$$T_1 = 413.79 - 273$$

$$= 140.79^\circ \text{C}$$

$T_1 = T_2$ is an isothermal process

$$T_2 = T_1 = 413.79 \text{ K}$$

$$W = P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$$

$$= 100 \times 0.3 \times \ln \left(\frac{0.9}{0.3} \right)$$

$$W = 32.9583 \text{ kJ}$$

ΔU = Change Internal Energy

$$\Delta U = m \cdot C_v \int dT$$

$$dT = 0$$

$$\Delta U = 0$$

There is no change in internal energy

1st law thermodynamics, $Q = W + \Delta U$

$$Q = W = 32.9583 \text{ kJ}$$

$$\therefore \Delta U = 0$$

* 0.

or

-bt

dt

Sol

* 0.9 kg of air at a pressure of 15 bar and 250°C expanded adiabatically and reversibly to a pressure of 1.5 bar. Determine the work done. $R = 0.287 \text{ kJ/kgK}$; $\gamma = 1.4$.

Sol Given

$$m = 0.9 \text{ kg}$$

$$P_1 = 15 \text{ bar} = 1500 \text{ kN/m}^2$$

$$T_1 = 250^\circ\text{C} = 250 + 273 = 523 \text{ K}$$

$$P V^\gamma = C$$

$$P_2 = 1.5 \text{ bar} = 150 \text{ kN/m}^2$$

$$R = 0.287 \text{ kJ/kgK}$$

$$\gamma = 1.4$$

$$W = ?$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_2 = T_1 \times \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 523 \times \left(\frac{150}{1500}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow T_2 = 270.886 \text{ K}$$

$$W = \frac{mR(T_1 - T_2)}{\gamma - 1} = \frac{0.9 \times 0.287 \times [523 - 270.886]}{1.4 - 1}$$

$$W = 162.8026 \text{ kJ}$$

* $V_1 = 0.15 \text{ m}^3$

$$P_1 = 3.8 \text{ bar} = 3.8 \times 100 = 380 \text{ kN/m}^2$$

$$T_1 = 150^\circ\text{C} = 150 + 273 = 423 \text{ K}$$

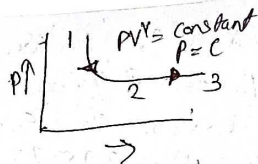
$$P_2 = 100 \text{ kN/m}^2 \quad P_3 = P_2 = 100 \text{ kN/m}^2$$

$$\text{Enthalpy } H_3 - H_2 = 70 \text{ kJ}$$

$$C_p = 1 \text{ kJ/kgK}$$

$$C_v = 0.714 \text{ kJ/kgK}$$

W = ?



$$\text{Let } W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$P_1 V_1 = P_2 V_2$$

$$V_2 = V_1 \left(\frac{P_1}{P_2} \right)^{\frac{1}{\gamma}}$$

$$= 0.15 \left(\frac{380}{100} \right)^{\frac{1}{1.4}}$$

$$V_2 = 0.39 \text{ m}^3$$

$$\gamma = \frac{C_p}{C_v} = \frac{1}{0.714} = 1.4$$

$$\left(\frac{T_1}{T_2} \right) = \left(\frac{V_2}{V_1} \right)^{\gamma-1} = \left(\frac{P_1}{P_2} \right)^{\frac{(\gamma-1)}{\gamma}}$$

$$\left(\frac{T_1}{T_2} \right) = \left(\frac{P_1}{P_2} \right)^{\frac{(\gamma-1)}{\gamma}} = \left(\frac{380}{100} \right)^{\frac{1.4-1}{1.4}}$$

$$= (3.8)^{0.286}$$

$$\frac{T_1}{T_2} = 1.465$$

$$T_2 = \frac{T_1}{1.465} = \frac{423}{1.465}$$

$$T_2 = 288.7 \text{ K}$$

$$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{380 \times 0.15 - 100 \times 0.39}{1.4 - 1}$$

$$= \frac{57 - 39}{0.4}$$

$$W = 45 \text{ kJ}$$

Let

Q

mg

0.47

v

v

gc

I

Let

$$Q = H_3 - H_2$$

$$m C_p (T_3 - T_2) = 70$$

$$0.47 \times 1 \times (T_3 - 288.7) = 70$$

$$T_3 = \frac{70}{0.47} + 288.7$$

$$T_3 = 437.6 \text{ K}$$

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$V_3 = \frac{V_2 T_3}{T_2} = \frac{0.39 \times 437.6}{288.7}$$

$$V_3 = 0.59 \text{ m}^3$$

Gas constant :- $R = C_p - C_v$

$$= 1 - 0.714$$

$$R = 0.286 \text{ kJ/kg K}$$

$$P_1 V_1 = m R T_1$$

$$m = \frac{P_1 V_1}{R T_1} = \frac{380 \times 0.15}{286 \times 423}$$

$$m = 0.47 \text{ kg}$$

$$W = P_2 (V_3 - V_2)$$

$$= 100 (0.59 - 0.39)$$

$$W_2 = 20 \text{ kJ}$$

Total work done W

$$W = W_1 + W_2$$

$$= 45 + 20$$

$$= 65 \text{ kJ}$$

③ Given = mass of air = 2 kg
 $P_1 = 10 \text{ bar} = 1000 \text{ kN/m}^2$
 $T_1 = 327 + 273 = 600 \text{ K}$
 $P_2 = 1 \text{ bar} = 100 \text{ kN/m}^2$
 $V_2 = ?$
 $T_2 = ?$

work energy transferred = ?
 during the process
 change in internal energy = ?
 change in enthalpy = ?

$$\gamma = \frac{C_p}{C_v} \quad \therefore C_v = C_p - R$$

$$= \frac{C_p}{C_p - R}$$

$$= \frac{1.005}{1.005 - 0.287}$$

$$\gamma = 1.4$$

$$V_1 = \frac{m R T_1}{P_1} = \frac{2 \times 0.287 \times 600}{1000}$$

$$\therefore V_1 = 0.3444 \text{ m}^3$$

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2} \right)^{\frac{1}{\gamma}}$$

$$V_2 = V_1 \left(\frac{P_1}{P_2} \right)^{\frac{1}{\gamma}} = 0.3444 \left(\frac{1000}{100} \right)^{\frac{1}{1.4}}$$

$$V_2 = 1.784 \text{ m}^3$$

$$T_2 = \frac{P_2 V_2}{m R}$$

$$T_2 = \frac{P_2 V_2}{m R}$$

$$= \frac{100 \times 1.784}{2 \times 0.287}$$

$$T_2 = 310.8 \text{ K}$$

$$= 310.8 - 273$$

$$T_2 = 37.8^\circ \text{C}$$

$$W = \left(\frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \right)$$

$$= \left(\frac{1000 \times 0.3444 - 100 \times 1.784}{1.4 - 1} \right)$$

$$W = 415 \text{ KJ}$$

$$Q = 0$$

$$\Rightarrow W + (U_2 - U_1)$$

$$\Rightarrow (U_2 - U_1) = -415 \text{ KJ}$$

enthalpy

$$H_2 - H_1 = m C_p (T_2 - T_1)$$

$$= 2 \times 1.005 (310.8 - 600)$$

$$H_2 - H_1 = -581.29 \text{ KJ}$$

* One kg of air at 1 bar and 27°C compressed polytropically to a pressure of 15 bar, and air temp. rises to 227°C . Determine.

(i) The Polytropic Index

(ii) The final Volume

(iii) The work of compression and

(iv) The amount of heat rejection from the air

Assume $R = 0.287 \text{ KJ/kgK}$

Given

$$m = 1 \text{ kg}$$

$$P_1 = 1 \text{ bar}$$

$$T_1 = 27^\circ\text{C} = 27 + 273 = 300 \text{ K}$$

$$P_2 = 15 \text{ bar}$$

$$T_2 = 227^\circ\text{C} = 227 + 273 = 500 \text{ K}$$

Polytropic index = ?

Final volume = ?

Work of compression = ?

Amount of heat rejection from the air = ?

$$\text{Polytropic index } (n) = \frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

Logarithm on both side

$$\log_e \left(\frac{T_2}{T_1} \right) = \frac{n-1}{n} \log_e \left(\frac{P_2}{P_1} \right)$$

$$\log_e \left(\frac{500}{300} \right) = \frac{n-1}{n} \log_e \left(\frac{15}{1} \right)$$

$$1 - \frac{1}{n} = 0.1886$$

$$\Rightarrow \frac{1}{n} = 0.8114$$

$$\Rightarrow n = 1.23$$

$$T_2 = P_2 V_2 = m R T_2$$

$$V_2 = \frac{m R T_2}{P_2}$$

$$= \frac{1 \times 0.287 \times 500}{15 \times 100}$$

$$V_2 = 0.0956 \text{ m}^3$$

$$W = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{mR(T_1 - T_2)}{n-1}$$

$$= \frac{1 \times 0.287(300 - 500)}{1.23 - 1}$$

$$W = -249.565 \text{ kJ/kg}$$

$$Q = \frac{\gamma - \eta}{\gamma - 1} \times \text{Polytropic work}$$

Assume γ for air = 1.4

$$Q = \frac{1.4 - 1.23}{1.4 - 1} \times -249.565$$

$$Q = -106.065 \text{ kJ/kg}$$

$$\text{Heat rejection} = 106.065 \text{ kJ/kg}$$

* A certain quantity of air has a volume of 0.028 m^3 at a pressure of 1.25 bar and temp. of 25°C . It is compressed to a volume of 0.0042 m^3 according to the law $PV^{1.3} = \text{const}$. Find the final temperature and work done during compression. Also determine the reduction in pressure at a constant volume required to bring the air back to its original temperature.

Given $V_1 = 0.028 \text{ m}^3$

$$P_1 = 1.25 \text{ bar} = 125 \text{ kN/m}^2$$

$$T_1 = 25^\circ\text{C} = 25 + 273 = 298 \text{ K}$$

$$V_2 = 0.0042 \text{ m}^3$$

$$T_2 = ?$$

$$W = ?$$

$$n = 1.3$$

2-3 = const Volume process

$$V_3 = V_2 = 0.0042 \text{ m}^3$$

$$T_3 = T_1 = 298 \text{ K}$$

Reduction in pressure ($P_2 - P_3$) for const volume process

For Polytropic Process 1-2

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$\frac{T_1}{T_2} = \left[\frac{0.0042}{0.028}\right]^{1.3-1}$$

$$\frac{T_1}{T_2} = (0.15)^{0.3}$$

$$T_2 = \frac{T_1}{0.566} = \frac{298}{0.566}$$

$$T_2 = 526.5 \text{ K}$$

$$T_2 = 526.5 - 273$$

$$= 253.5^\circ\text{C}$$

Polytropic Process

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma$$

$$= \left(\frac{0.0042}{0.028}\right)^{1.3}$$

$$\frac{P_1}{P_2} = 0.085$$

$$P_2 = \frac{P_1}{0.085} = \frac{1.25}{0.085}$$

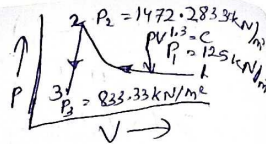
$$P_2 = 14.7 \text{ bar}$$

$$= 1.47 \times 10^6 \text{ N/m}^2$$

$$W = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} = \frac{1.47 \times 10^6 \times 0.0042 - 0.125 \times 10^6 \times 0.028}{1.3 - 1}$$

$$= \frac{6174 - 3500}{0.3}$$

$$W = 8919 \text{ J or } 8.913 \text{ kJ}$$



for

Reo

* A

1.3

135

pn

b

(i)

(ii)

(iii)

(1)

Sc

283.8 kN/m²
 = 12.5 kN/m²
 1
 1

For const Volume Process 2-3;

$$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$P_3 = \frac{P_2 \times T_3}{T_2} = \frac{14.7 \times 298}{526.5}$$

$$P_3 = 8.32 \text{ bar}$$

Reduction in Pressure,

$$P_2 - P_1 = 14.7 - 8.32$$

$$P_2 - P_1 = 6.38 \text{ bar}$$

* A mass of air has initial pressure of 1.3 MN/m², volume 0.014 m³ and temperature 135°C. It is expanded polytropically until its pressure is 275 kN/m² and its volume becomes 0.056 m³. Assume $C_p = 1.005 \text{ kJ/kgK}$, $C_v = 0.718 \text{ kJ/kgK}$. Determine

- (i) The mass of air
- (ii) The final temperature
- (iii) The law of expansion
- (iv) work done
- (v) Heat transfer
- (vi) Change in internal energy

Sol $P_1 = 1.3 \text{ MN/m}^2 = 1300 \text{ kN/m}^2$

$$V_1 = 0.014 \text{ m}^3$$

$$T_1 = 135^\circ\text{C} = 135 + 273 = 408 \text{ K}$$

$$\text{Final Pressure } (P_2) = 275 \text{ kN/m}^2$$

$$\text{Final Volume } (V_2) = 0.056 \text{ m}^3$$

$$C_p = 1.005 \text{ kJ/kgK}$$

$$C_v = 0.718 \text{ kJ/kgK}$$

mass of air = ?

final temp. = ?

Law of expansion = ?

work done = ?

Heat transfer = ?

Change in internal energy = ?

$$\text{mass of the air (m)} = \frac{P_1 V_1}{R T_1} = \frac{1300 \times 0.014}{0.287 \times 408}$$
$$m = 0.1354 \text{ kg}$$

$$\text{From gas equation, } T_2 = \frac{P_2 V_2}{m R}$$
$$= \frac{275 \times 0.056}{0.1354 \times 0.287}$$
$$= 345.29 \text{ K}$$
$$t_2 = 345.29 - 273$$
$$t_2 = 72.29^\circ \text{C}$$

$$\text{Polytropic index, } (n) = \frac{\log_e \left(\frac{P_2}{P_1} \right)}{\log_e \left(\frac{V_1}{V_2} \right)} = \frac{\log_e \left(\frac{275}{1300} \right)}{\log_e \left(\frac{0.014}{0.056} \right)}$$

$$n = 1.12$$

$$W = \frac{P_1 V_1 - P_2 V_2}{n - 1} = \frac{1300 \times 0.014 - 275 \times 0.056}{1.12 - 1}$$

$$W = 23.33 \text{ kJ}$$

$$Q = \frac{(\gamma - n)}{(\gamma - 1)} \times \text{work done}$$

$$= \frac{1.4 - 1.12}{1.4 - 1} \times 23.33$$

$$Q = 16.33 \text{ kJ}$$

Non flow energy equation,

$$Q = (U_2 - U_1) + W$$

$$16.33 = (U_2 - U_1) + 23.33$$

$$(U_2 - U_1) = 16.33 - 23.33 \\ = -7 \text{ kJ}$$

* Air at 20°C and 1.05 bar occupies 0.025 m^3 .
The air is heated at constant volume until the pressure is 4.5 bar , and then cooled at constant pressure back to original temperature. Calculate.

(i) The net heat flow from the air

(ii) The net entropy change

Sketch the process on T-S diagram.
Assume C_p and C_v values for air are 0.718 kJ/kgK and 1.005 kJ/kgK respectively.

Given

$$C_p = 0.718 \text{ kJ/kgK}$$

$$C_v = 1.005 \text{ kJ/kgK}$$

$$P_1 = 1.05 \text{ bar}$$

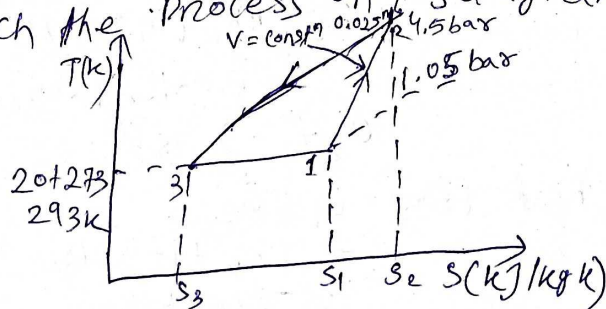
$$V_1 = 0.025 \text{ m}^3$$

$$T_1 = 20^\circ\text{C}$$

net heat flow from the air = ?

net entropy change = ?

Sketch the process on T-S diagram = ?



$$T_1 = 20 + 273 = 293 \text{ K}$$

$$V_1 = V_2 = 0.025 \text{ m}^3$$

$$P_1 = 1.05 \text{ bar} = 1.05 \times 10^5 \text{ N/m}^2$$

$$P_2 = 4.5 \text{ bar} = 4.5 \times 10^5 \text{ N/m}^2$$

Net heat flow for a perfect gas,

$$m = \frac{P_1 V_1}{R T_1} = \frac{1.05 \times 10^5 \times 0.025}{0.287 \times 10^3 \times 293}$$

$$= \frac{2625}{84091}$$

$$m = 0.0312 \text{ kg}$$

perfect gas at constant volume.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{1.05}{293} = \frac{4.5}{T_2}$$

$$T_2 = \frac{4.5 \times 293}{1.05} = \frac{1318.5}{1.05}$$

$$T_2 = 1255.7 \text{ K}$$

$$\text{const volume} = Q_1 = m C_v (T_2 - T_1)$$

$$= 0.0312 \times 0.718 (1255.7 - 293)$$

$$Q_1 = 21.56 \text{ kJ}$$

$$\text{const pressure: } Q_2 = m C_p (T_3 - T_2)$$

$$Q_2 = m C_p (T_1 - T_2) \quad \because T_1 = T_3$$

$$= 0.0312 \times 1.005 (293 - 1255.7)$$

$$Q_2 = -30.18 \text{ kJ}$$

$$\text{Net heat flow} = Q_1 + Q_2$$

$$= 21.56 + (-30.18)$$

$$= -8.62 \text{ kJ}$$

Air is cooled at const pressure back to original temperature Heat rejected = 8.62 kJ

$$\text{net decrease in entropy, } ds = s_1 - s_2$$

$$ds = (s_2 - s_3) - (s_2 - s_1)$$

At const pressure $da = mC_p dT$

$$m(s_2 - s_3) = \int_{293}^{1255.7} \frac{mC_p dT}{T}$$

$$= 0.0312 \times 1.005 \times \log_e \frac{1255.7}{293}$$

$$= 0.031356 \times \log_e \frac{1255.7}{293}$$

$$s_2 - s_3 = 0.0456 \text{ kJ/k}$$

At constant volume $da = mC_v dT$

$$m(s_2 - s_1) = \int_{293}^{1255.7} \frac{mC_v dT}{T}$$

$$= 0.0312 \times 0.718 \times \log_e \frac{1255.7}{293}$$

$$s_2 - s_1 = 0.0326 \text{ kJ/k}$$

$$m(s_1 - s_3) = s_1 - s_3$$

$$= (s_2 - s_3) - (s_2 - s_1)$$

$$= 0.0456 - 0.0326$$

$$m(s_1 - s_3) = 0.013 \text{ kJ/k}$$

$$\text{Decrease in entropy} = 0.013 \text{ kJ/k}$$

* 0.04 m³ of nitrogen contained in a cylinder behind a piston is initially at 1.05 bar and 15°C. The gas is compressed isothermally and reversibly until the pressure is 4.8 bar.

Calculate (i) The change of entropy

(ii) The heat flow

(iii) The work done

Sketch the process on a p.v and T-s diagram

Assume nitrogen to act as a perfect gas.
molecular weight of nitrogen = 28

Sol $P_1 = 1.05 \text{ bar} = 1.05 \times 10^5 \text{ N/m}^2$

$$V_1 = 0.04 \text{ m}^3$$

$$T_1 = 15 + 273 = 288 \text{ K}$$

$$P_2 = 4.8 \text{ bar} = 4.8 \times 10^5 \text{ N/m}^2$$

$$T_2 = T_1 = 288 \text{ K}$$

molecular weight of nitrogen = 28

Change of entropy = ?

heat flow = ?

work done = ?

Characteristic gas constⁿ
 $R = \frac{\text{universal gas constant } R_0}{\text{molecular weight } m}$

$$= \frac{8314}{28}$$

$$R = 297 \text{ J/kgK}$$

Final pressure of gas,

$$P_1 V_1 = m R T_1$$

$$m = \frac{P_1 V_1}{R T_1}$$

$$= \frac{1.05 \times 10^5 \times 0.04}{297 \times 288}$$

$$m = 0.0491 \text{ kg}$$

The change of entropy

$$S_2 - S_1 = m R \log_e \frac{P_1}{P_2}$$

$$= 0.0491 \times \frac{297}{10^3} \log_e \left(\frac{1.05}{4.8} \right)$$

$$S_2 - S_1 = -0.02216 \text{ kJ/K}$$

Decrease in entropy

$$S_1 - S_2 = 0.02216 \text{ kJ/K}$$

$$\begin{aligned}\text{Heat rejected} &= \text{Shaded area on } T-s \text{ diagram} \\ &= T(S_1 - S_2) \\ &= 288 \times 0.02216\end{aligned}$$

$$\begin{aligned}\text{Heat rejected} &= 6.382 \text{ kJ} \\ \text{For an isothermal process for a perfect gas, } W &= Q = 6.382 \text{ kJ} \\ \text{Work done on air} &= 6.382 \text{ kJ}\end{aligned}$$

* calculate the change of entropy of 1 kg of air expanding polytropically in a cylinder behind a piston from 7 bar and 600°C to 1.05 bar. The index of expansion is 1.25.

$\frac{R_0}{m}$

$$\begin{aligned}\text{Given } P_1 &= 7 \text{ bar} = 7 \times 10^5 \text{ N/m}^2 \\ T_1 &= 600 + 273 = 873 \text{ K} \\ P_2 &= 1.05 \text{ bar} = 1.05 \times 10^5 \text{ N/m}^2 \\ \text{Index of expansion } n &= 1.25 \\ \text{mass of air } m &= 1 \text{ kg}\end{aligned}$$

$$\begin{aligned}\text{Using the relation, } \frac{T_2}{T_1} &= \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \\ \frac{T_2}{873} &= \left(\frac{1.05}{7}\right)^{\frac{1.25-1}{1.25}} \\ T_2 &= 873 \times \left(\frac{1.05}{7}\right)^{\frac{0.25}{1.25}} \\ &= 873 \times (0.15)^{0.2} \\ T_2 &= 597.3 \text{ K}\end{aligned}$$

The change in entropy can be calculated

$$\begin{aligned}S_2 - S_1 &= C_v \left(\frac{n-\gamma}{n-1}\right) \log_e \frac{T_2}{T_1} \\ &= 0.718 \left(\frac{1.25-1.3999}{1.25-1}\right) \log_e \left(\frac{597.3}{873}\right) \\ &= 0.718 \times (-0.596) \times (-0.3795) \\ \Rightarrow S_2 - S_1 &= 0.1626 \text{ kJ/K}\end{aligned}$$

3rd unit Properties Processes of Perfect Gas

* Vapour :-

Vapour is a substance in the gaseous phase at a temperature lower than its critical temperature. ~~lower than its critical~~

Example

* Steam, carbon dioxide, ammonia as vapour.

* A vapour becomes dry when it is completely evaporated.

* If the dry vapour is further heated, the process is called super heating and vapour is called super heated vapour.

* The behaviour of super heated vapour is similar to that of a perfect gas.

Gas :-

⇒ Gas is a state of a substance, whose evaporation from liquid state is fully completed.

Perfect gas

⇒ In perfect gas, molecules occupy infinite small space and there exists no force of attraction between its molecules.

Laws of Perfect gases

⇒ The behavior of a perfect gas, undergoing any change in pressure, volume and temperature is governed by

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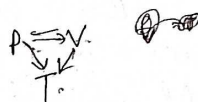
⇒ Boyle's law

⇒ Charles's law

⇒ Regnault's law

⇒ Avogadro's law

⇒ Joule's law.



Boyle's law

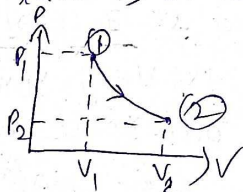
⇒ Boyle's law gives relation between pressure and volume when temperature is kept constant.

⇒ Boyle's law states that, at constant temperature, the volume (V) occupied by a gas is inversely proportional to the pressure (P)

⇒ As the pressure increases, the volume of the gas decreases and vice versa,

$$P \propto \frac{1}{V} \text{ or } PV = \text{constant}$$

⇒ A plot of pressure versus volume for Boyle's law is a rectangular hyperbola.



⇒ In Boyle's law

$$P_1 V_1 = P_2 V_2 \text{ and}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where

P_1 and V_1 are initial pressure and volume

P_2 and V_2 are final pressure and volume

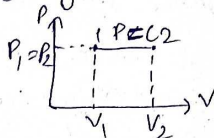
Charles's law

⇒ Charles's law gives relation between temperature and volume (V) when pressure is kept constant.

⇒ At constant pressure, the volume of a gas is directly proportional to its absolute temp.

⇒ As the temperature of gas increases, the volume of the gas also increases and vice versa.

⇒ mathematically $V \propto T$ at P constant $\frac{V}{T} = C$



⇒ In Charles's law, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

where

T_1 and V_1 are initial temperature and volume

T_2 and V_2 are final temp. and volume.

Gay-Lussac's law
⇒ Charles's law can be otherwise stated as, at constant volume, the temp. of a gas is directly proportional to its absolute pressure. This law be otherwise called as Gay-Lussac's law.

⇒ Gay-Lussac's law is very similar to Charles's law with the only difference being the type of container, whereas the container in a Charles's law experiment is flexible, it is rigid in a Gay-Lussac's law experiment.

⇒ mathematically $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

where T_1 and P_1 are initial temp. and pressure

T_2 and P_2 are final temp. and pressure

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Avogadro's law

⇒ It states that equal volumes of all gases, at the same temperature and pressure, contain equal number of molecules.

⇒ Consider characteristic gases equation in terms of specific volume.

$$PV = RT$$

⇒ multiply both sides by M molecular mass of the gas in kg-mole.

$$MPV = MRT$$

⇒ The product of molecular weight and specific volume is called molar volume.

$$P \cdot V_{\text{mol}} = R_u \cdot T$$

⇒ But R_u = universal gas constant is same for all gases.

⇒ For given set of conditions of P and T , V_{mol} is constant for all gases at NTP.

⇒ Hence at 0°C and 760 mm Hg (101.325 kN/m^2) the volume of 1 kg mole is 22.4 m^3 .

⇒ From Avogadro's law, 1 kg mole of any perfect gas occupies a volume of 22.4 m^3 and contains 6×10^{23} molecules at NTP.

⇒ The number 6×10^{23} is called Avogadro's number.

Joule's law

⇒ It states the change of internal energy of a perfect gas is directly proportional to the change of temperature.

$$du = C_v dt$$

$$u_2 - u_1 = m C_v (T_2 - T_1)$$

where m = mass of the gas
 C_v = Specific heat at constant volume
 $T_2 - T_1$ = change of temp.

⇒ From above equation if the temp. of a given mass m of a gas change from T_1 to T_2 . The internal energy will change from u_1 to u_2 .

⇒ The change in internal energy ($u_2 - u_1$) will be same irrespective of the manner the pressure (p) and volume (v) of the gas have changed.

Specific heat

⇒ It is the amount of heat required to raise the temperature of its unit mass through one degree.

⇒ All liquids and solids have one specific heat only.

⇒ Gases usually have two types of specific heats.

$$C_p = 1.005 \text{ kJ/kg} \cdot \text{K}$$

$$C_v = 0.718 \text{ kJ/kg} \cdot \text{K} \text{ and,}$$

Specific heat at constant volume (C_v)

⇒ It is the amount of heat required to raise the temperature of a unit mass of gas through one degree, when it is heated at constant pressure.

⇒ It is generally denoted by (C_p)

Regnault's law

⇒ The two specific heats of gas (i.e. specific heat at constant pressure C_p and specific heat at constant volume C_v) of a perfect gas do not change with the change in temp.

⇒ The value of C_p and C_v are constant and hence their ratio is also constant for a given perfect gas. Ratio of C_p and C_v is denoted by γ (gamma) and is called adiabatic index.

$$\text{Adiabatic index, } \gamma = \frac{C_p}{C_v}$$

$$\text{For air } C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$$

$$C_v = 0.717 \text{ kJ/kg}\cdot\text{K} \text{ and } \gamma = 1.4$$

Dalton's law of partial pressure

⇒ According to Dalton's law of partial pressure, The pressure of a gas mixture is equal to the sum of pressures of its each components if each component is exerted alone of the temp. and volume of the mixture. i.e., This law is also called as Dalton's law of additive pressure.

$$\begin{array}{ccc} \text{Gas A} & + & \text{Gas B} \\ \frac{P_A}{V, T} & & \frac{P_B}{V, T} \\ & & \dots \\ & & \frac{P_A + P_B}{V, T} \end{array} = \text{Gas mixture}$$

$$P_m = P_1 + P_2 + \dots + P_n = \sum_{i=1}^n P_i$$

Where P_m = mixture pressure

$P_1, P_2, \dots, P_i$ = each component's pressure.

S.T.P :- Standard Temp. and Pressure (298K)

N.T.P :- Normal Temperature Pressure (0°C)

Assignment
all units atmospheric pressure

units unit

Atmospheric Pressure

$$1 \text{ atm} = 101,325 \text{ Pa} \approx 14.7 \text{ PSI}$$

$$1 \text{ kPa} = 1000 \text{ Pa} = 0.145 \text{ PSI}$$

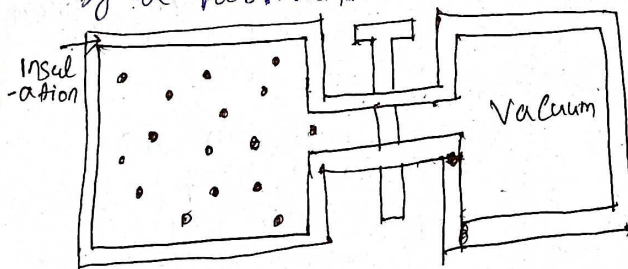
$$1 \text{ PSI} = 6894.76 \text{ Pa} \approx 6.89 \text{ kPa}$$

Free expansion process :-

⇒ The free expansion process is an irreversible non-flow process.

⇒ A Free Expansion occurs when a fluid is allowed to expand suddenly into a vacuum chamber through an orifice of large dimensions.

⇒ Consider two chambers A and B separated by a partition.



Free Expansion

⇒ Let the chamber A contains a Perfect gas having Volume V_1 , pressure P_1 and temperature T_1 and the chamber B is completely evacuated.

8k)
 273K
 73
 25
 18

These chambers are perfectly insulated so that no heat transfer takes place from or to its surroundings.

⇒ If the partition is removed, the gas will expand freely and occupy the whole space.

⇒ By this, the volume of gas increases to V_2 , pressure decreases to P_2 and temperature may also decrease to T_2 .

⇒ Since there is no expansion of the boundary of the system, because it is rigid, therefore no work is done.

Thus, for a free expansion process,

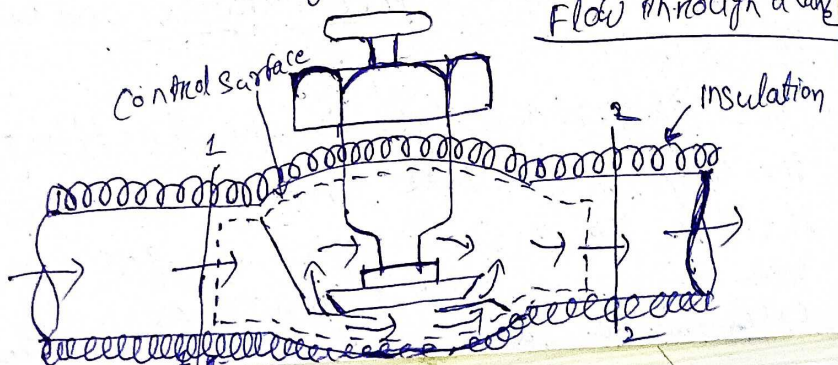
$$Q_{1-2} = 0$$

$$W_{1-2} = 0$$

$$\text{Then, } U_2 - U_1 = 0$$

Throttling process :-

⇒ The throttling process is an irreversible steady flow expansion process in which a perfect gas is expanded through an orifice of minute dimensions such as a narrow throat or slightly opened valve.



⇒ Due to the fall in pressure during expansion the gas should come out with a large velocity but due to high frictional resistance between the gas and the walls of the aperture, there is no considerable change in velocity.

⇒ The kinetic energy of the gas is converted into heat which is utilised in warming the gas to its initial temp

⇒ No heat is supplied or rejected during the throttling process and also no work is done, therefore

$$Q_{1-2} = 0 \text{ and } W_{1-2} = 0$$

⇒ Steady flow energy equation for unit mass

$$\text{flow is } \left[h_1 + \frac{V_1^2}{2} + gz_1 + Q_{1-2} = h_2 + \frac{V_2^2}{2} + gz_2 + W_{1-2} \right]$$

⇒ Since there is no considerable change in velocity and the inlet and outlet are at the same level, therefore $V_1 = V_2$ and $z_1 = z_2$.

⇒ The steady flow energy equation is written as $h_1 = h_2$

⇒ Thus the throttling process is a constant enthalpy process.

Comparison between free expansion and throttling processes :-

⇒ The difference between the throttling process and the free expansion process is that in the former case, the gas leaves with negligible velocity where as in the latter case, the gas leaves with a large velocity.

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General laws for expansion and compression

⇒ The general law of expansion or compression of a perfect gas is $PV^n = \text{constant}$. It gives the relationship between pressure and volume of a given quantity of gas.

⇒ The value of n depends upon the nature of gas, and condition under which the changes take place.

⇒ The value of n may be between zero and infinity. But the following values of n are important from the subject point of view.

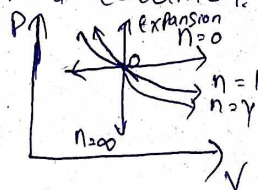
* When $n=0$, this means $PV^0 = \text{constant}$, i.e. $P = \text{constant}$. In other words, for the expansion or compression of a perfect gas at constant pressure, $n=0$.

* When $n=1$, then $PV = \text{constant}$, i.e., the expansion or compression is isothermal or hyperbolic.

⇒ When n lies between 1 and ∞ , the expansion or compression is polytropic, i.e. $PV^n = C$.

⇒ When $n=\gamma$, the expansion or compression is adiabatic, i.e. $PV^\gamma = \text{constant}$.

⇒ When $n=\infty$, the expansion or compression is at constant volume i.e. $V = \text{constant}$.



$$PV^n = C$$

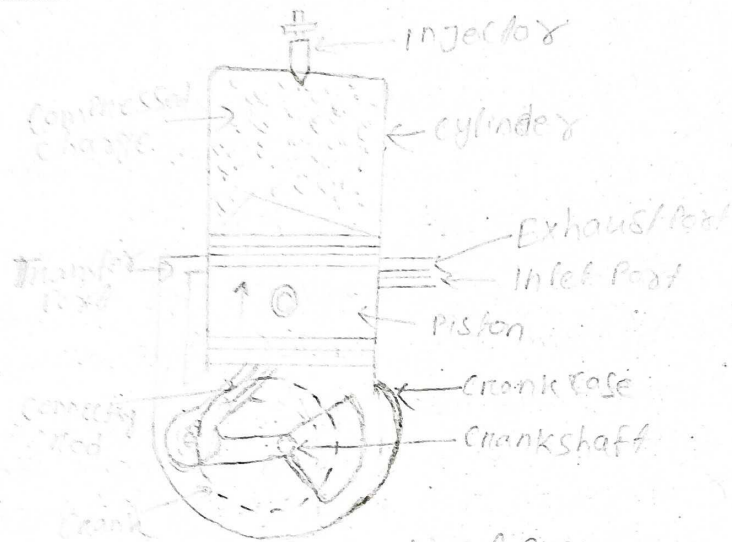
$$n=0, P=C$$

$$n=1, PV=C$$

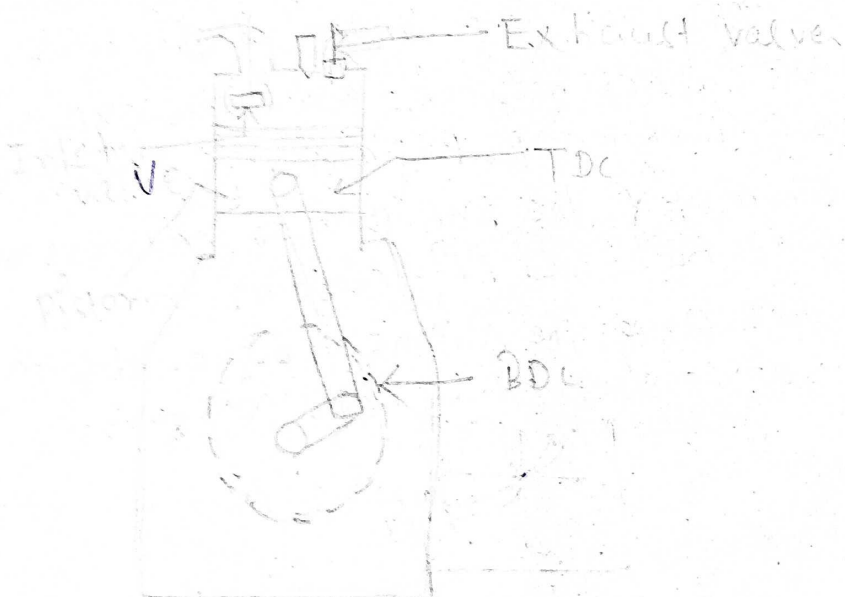
$$n=\gamma, PV^\gamma=C$$

Chapter (4) Internal Combustion Engine
Diagram

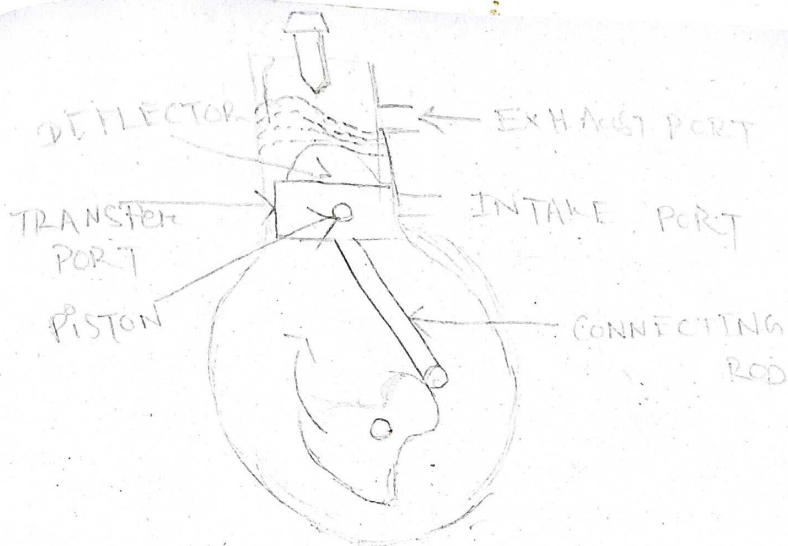
① Two stroke diesel engine



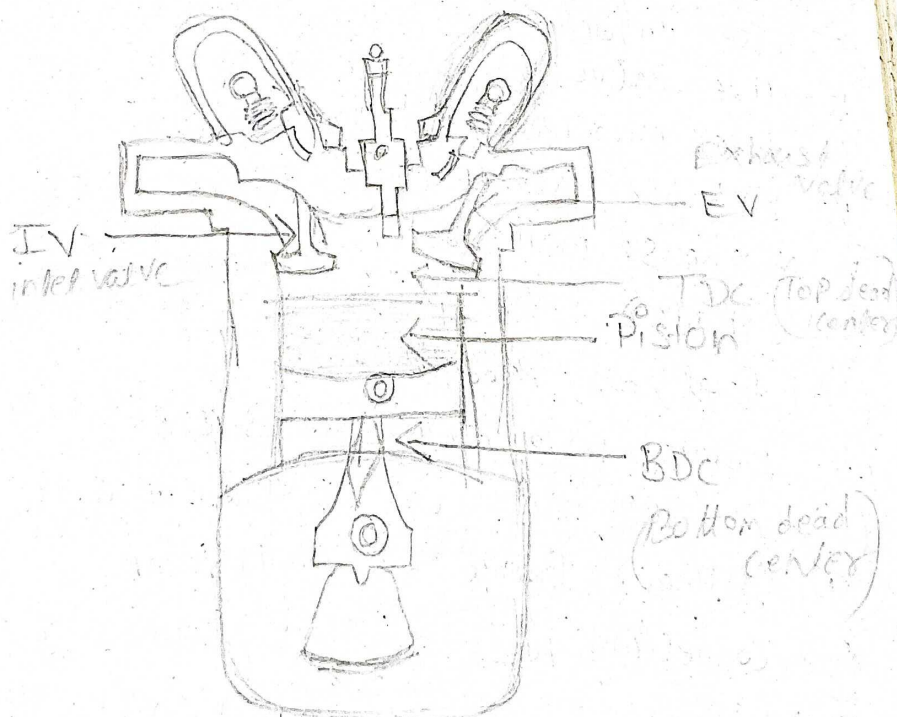
Two stroke diesel engine



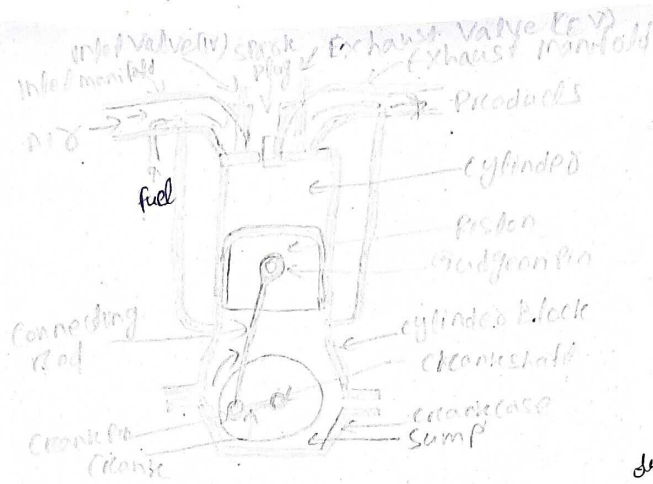
Four stroke diesel engine



TWO STROKE PETROL ENGINE



FOUR STROKE PETROL ENGINE



I.C. Engine

due to Ignition
Process

- (i) ~~Spark~~ Spark Plug
- (ii) Fuel Injector
- (iii) Inlet Valve (IV)
- (iv) Inlet manifold
- (v) Exhaust Valve (EV)
- (vi) Exhaust manifold
- (vii) Cylinder
- (viii) Fuel, air, products
- (ix) Piston, piston rings, oil rings, rings
- (x) Gudgeon pin
- (xi) cylinder Block
- (xii) connecting rod
- (xiii) Crank
- (xiv) crank pin
- (xv) crank Shaft
- (xvi) crank case
- (xvii) Sump
- (xviii) water Jacket
- (xix) cooling Jacket
- (xx) Spring

Combustion :- Burning of fuel in presence of air & oxygen.

(1) Swept Volume

(2) A.F.M = Air fuel mixture

(3) B.D.C = Bottom Dead center

(4) T.D.C = Top Dead center

(5) Stroke length, Bore diameter $\rightarrow$ cylinder T.D.C to B.D.C

(6) Crankshaft is also known as $\xrightarrow{\text{include swept volume}}$ Engine shaft

(7) C.I = diesel

(8) S.I = petrol

(9) suction stroke

(10) compression stroke

(11) working/Power/Expansion stroke

(12) Exhaust stroke

$$\frac{\text{Clearance Volume} + \text{Swept Volume}}{\text{Total Volume}}$$

(13) E.C ~~Eng~~ Engine and I.C Engine differentiation

(14) C.I. and S.I differentiation.

(15) 2 Stroke and 4 Stroke differentiation.

(16) Relationship betⁿ Compression Ratio and Clearance Ratio

Compression Ratio $\overset{\text{always}}{>}$ 1

Compression Ratio Petrol engine 6 to 12

" " diesel engine 16 to 22

" " Dual diesel engine 12 to 18

clearance Ratio is always less than 1

$$\text{clearance Ratio} = \frac{V_C}{V_S} = \frac{\text{clearance volume}}{\text{clearance swept}}$$

* What is I.C. Engine?

IC engine stands for internal combustion engine. It's a type of heat engine that generates power by burning fuel (petrol, diesel or gas) inside a combustion chamber within the engine.

Working principle:-

- ① Air-fuel mixture enters the cylinder.
- ② Compression by piston,
- ③ Spark plug ignites mixture, producing power.
- ④ Piston moves down, rotating crankshaft
- ⑤ Crankshaft converts linear motion to rotary.

Differentiate between EC Engine and IC Engine

E. C Engine	I.C. Engine
⇒ It is external combustion	⇒ It is internal combustion
⇒ Fuel combustion takes place outside the cylinder	⇒ Fuel combustion takes place inside the cylinder
⇒ Larger in size and less efficient.	⇒ Compact in size and more efficient.
⇒ More initial cost	⇒ Low initial cost
⇒ Working fluid is steam	⇒ Working fluid is mixture of air and fuel
⇒ Starting is difficult and more time is required.	⇒ Easier and quick starting
⇒ Cheaper fuel may be used like coal	⇒ Costly fuels are required like petrol and diesel
⇒ Less suitable for mobile applications	⇒ More suitable for mobile application

The combustion of fuel takes place outside the cylinder.

⇒ working temperature and pressure in this engine are lower than I.C. engine.

⇒ There is no piston rod and hence no stuffing box.

⇒ It requires big boiler to store water for converting it into E.C. engine.

The combustion of fuel takes place inside the cylinder.

⇒ working temperature and pressure in this engine are much higher than E.C. engine.

⇒ I.C. engine are single acting piston is directly connected to connecting rod.

⇒ It requires small boiler to store water for converting it into I.C. engine.

* Difference between S.I and C.I. engine

S.I engine (petrol engine)	C.I engine (Diesel engine)
works on principle of constant volume (Otto cycle)	works on principle of diesel (constant pressure) cycle.
⇒ fuel used petrol and air	⇒ fuel used Diesel and heavy oil.
⇒ during suction stroke, requires carburetor.	⇒ only air is introduced during suction stroke requires fuel injector.
⇒ Compression ratio is low maximum compression ratio is limited to 10:1	⇒ Compression ratio is high and range from 16:1 to 21:1
⇒ Ignition takes place due to spark. Requires spark plug and ignition system.	⇒ Self Ignition due to high temp. of compressed air. Does not require spark plug and ignition system.
⇒ Lower thermal efficiency due to low compression ratio. Thermal efficiency is about 25%.	⇒ Higher thermal efficiency due to high compression ratio. Thermal efficiency is about 40%.

Lighter due to low compression ratio and low peak pressure.

⇒ Initial cost is low but maintenance is costly due to high cost of fuel. (petrol)

⇒ Develops less power and generally used for light duty vehicles (scooters, motors, cycles, cars)

Higher due to high compression ratio and high peak pressure.

⇒ Initial cost is high, but maintenance cost is low due to low cost of fuel. (diesel)

⇒ Develops large power and generally used for high duty vehicle (tractors, trucks and buses)

⇒ Consume is more time is heat

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Difference between two stroke and four stroke engine

Two stroke engine	four stroke engine
⇒ One power stroke in one revolution of the crankshaft	⇒ One power stroke in two revolution of the crankshaft
⇒ Simple in design and lighter in construction for the same power	⇒ The same power complicated design and heavier in construction
⇒ These engines are generally air cooled	⇒ These engines are generally water cooled.
⇒ It is easily reversible since there are no valves	⇒ It is not easily reversible due to the presence of valves.
⇒ It gives more noise due to sudden release of exhaust gases.	⇒ Noise is less. Exhaust gases released in separate stroke.
⇒ Power developed for the same engine speed is theoretically twice that of a four stroke cycle engine.	⇒ Power developed for the same engine speed is theoretically half that of a two stroke cycle engine.
⇒ Uniform torque is obtained hence a lighter flywheel can be used.	⇒ Non uniform torque on the crankshaft. Hence a heavier flywheel is required for balancing.
⇒ Mechanical efficiency is high no moving parts like cam, followers, rocker arm valves etc. This reduces frictional losses.	⇒ Mechanical efficiency is less. Power is lost due to friction caused by valve mechanism.

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⇒ Consumption of lubricating oil is more because only less time is available for removing heat.

⇒ more wear and tears of the moving parts since there is one power stroke in one revolution of the crankshaft.

⇒ some of the fresh air-fuel mixture may escape with exhaust gases, hence fuel consumption is more.

⇒ Scavenging is poor since exhaust port is open only for a short time.

⇒ Poor scavenging leads to mixing of fresh charge with exhaust gases, this results in poor performance, slow running and poor efficiency.

⇒ Used in light vehicles.
Examples: - motorcycles, scooters, mopeds etc.

⇒ Consumption of lubricating oil is less because more time is allowed for removing heat from the cylinder.

⇒ wear and tears of the parts is less.

⇒ fuel consumption is less since fuel cannot escape with exhaust gases.

⇒ Scavenging is poor since exhaust port is open only for a short time.

⇒ Scavenging is better. There is a separate exhaust stroke for the removal of exhaust gas.

⇒ Better performance and efficiency is also better.

⇒ used in heavy vehicle.
Example: - Automobile, buses, trucks etc.

Two stroke diesel engine

Working

⇒ Two stroke engine requires two strokes of piston to complete the cycle:

First stroke (Upward stroke of the piston)

⇒ Piston moves from bottom dead (B.D.C) Centre to top dead centre (T.D.C)

⇒ First transfer port is covered which is followed by the covering of the exhaust port.

- ⇒ Air which is transferred already in cylinder is compressed by the upward movement of the piston.
 - ⇒ Pressure and temperature of the air increases and at the same time fresh air is admitted into the crankcase.
 - ⇒ Fuel is injected into the hot compressed air when the piston almost reaches T.D.C.
 - ⇒ Fuel mixes with air and burns.
- Second Stroke (Downward stroke of the piston)

- ⇒ Burning gases expand in the cylinder expansion forces the piston down thus useful work is obtained.
- ⇒ Air in the crankcase is compressed by the downward movement of the piston.
- ⇒ Exhaust port is uncovered at the end of expansion, the burnt gases escape through it.
- ⇒ Transfer port is also uncovered shortly after the exhaust port is opened, thus partially compressed air enters the cylinder through the transfer port from the crankcase.

Two stroke petrol engine :-

- ⇒ Two stroke engine requires two strokes of piston to complete the cycle.

First stroke :-

- ⇒ Initially piston is at bottom dead centre both transfer and exhaust ports remain open.
- ⇒ As the piston moves from bottom dead centre to top dead centre transfer port is first covered which is followed immediately by the covering of exhaust port.

⇒ Air fuel mixture which is transferred already is compressed by the piston movement.

⇒ Temperature and pressure increases at the end of compression.

⇒ The inlet port is uncovered.

⇒ The upward movement of the piston creates suction and the mixture of fuel and air is drawn into the crankcase.

Second Stroke

⇒ Electric spark is introduced by spark plug over the compressed charge resulting in combustion.

⇒ Burning gases expand in the cylinder and force the piston downwards.

⇒ Downwards movement of the piston covers the inlet port and compresses the charge in the crankcase.

⇒ During this process exhaust port is opened first and the transfer port is uncovered little later.

⇒ Burnt gases escape to the atmosphere through exhaust port and partially compressed charge enters the cylinder through transfer port.

⇒ Top surface of the piston is made in deflected shape so that the fresh charge entering the cylinder is deflected upwards thus escape of fresh charge along with exhaust gases is reduced.

Four stroke diesel engine

⇒ In a four stroke diesel engine the working cycle consists of the following events.

⇒ Suction stroke

⇒ Compression stroke

⇒ Power stroke

⇒ Exhaust stroke

Suction stroke

⇒ Piston moves down from top dead centre to bottom dead centre

⇒ Inlet valve is kept opened and exhaust valve is kept closed.

⇒ Pressure inside the cylinder is reduced below atmospheric pressure i.e. vacuum is created inside the cylinder.

⇒ Atmospheric air in ordinary engine and partially compressed air from the turbocharger in a turbocharged engine is sucked into the cylinder through air cleaner and inlet valve.

⇒ When the piston reaches B.D.C suction stroke is completed.

Compression stroke

⇒ Piston moves from B.D.C to T.D.C.

⇒ Both inlet and exhaust valve are kept closed.

⇒ Air is compressed due to the piston movement.

⇒ Pressure raises up to 60 bar and temperature to 600°C.

⇒ When the piston reaches near T.D.C fine spray of fuel is injected into the high pressure air.

⇒ Ignition of air fuel mixture takes place.

⇒ Burning of fuel in cylinder is due to high pressure and temp. already developed in the cylinder and heat addition is taken as a constant pressure process in diesel engines.

Power Stroke

⇒ Burning gases expands rapidly and exert a impulse on the piston.

⇒ Piston is pushed from T.D.C to B.D.C.

⇒ This reciprocating movement of the piston is converted into rotary motion of the crankshaft through connecting rod.

⇒ Thus mechanical power is obtained.

⇒ Both inlet and exhaust valves remain closed.

⇒ During power stroke the temp and pressure of burnt gases decreases.

Exhaust Stroke

⇒ Piston moves upward from B.D.C to T.D.C

⇒ Exhaust valve is kept opened and inlet valve is kept closed.

⇒ Burnt gases are forced out through the exhaust valve.

⇒ Exhaust stroke completes the cycle.

⇒ Exhaust valve closes shortly after T.D.C

⇒ Inlet valve opens slightly before T.D.C and ready to receive fresh air to start a new cycle.

Four stroke petrol engine

- ⇒ In a four stroke petrol engine the working cycle consists of the following events.
- ⇒ Suction Stroke
- ⇒ Compression stroke
- ⇒ Power Stroke
- ⇒ Exhaust stroke
- ⇒ one cycle is completed in two revolutions of the crankshaft and hence this is known as four stroke cycle engine.

Suction Stroke

- ⇒ Piston moves down from top dead centre to B.D.C.
- ⇒ Inlet valve is kept opened and exhaust valve is kept closed.
- ⇒ Pressure inside the cylinder is reduced below atmospheric pressure i.e. vacuum is created inside the cylinder.
- ⇒ Air-fuel mixture is sucked into the cylinder through inlet valve.
- ⇒ When the piston reaches B.D.C suction stroke is completed.

Compression Stroke

- ⇒ Piston moves from BDC to TDC
- ⇒ Both inlet and exhaust valves are kept closed.
- ⇒ Pressure and temperature of the charge increases.
- ⇒ When the piston reaches near T.D.C a spark is introduced by spark plug.
- ⇒ Air fuel mixture gets ignited.
- ⇒ Burning of mixture raises the temp. upto 2000°C and pressure to 30 to 40 bar but the volume remains constant.

Power Stroke

- ⇒ Products of combustion expand rapidly and exert an impulse on the piston.
- ⇒ Piston is pushed from T.D.C to B.D.C.
- ⇒ Thus mechanical power is obtained.
- ⇒ Both the valves remain closed.
- ⇒ During power stroke the temperature and pressure of burnt gases decreases.
- ⇒ This reciprocating movement of the piston is converted into rotary motion of the crankshaft through connecting rod.

Exhaust Stroke

- ⇒ Piston moves upward from B.D.C to T.D.C
- ⇒ Exhaust valve is kept opened and Inlet valve is kept closed.
- ⇒ Burnt gases are forced out through the exhaust valve.
- ⇒ Exhaust stroke completes the cycle.
- ⇒ Exhaust valve closes shortly after T.D.C.
- ⇒ Inlet valve opens slightly before T.D.C and ready to receive fresh charge to start a new cycle.

Engine basic nomenclature

Cylinder bore

- ⇒ The diameter of engine cylinder in mm can be called as cylinder bore.

Piston Area

- ⇒ The area of a circle of diameter equal to the cylinder bore is called the piston area.
- ⇒ It is denoted by 'A' and is expressed in cm^2

$$\Rightarrow \text{mean piston speed} = \frac{2LN}{60}$$

where L = Length of stroke (mm)
 N = Number of crankshaft revolution per min. (rpm)

Stroke

- $\Rightarrow$ Distance traveled by the piston from one extreme position to the other.
- $\Rightarrow$ Ratio of stroke to cylinder bore is imp. parameter is classifying the size of the engine.
- $\Rightarrow$ If $d < L$, it is called under-square engine
- $\Rightarrow$ If $d = L$, it is called square engine
- $\Rightarrow$ If $d > L$, it is called over-square engine.

Top Dead Center (TDC)

- $\Rightarrow$ It is the dead center when the piston is farthest from the crankshaft.
- $\Rightarrow$ It is designated as TDC for vertical engines and inner dead center for horizontal engine

Bottom dead center (BDC)

- $\Rightarrow$ It is the dead center when the piston is nearest to the crankshaft.
- $\Rightarrow$ It is designated as BDC for vertical engines and outer dead center for horizontal engines.

Swept Volume

- $\Rightarrow$ Volume displaced by the piston as it travels through one stroke.
- $\Rightarrow$ Swept volume is defined as stroke times bore.
- $\Rightarrow$ Displacement can be given for one cylinder or entire engine.

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Cubic Capacity

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⇒ the displacement volume of a cylinder multiplied by number of cylinders in the engine will give the cubic capacity.

⇒ for example - cubic capacity = $V_s \times k$

Clearance Volume (V_c)

⇒ the Nominal Volume of the Combustion Chamber above the piston, when it is at the top dead center is the clearance volume.

⇒ It is denoted as V_c and expresses in cubic centimeter (cc)

Compression ratio (r)

⇒ It is the ratio of the total cylinder volume when the piston is at the bottom dead center V_T to the clearance volume, V_c .

⇒ It is denoted $r = \frac{V_T}{V_c} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c}$

Relationship of Clearance Volume and Compression ratio

$$\text{Compression ratio} = \frac{V_c + V_s}{V_c}$$

$$\text{Clearance volume} = \frac{V_c}{V_s}$$

Relationship

Then ~~Compression ratio = $\frac{1}{\frac{V_c}{V_s} + 1}$~~

~~Clearance volume = $\frac{1}{\frac{V_c + V_s}{V_c} - 1}$~~

I. c engine parts

(1) Spark Plug:- The supply the spark that ignites the air/fuel mixture creating the explosion which makes your engine produce power.

(2) Fuel Injector:-

A device that regulates the flow of fuel into an engine's combustion chamber. It's a key component of modern cars, and is often called the heart of the engine.

(3) Intake Valve:- A valve in an internal combustion engine that allows air and fuel to enter the cylinders.

(4) Exhaust Valve:-

Control the flow of burnt gases out of the cylinders.

(5) Intake manifold:-

To evenly distribute the combustion mixture to each intake port in the cylinder head.

(6) Exhaust manifold:-

To contain the gases that leave the cylinder head's exhaust ports just after each power stroke.

(7) Cylinder:-

A chamber where fuel is burned to create power.

(8) Piston

A moving disk enclosed in a cylinder which is made gas-tight by piston rings.

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(9) Gudgeon Pin :-

It connects the piston to the connecting rod and provides a bearing for the connecting rod to pivot upon as the piston moves.

(10) Piston Rings :-

A metallic split ring that is attached to the outer diameter of a piston in an internal combustion engine or steam engine.

(11) Oil Rings

A piston rings that's located in the ring groove closest to the crankcase.

(12) Water ~~Jackets~~ Jackets :-

A water filled casing that surrounds the cylinder block of an internal combustion engine and cools the engine interior.

(13) Connecting Rod :-

To support the connecting rod, allowing it to rotate smoothly on the crank pin while reducing direct friction between the metals.

(14) Crank Pin :-

Responsible for the proper operation of the engine and converting a linear motion to a rotational motion.

(15) Crank :- A key component of an internal combustion engine that converts the piston's linear motion into a rotational motion.

(16) Crank Shaft :- Converts the linear motion generated by the engine into rotational motion.

(17) Crank Case :- Lubricates and cools the moving parts.

Relation betⁿ compression ^{ratio (r)} and
clearance Volume (C)

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

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

$$V_c = CV_s$$

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

$$r = \frac{V_s}{V_c} (C+1)$$

$$= \frac{1}{\left(\frac{V_c}{V_s}\right)} (C+1)$$

$$= \frac{1}{C} (C+1)$$

$$\Rightarrow \frac{C+1}{C} = 1 + \frac{1}{C}$$

GAS Power cycle

* Heat engines whose working fluid is a gas rather than a vapour undergo gas power thermodynamic cycles.

⇒ It is used in rotating gas turbine engines and reciprocating petrol engines.

⇒ The air used as working fluid in these engines is an example of a gas power cycle.

Some examples of gas power cycles

- Include:
- (i) Carnot cycle
 - (ii) Otto cycle
 - (iii) Diesel cycle
 - (iv) Dual cycle

Carnot cycle

⇒ Carnot cycle is also called as constant temp. cycle.

⇒ This cycle was introduced by a French engineer Sadi Carnot.

⇒ It consists of four processes:-

(i) Isothermal expansion

(ii) adiabatic expansion / isentropic expansion

(iii) Isothermal compression

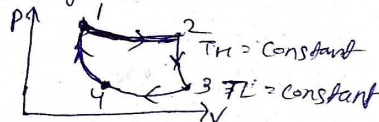
(iv) isentropic compression or adiabatic compression

⇒ Both of these are ideal processes

⇒ A Carnot engine can be considered to be similar to piston and cylinder type of engine

1) Isothermal expansion

- ⇒ Reversible isothermal expansion.
- ⇒ Heat transfer between the heat source and the cylinder occurs with an infinitesimal temp. difference, hence, it is a reversible heat transfer process.
- ⇒ Gas in the cylinder expands slowly, does work to its surroundings, and remains at a constant temperature T_H .
- ⇒ The total amount of heat transferred to the gas during this process is Q_H .



⇒ Heat supplied = work done by the gas during isothermal expansion.

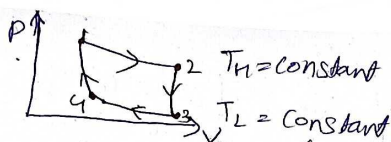
$$Q_H = dU + W_H$$

$$Q_H = W_H$$

$$Q_H = P_H V_H \log_e \left(\frac{V_2}{V_1} \right)$$

Reversible adiabatic or isentropic expansion

- ⇒ Reversible adiabatic expansion.
- ⇒ The heat source is removed and the gas expands in an adiabatic manner.
- ⇒ Gas in the cylinder continues to expand slowly, do work to its surroundings till the temperature of the gas drops from T_H to T_L .
- ⇒ Assuming the piston moves frictionless and the process to be quasi-equilibrium, the process is reversible as well as adiabatic.

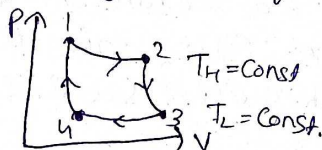


$$Q_2 = 0$$

Isobaric Isothermal Compression

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- ⇒ The cylinder is brought into contact with a heat sink at temperature T_L .
- ⇒ The piston is pushed by an external force and which does work on the gas.
- ⇒ During the compression, the gas temperature maintains at T_L and the process is a reversible heat transfer process.
- ⇒ The total amount of heat rejected to the heat sink from the gas during this process is Q_L .

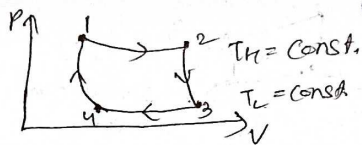


- ⇒ Heat Rejected = work done on the air during isothermal compression.

$$Q_3 = P_3 V_3 \log_e \left(\frac{V_3}{V_4} \right) = n R T_L \log_e \left(\frac{V_3}{V_4} \right) \quad (P.V. = nRT)$$

adiabatic Compression

- ⇒ The heat sink is removed and the gas is compressed in an adiabatic manner.
- ⇒ Gas in the cylinder continues to be compressed slowly, accepting work from its surroundings till the temperature of gas rises from T_L to T_H .
- ⇒ The gas returns to its initial state, which completes the cycle.



⇒ for process $du = 0$

Assumptions :-

- ⇒ The working substance must, at any instant, be at the same temp. as that of hot source while heat is being absorbed.
- ⇒ the working fluid must at any instant, be at the same temp. as that of cold body while heat is being rejected.
- ⇒ There must be no free or imperfectly resisted expansions and compressions.
- ⇒ Carnot cycle satisfies all these conditions and hence it is a reversible cycle.

At standard efficiency

$$\Rightarrow \text{Workdone} = \text{Heat Supplied} - \text{Heat rejected}$$

$$= mRT_1 \log_e(r) - mRT_3 \log_e(r)$$

$$\Rightarrow \text{Efficiency of the cycle} = \frac{\text{workdone}}{\text{Heat Supplied}}$$

$$\eta_{\text{Carnot}} = \frac{mRT_1 \log_e(r) - mRT_3 \log_e(r)}{mRT_1 \log_e(r)}$$

$$\eta_{\text{Carnot}} = \frac{T_1 - T_3}{T_1}$$

$$\eta_{\text{Carnot}} = 1 - \frac{T_3}{T_1} = 1 - \frac{T_L}{T_H}$$

⇒ The Carnot theorem states that of all engines operating betn a given constant temp. source (T_H) and a given const. temp. sink (T_L), none has a higher efficiency than a reversible

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Significance of Carnot cycle

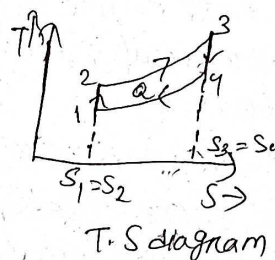
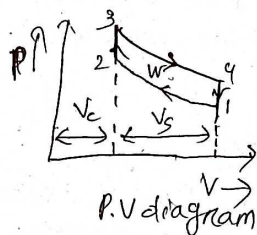
- ⇒ Efficiency of Carnot cycle is given by $\eta = 1 - \frac{T_L}{T_H}$
- ⇒ From the above equation it is evident that,
 - ⇒ The efficiency of cycle depends only on temp. limits and is independent of properties of fuel used in the cycle.
 - ⇒ Carnot cycle is having maximum efficiency among all cycles when operating betⁿ same temp. limits.
 - ⇒ Hence efficiency of different cycles working with different fuels can be compared with efficiency of Carnot cycle when operating between same temp. limits.

Limitations of Carnot cycle

- ⇒ No. actual engine will operate on Carnot cycle practically on account of following limitations,
 - ⇒ P-V diagram is very narrow.
 - ⇒ Hence, cycle develops very small amount of work which may not sufficient to overcome friction between piston and cylinder.
 - ⇒ In Carnot cycle, the piston should move very slowly in isothermal process and very fast in adiabatic process which is not practicable.
- ⇒ The efficiency of Carnot cycle is improved
 - * Either by increasing the higher temp. by keeping the lower temp. constant.
 - * Or by decreasing lower temp. by keeping the higher temp. constant.
- ⇒ In the second method, increase in efficiency is more for same amount of change in temperature.

Otto cycle

- ⇒ This is the cycle which was introduced by Dr. A.N. Otto; a German scientist in the year 1876
- ⇒ It is a constant volume cycle since the heat addition takes place at constant volume.
- ⇒ petrol and gas engines are operated on this cycle.
- ⇒ This cycle consists of the following four processes:
 - (i) Isentropic compression / Adiabatic compression
 - (ii) constant volume heat addition
 - (iii) Isentropic expansion / Adiabatic expansion
 - (iv) constant volume heat rejection.
- ⇒ The P.V and T.S diagram are:-



(i) Isentropic compression:-

- ⇒ During this process, pressure increases from P_1 to P_2 and temp. increases from T_1 to T_2
- ⇒ volume decreases from V_1 to V_2 and entropy remains constant ($S_1 = S_2$)
- ⇒ No heat transfer across the walls of the cylinder, hence no change in entropy.
- ⇒ Internal energy increased and work is done on the system $Q = 0$, $W = -dU$

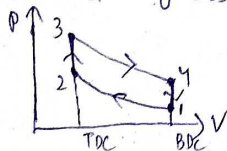
(i) Constant Volume heat addition

During this process, pressure increases from P_2 to P_3 , temperature increases from T_2 to T_3 and entropy increases from S_2 to S_3 or S_1 to S_3 (since $S_1 = S_2$)

But, the volume remains constant ($V_2 = V_3$)

Work done is zero, $W = 0$

Heat supplied during $Q_s = m \times C_v (T_3 - T_2) \text{ kJ}$

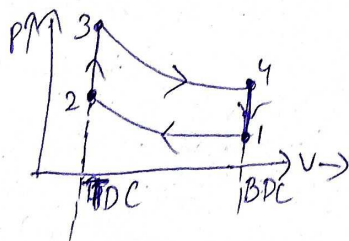


(ii) Isentropic expansion/Adiabatic expansion

During this process, pressure decreases from P_3 to P_4 , temperature decreases from T_3 to T_4 and volume increases from V_3 to V_4

No heat transfer and entropy remains constant ($S_3 = S_4$)

$$Q = 0; W = -du$$



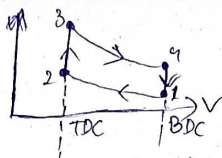
(iv) Constant Volume heat rejection

During this process pressure decreases from P_4 to P_1 , temperature decreases from T_4 to T_1 and entropy decreases from S_4 to S_1 or S_3 to S_1 . Thus cycle completes.

But, volume remains constant ($V_4 = V_1$)

Internal energy is also decreases.

$$W = 0; Q = du$$



Assumptions made in Otto cycle

- ⇒ Air is assumed as working medium and behaves as ideal gas.
- ⇒ Heat added to air from the external source, and heat rejected from the air to external sink.
- ⇒ Walls of the engine are perfectly insulated.
- ⇒ No dissociation of atoms of air and specific heats C_p and C_v are assumed to be constant.
- ⇒ Fixed mass of air will undergo through cyclic change and no heat loss in the cycle.

⇒ Since processes 1 and 3 are adiabatic processes. The heat transfer during the cycle takes place only during processes 2 and 4 respectively.

$$\eta_{\text{Otto}} = \frac{\text{Workdone}}{\text{Heat Supplied}}$$

Thermal efficiency can be written as,

$$\eta_{\text{Otto}} = \frac{\text{Heat Supplied} - \text{Heat Rejected}}{\text{Heat Supplied}}$$

consider 'm' kg of working fluid

$$\Rightarrow \text{Heat added} = m C_v (T_3 - T_2)$$

$$\Rightarrow \text{Heat rejected} = m C_v (T_4 - T_1)$$

$$= m C_v (T_3 - T_2) - m C_v (T_4 - T_1)$$

$$\eta_{\text{Otto}} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

⇒ This expression is in terms of temp. only.
 ⇒ If the temp. at all points of the cycle is known, then only we can use above equation.
 ⇒ Hence the efficiency equation is simplified in terms of volume ratio.

⇒ From P-V diagram ⇒ Total cylinder volume = $V_1 = V_4$
 ⇒ Clearance volume = $V_c = V_2 = V_3$
 ⇒ Stroke volume = $V_s = V_1 - V_2 = V_4 - V_3$

Compression Ratio (γ)

⇒ Compression ratio (γ) is the ratio betⁿ total cylinder volume and clearance volume.

Process-1
 ⇒ Adiabatic compression ratio $\gamma = \frac{V_1}{V_2} = \frac{\text{Total cylinder volume}}{\text{clearance volume}}$

$$\gamma = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

⇒ During the adiabatic process, compression ratio is equal to expansion ratio.

Process-2
 ⇒ The adiabatic relation betⁿ T and V is,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} = \gamma^{\gamma-1}$$

$$T_2 = T_1 \times (\gamma)^{\gamma-1}$$

Process-3

⇒ The adiabatic relation betⁿ T and V is $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{\gamma-1} = \gamma^{\gamma-1}$

$$T_3 = T_4 \times (\gamma)^{\gamma-1}$$

$$\eta_{\text{otto}} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

Substituting T_2 and T_3 value in eqn (1)

$$\eta_{\text{otto}} = 1 - \frac{(T_4 - T_1)}{T_4 (\gamma)^{\gamma-1} - T_1 (\gamma)^{\gamma-1}}$$

$$\eta_{\text{otto}} = 1 - \frac{(T_4 - T_1)}{(T_4 - T_1)(\gamma)^{\gamma-1}}$$

$$\eta_{\text{otto}} = 1 - \frac{1}{(\gamma)^{\gamma-1}}$$

⇒ from above eqn, the efficiency of otto cycle increases with increase in compression ratio and vice versa.

Effect of compression ratio on the efficiency of otto cycle

- ⇒ As the compression ratio increases the efficiency also increases.
- ⇒ In the practical engine, the compression ratio is limited by temperature T_2 .
- ⇒ If T_2 is too high pre-ignition occurs, so compression ratio (γ) is limited by 7 or 8.
- ⇒ If $\gamma > 8$, there is no considerable increase in efficiency.
- ⇒ For same temp. limits, efficiency of otto cycle is less than that of carnot cycle.



Diesel cycle

Diesel cycle is the cycle which was introduced by Rudolph Diesel in 1893.

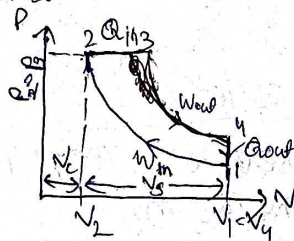
⇒ This cycle is used in diesel engines.

⇒ This is the basic cycle for engines working with heavy oils, and diesel fuel.

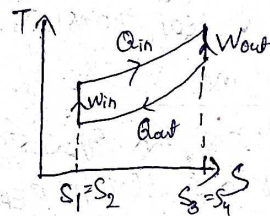
⇒ This is also known as constant pressure cycle since heat is added during the constant pressure process.

⇒ The diesel cycle has the following sequence of processes:-

- (1) Isentropic compression or Adiabatic compression.
- (2) Constant pressure heat addition.
- (3) Isentropic expansion / Adiabatic expansion.
- (4) Constant volume heat rejection.



P-V diagram



T-S diagram

Process of diesel cycle

(1) Adiabatic compression process

⇒ During the process, air is compressed from P_1 to P_2 .

⇒ Entropy remains constant ($S_1 = S_2$).

⇒ No heat is rejected during compression (no heat transfer across the walls of the cylinder).

⇒ Work is done on the air.

⇒ Volume reduces to V_2 from initial volume V_1 .



Constant pressure heat addition process

- ⇒ During the process, air is heated from T_2 to T_3 but pressure remains constant ($P_2 = P_3$).
- ⇒ Temperature increases to T_3 from T_2 .
- ⇒ Volume ~~increases~~ increases to V_3 from V_2 .
- ⇒ Heat supplied during the process $Q_2 = m C_p (T_3 - T_2)$

Adiabatic expansion process

- ⇒ At point 3, supply of heat is cut off. This point is known as cut off point.
- ⇒ During this process, air expands isentropically from P_3 to P_4 .
- ⇒ But, temperature decreases from T_3 to T_4 .
- ⇒ Work done by the air at the expense of internal energy.
- ⇒ No heat transfer.

Constant Volume heat rejection process

- ⇒ During this process, heat is rejected from air but volume remains constant.
- ⇒ Thus, the temperature decreases from T_4 to T_1 .
- ⇒ No work done.
- ⇒ Decreases in internal energy.
- ⇒ Heat rejected $Q_R = m C_v (T_4 - T_1)$

Assumptions:-

- ⇒ Working fluid is air.
- ⇒ There is no friction.
- ⇒ Compression and expansion are isentropic. There is no entropy change.

- ⇒ During the air
- ⇒ Ideal
- ⇒ Air has a
- ⇒ There

- ⇒ Heat
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- ⇒ He

- ⇒

- ⇒

During heat addition and heat rejection the air temp. does change.

ideal gas state equation is valid $PV = RT$.

Air behaves as a perfect gas, specific heat has a constant value.

Thermal efficiency of the diesel cycle,

$$\eta_{\text{diesel}} = \frac{\text{Heat Supplied} - \text{Heat Rejected}}{\text{Heat Supplied}}$$

Heat Supplied process, $Q_s = m C_p (T_3 - T_2)$

Heat Rejected process, $Q_R = m C_v (T_4 - T_1)$

$$\begin{aligned} \eta_{\text{diesel}} &= \frac{Q_s - Q_R}{Q_s} \\ &= \frac{m C_p (T_3 - T_2) - m C_v (T_4 - T_1)}{m C_p (T_3 - T_2)} \\ &= 1 - \frac{m C_v (T_4 - T_1)}{m C_p (T_3 - T_2)} \end{aligned}$$

$$\eta_{\text{diesel}} = 1 - \frac{(T_4 - T_1)}{\gamma (T_3 - T_2)}$$

Hence compression ratio $\gamma = \frac{V_1}{V_2} = \frac{\text{Total Cylinder Volume}}{\text{Clearance Volume}}$

Cut off ratio, $\rho = \frac{\text{Cut-off Volume}}{\text{Clearance Volume}} = \frac{V_3}{V_2}$

Expansion ratio $= \frac{V_4}{V_3} = \frac{V_1}{V_3} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} = \gamma \cdot \rho$

$$\Rightarrow \frac{V_1}{V_2} = \frac{V_3}{V_3} \cdot \rho$$

$$\Rightarrow \gamma \cdot \rho = \rho \cdot \rho$$

⇒ from adiabatic relation.

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

$$T_2 = T_1 \times (r)^{\gamma-1}$$

⇒ from constant pressure process

$$\Rightarrow \frac{V}{T} = C$$

$$\Rightarrow \frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$\Rightarrow \frac{T_3}{T_2} = \frac{V_3}{V_2} = r$$

$$\Rightarrow T_3 = T_2 \times r = T_1 (r)^{\gamma-1} r$$

$$\Rightarrow T_3 = T_1 (r)^{\gamma}$$

⇒ using adiabatic equation

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{r}{P}\right)^{\gamma-1}$$

$$T_4 = \frac{T_3}{\left(\frac{r}{P}\right)^{\gamma-1}}$$

$$= \frac{T_1 (r)^{\gamma}}{\left(\frac{r}{P}\right)^{\gamma-1}}$$

$$\Rightarrow T_4 = \frac{T_1 (r)^{\gamma} \cdot P^{\gamma-1}}{(r)^{\gamma-1}}$$

$$\Rightarrow T_4 = T_1 \cdot P^{\gamma}$$

⇒ substituting T_2 , T_3 and T_4 value in η_{diesel} equation

$$\eta_{\text{diesel}} = 1 - \frac{1}{\gamma} \left[\frac{T_1 P^{\gamma} - T_1}{T_1 (r)^{\gamma-1} P - T_1 (r)^{\gamma-1}} \right]$$

$$= 1 - \frac{1}{\gamma} \left[\frac{T_1 (P^{\gamma} - r^{\gamma})}{T_1 (r)^{\gamma-1} (P - r)} \right]$$

$$\eta_{\text{diesel}} = 1 - \frac{1}{\gamma(\gamma-1)} \left[\frac{p_2^{\gamma-1}}{p_1^{\gamma-1}} \right]$$

- ⇒ If compression ratio increases, the efficiency of the diesel cycle increases and vice versa.
 - ⇒ The efficiency of diesel cycle decreases with increases of cut off ratio and vice versa.
- mean effective pressure

⇒ A parameter used to describe the performance of reciprocating engine is mean effective pressure.

⇒ The mean effective pressure is the theoretical constant pressure that, if it is acted on the piston during the power stroke, would produce the same net work as actually developed in one cycle. Thus, $m.e.p. = \frac{\text{net work for one cycle}}{\text{Swept Volume}}$

⇒ It should be noted that since the m.e.p. is obtained from an indicator diagram, it is generally known as the indicator mean effective pressure (m.e.p.)

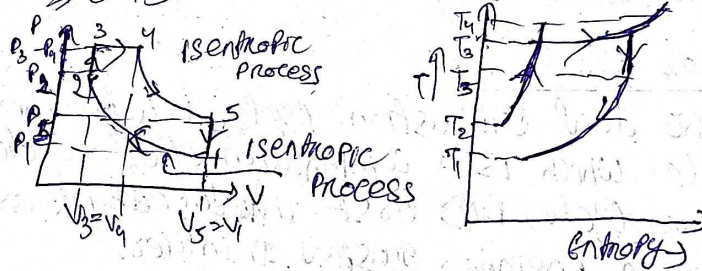
Dual cycle :-

⇒ The dual combustion cycle is a ~~thermo~~ thermal cycle which is a combination of Otto cycle and diesel cycle, ~~first~~ first introduced by Russian German engineer ~~Trinkler~~ Otto.

⇒ The dual combustion cycle is also known as the limited pressure or mixed cycle, Trinkler cycle, Seiliger cycle or Sabathe cycle.

⇒ Heat is added partly at constant volume and partly at constant pressure.

- W^c
- ⇒ The advantage is that more time is available for the fuel to completely burn.
 - ⇒ because of lagging characteristics of fuel this cycle is invariably used for diesel and hot spot ignition engines
 - ⇒ The idea dual combustion cycle consists of two reversible adiabatic or isentropic, two constant volume and a constant pressure processes.
 - ⇒ These processes are represented on P-V and T-S diagram is shown in fig.
 - ⇒ The dual combustion cycle consists of the following operation,
 - ⇒ Reversible adiabatic compression
 - ⇒ constant volume heat addition
 - ⇒ constant pressure heat addition.
 - ⇒ Reversible adiabatic expansion
 - ⇒ constant volume heat rejection.



Dual Cycle on P-V and T-S diagram.

Air standard efficiency

$$\text{Total heat supplied} = C_v (T_3 - T_2) + C_p (T_4 - T_3)$$

$$\text{Heat rejected during operation} = C_v (T_5 - T_1)$$

$$\text{workdone} = \text{Heat supplied} - \text{heat rejected}$$

$$= C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)$$

$$\eta_{\text{dual}} = \frac{\text{workdone}}{\text{Heat supplied}}$$

$$= \frac{C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \dots \text{eqn (1)}$$

$$\left[\because \gamma = \frac{C_p}{C_v} \right]$$

$$\text{Compression ratio, } \gamma = \frac{V_1}{V_2}$$

adiabatic compression process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = (\gamma)^{\gamma-1} \dots \text{eqn (2)}$$

During constant volume heating process,

$$\frac{P_3}{T_3} = \frac{P_2}{T_2}$$

$$\text{or } \frac{T_3}{T_2} = \frac{P_3}{P_2} = \beta$$

where

β is known as pressure

or explosion ratio

$$\text{or } T_2 = \frac{T_3}{\beta} \dots \text{eqn (3)}$$

During adiabatic expansion process

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4} \right)^{\gamma-1}$$

$$= \left(\frac{\gamma}{\beta} \right)^{\gamma-1}$$

$$\therefore \frac{V_3}{V_4} = \frac{V_1}{V_2}$$

$$= \frac{V_1}{V_2} \times \frac{V_3}{V_4}$$

$$= \frac{V_1}{V_2} \times \frac{V_3}{V_4}$$

$$= \frac{\gamma}{P}, \text{ } P \text{ being the cut-off ratio.}$$

During constant pressure heating process,

$$\frac{V_3}{T_3} = \frac{V_4}{T_4}$$

$$T_4 = T_3 \frac{V_4}{V_3}$$

$$T_4 = P T_3$$

Putting the value of T_4 in the eqn we get,

$$\frac{P T_3}{T_5} = \left(\frac{\gamma}{P} \right)^{\gamma-1}$$

Now substituting the value of T_1, T_2, T_4 and T_5 in eqn. 1 we get,

$$\eta_{\text{dual}} = \frac{\left[1 - P T_3 \left(\frac{P}{\gamma} \right)^{\gamma-1} - \frac{T_3}{\beta} \cdot \frac{1}{(\gamma)^{\gamma-1}} \right]}{\left[\left(\frac{T_3 - T_2}{\beta} \right) + \gamma (P T_3 - T_3) \right]}$$

$$= 1 - \frac{1}{(\gamma)^{\gamma-1}} \left(P^{\gamma} - \frac{1}{\beta} \right)$$

$$\text{i.e., } \eta_{\text{dual}} = 1 - \frac{1}{(\gamma)^{\gamma-1}} \cdot \frac{(\beta \cdot P^{\gamma} - 1)}{[(\beta - 1) + \beta \gamma (P - 1)]}$$

work done is given by,

$$\begin{aligned}
 W &= P_3(V_4 - V_3) + \frac{P_4 V_4 - P_5 V_5}{\gamma - 1} - \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} \\
 &= P_3 V_3 (P - 1) + \frac{(P_4 V_4 - P_5 V_5) - (P_2 V_2 - P_1 V_1)}{\gamma - 1} \\
 &= \frac{P_3 V_3 (P - 1)(\gamma - 1) + P_4 V_4 \left(P - \frac{P_5}{P_4} r\right) - P_2 V_2 \left(1 - \frac{P_1}{P_2} r\right)}{\gamma - 1}
 \end{aligned}$$

$$\text{Also, } \frac{P_5}{P_4} = \left(\frac{V_4}{V_5}\right)^\gamma = \left(\frac{P}{r}\right)^\gamma$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\gamma = r^\gamma$$

$$\text{Also } P_3 = P_4$$

$$V_2 = V_3$$

$$V_5 = V_1$$

$$\begin{aligned}
 \therefore W &= \frac{V_3 \left[P_3 (P - 1)(\gamma - 1) + P_3 (P - P^\gamma r^{1-\gamma}) - P_2 (1 - r^{1-\gamma}) \right]}{(\gamma - 1)} \\
 &= \frac{P_2 V_2 \left[P (P - 1)(\gamma - 1) + P (P - P^\gamma r^{1-\gamma}) - (1 - r^{1-\gamma}) \right]}{(\gamma - 1)} \\
 &= \frac{P_1 (\gamma)^\gamma \frac{V_1}{r} \left[P \gamma (P - 1)(P - 1) + P_3 (P - P^\gamma r^{1-\gamma}) - P_2 (1 - r^{1-\gamma}) \right]}{(\gamma - 1)} \\
 &= \frac{P_1 V_1 (\gamma)^{\gamma-1} \left[P \gamma (P - 1) + (P - 1) - \gamma^{\gamma-1} (P P^\gamma) \right]}{\gamma - 1}
 \end{aligned}$$

mean effective pressure (P_m) is given by

$$P_m = \frac{W}{V_1 - V_2}$$

$$= \frac{W}{V_1 \left(\frac{n-1}{n} \right)}$$

$$P_m = \frac{P_1 V_1 \left[r^{1-\gamma} \beta \gamma (p-1) + (\beta-1) - r^{1-\gamma} (\beta p^\gamma - 1) \right]}{(\gamma-1) V_1 \left(\frac{n-1}{n} \right)}$$

$$P_m = \frac{P_1 (V_1)^\gamma \left[\beta (p-1) + (\beta-1) - r^{1-\gamma} (\beta p^\gamma - 1) \right]}{(\gamma-1) n-1}$$

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Chapter-6

Fuels and Combustion

Fuel

→ Fuel is a substance which releases heat energy when burned at sufficiently high temperature.

→ The release of sufficient heat energy by burning can take place only if a supply of oxygen is available and combustion is started by a sufficiently high temperature.

→ The atmospheric air is the usual source of oxygen.

Uses of Fuel

→ Fuel is one of the most important sources of energy. ^{used in power plants} ~~when burned at sufficiently high~~

→ Fuels are also used for other industrial purposes.

→ The fuel used in blast furnace is not only supplies heat but also fulfills the important role of a reducing agent.

Fuel Constituents

→ All fuels contain hydrogen and carbon, and they are sometime referred as hydrocarbons.

→ Fuels usually contain: (i) Hydrogen (ii) Carbon (iii) Sulphur (iv) Oxygen (v) Nitrogen (vi) Ash.

Characteristics of Fuel

→ Easy ignition.

→ High heating value (calorific value)

→ Low smoke emission

→ Easily controllable combustion properties

→ Low content of impurities (low ash and sulphur)

→ They can be stored for long period without deterioration and are easy to handle, control and transport.

Types of fuels

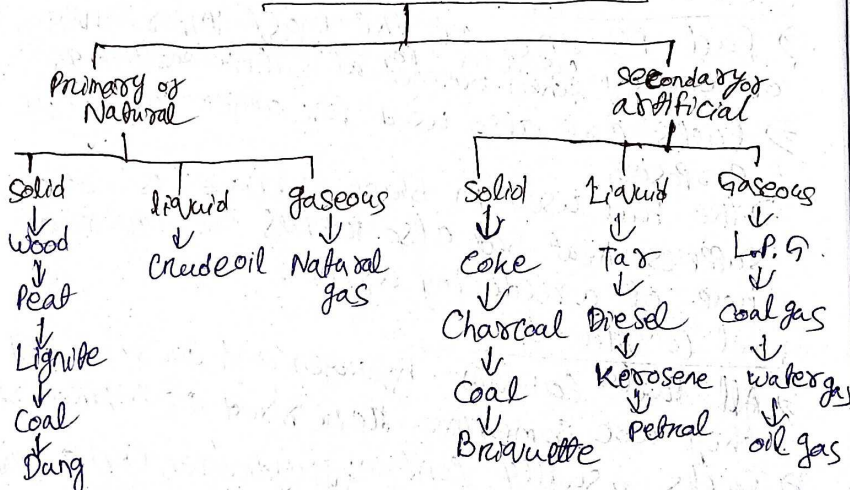
⇒ Fuels may broadly be classified in two ways
⇒ According to the physical state in which they exist in nature.

- (i) Solid fuels
- (ii) Liquid fuels
- (iii) Gaseous fuels

⇒ According to the nature of their origin.

- (i) Natural fuels (Primary fuels or fossil fuels)
- (ii) Artificial fuels (secondary fuel or prepared fuels)

⇒ According to the nature of their origin



⇒ Solid fuels consist mainly carbon together with hydrogen, sulphur and some incombustible ash.

⇒ wood, Peat, lignite, bituminous coal, anthracite coal etc are examples of Solid fuels.

Advantages

⇒ Easy to transport

⇒ Cost of production is low.

⇒ Posses moderate ignition temperature

⇒ Convenient to store without any risk of spontaneous explosion.

Disadvantages

- ⇒ Ash content is high
- ⇒ Large proportion of heat is wasted.
- ⇒ Burn with clinker formation.
- ⇒ Combustion operation cannot be controlled easily.
- ⇒ Cost of handling is high.

Solid Fuels

Wood

- ⇒ It is used to a considerable extent as a domestic fuel.
- ⇒ Wood was the only form of fuel available 250 years ago.
- ⇒ It contains about 50% carbon, 6% hydrogen, 43% oxygen and 1% ash.
- ⇒ The calorific value of air-dried wood ranges from 10,500 kJ/kg to 14,650 kJ/kg.
- ⇒ The wood is cheaply available but the disadvantages of wood as a industrial fuel is its large moisture content and low calorific value.

Coal

- ⇒ Coal is a mineral substance of vegetable origin.
- ⇒ The large deposits of coal in India are in Bengal, Bihar and Madhya Pradesh.
- ⇒ Most of the Indian coal is of low grade.
- ⇒ Over 30% of coal output in India is consumed by railways, another similar proportion is used by industry including iron and steel works.
- ⇒ This leaves barely 40% of coal mined for use of the power supply undertakings.
- ⇒ Anthracite is most valuable and peat the least.

⇒ The stages of coal formation is summarised below.

plant debris → peat → lignite → brown coal → bituminous coal → anthracite coal

Peat

- ⇒ Not widely used because it has lower heating value.
- ⇒ First stage in the formation of coal from wood.
- ⇒ It is associated with large amount of water and it may be as much as 90% moisture and only 10% solid.
- ⇒ Its calorific value 15000 kJ/kg is slightly greater than wood.
- ⇒ During burning it emits large smoke and it's not considered as an ~~important~~ important fuel.

Lignite

- ⇒ Lignite contains 20 to 60% moisture and small percentage of carbon.
- ⇒ Lignite with 20% moisture are brown in color, and are referred as brown coals.
- ⇒ It is used for generation of thermal power, fertiliser manufacture and for making briquettes to be used as domestic fuel.
- ⇒ Its calorific value is about 21000 kJ/kg .

Bituminous Coal

- ⇒ Bituminous coal contains 78 to 90% carbon, 20 to 45% volatile matter and small percentage (4-6%) moisture.
- ⇒ It represents third stage of coal formation in peat anthracite series.
- ⇒ The calorific value is about 31600 kJ/kg
- ⇒ It burns with long yellow and smoky flames.

Anthracite Coal

- ⇒ It contains 90% to 98% carbon and little volatile matter which is less than 8%.
- ⇒ It represents the last stage of coal formation.
- ⇒ It burns without smoke, with a short, non-luminous flame giving intense local heating.
- ⇒ The calorific value of fuel is about 35000 kJ/kg and is suitable to use in steam generating units.

Charcoal or wood charcoal

- ⇒ Charcoal is prepared by the dry distillation of wood.
- ⇒ Water and various kinds of volatile matters are expelled.
- ⇒ It contains about 80% carbon and 3% ash.
- ⇒ Its calorific value lies about 25000 kJ/kg.
- ⇒ Most widely used as metallurgical coal processes.

Advantages

- ⇒ Cheaper than other fuel.
- ⇒ Coal is used as raw material for producing other fuels such as coke, producer gas and water gas.
- ⇒ Risk of fire is minimum.

Disadvantages

- ⇒ Contains incombustible matter.
- ⇒ Need large amount of storage space.
- ⇒ Properties are not uniform.
- ⇒ Slow deterioration may take place with time.
- ⇒ Handling is not easy, and therefore may be costly.

fuel	mass analysis %						moisture content of fuel % by mass	volatile matter % by mass in dry fuel	Cal. Value KJ/kg	
	C	H ₂	O ₂	N ₂	S	Ash			Higher	Lower
Wood	42.5	6.78	48.62	0.5	-	1.6	15	80	15826	14319
peat	43.7	6.92	49.36	1.52	-	9.00	20	65	15910	14486
Lignite	56.52	5.72	31.89	1.0	0.62	4.25	15	50	21646	20390
Bituminous	81.93	4.87	5.98	1.32	1.0	4.9	2	25	33944	32406
Anthracite	90.27	3.00	2.32	0.8	0.64	2.9	1	4	34588	33913

Liquid fuel

- ⇒ The most important source of liquid fuel is crude oil, which occurs naturally and contains fractions of solid, liquid and gaseous hydrocarbons.
- ⇒ The liquid fuels and oils are separated from the crude oil by fractional distillation.
- ⇒ Liquid fuels are also obtained from coal.
- ⇒ The important liquid fuels are petrol, kerosene, diesel oil and alcohol.

Petrol or gasoline

- ⇒ Petrol is the lightest and most volatile liquid fuel.
- ⇒ It is mostly used as a fuel for petrol engines, air craft engines.
- ⇒ Its calorific value is about 46800 kJ/kg.

kerosene :-

- ⇒ It is also known as paraffin oil
- ⇒ It is obtained by fraction distillation of crude oil betn 140°C and 280°C
- ⇒ used as a fuel in farm tractors and jet engines

Cal. Value kJ/kg	Higher	Lower
15826	14319	
15910	14486	
1646	20390	
399	32406	
33913		

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⇒ Heavier and volatile than petrol and is used for illumination as well as heating purposes.
⇒ its calorific value is about 45875 kJ/kg.

Diesel oil

⇒ Diesel oil may be obtained by straight distillation of several crude oils.

⇒ used in diesel engines

⇒ its calorific value is about 44800 kJ/kg.

Heavy fuel oil

⇒ It is obtained by distillation of crude oil between 200°C to 360°C.

⇒ mostly used in steam power plant, heating furnaces and diesel engines.

⇒ its calorific value is 43900 kJ/kg.

Advantages

⇒ Relatively higher calorific value.

⇒ Burns without leaving a solid residue and with less smoke.

⇒ can be stored for long periods without deterioration.

⇒ Requires less storage space.

⇒ easy to handle and control

⇒ Requires a small volume of excess air

⇒ Relative cleanliness.

Limitations

⇒ may have higher sulphur content

⇒ Highest cost.

⇒ Risk of fire.

fuel	specific gravity	mass analysis %			cal. value kJ/kg	
		Carbon	Hydrogen	Sulphur	Higher	Lower
Petrol	0.74	85.4	14.6	-	46892	43710
Kerosene	0.79	86.3	13.6	0.1	46180	43166
Diesel oil	0.87	86.3	12.8	0.9	45977	43166
Heavy fuel oil	0.95	86.1	11.8	2.1	45961	41366

Gaseous fuels :-

Natural gas

- ⇒ Natural gas is found in the petroleum under the earth's surface.
- ⇒ It consists of methane (CH_4) and ethane (C_2H_6) together with small amounts of Hydrogen Sulphide, Carbon dioxide and Nitrogen.
- ⇒ Its calorific value is about 21000 kJ/m^3 .

Coal gas

- ⇒ It is obtained by the destructive distillation of bituminous coal in a fireclay retort.
- ⇒ It consists of carbon monoxide, carbon dioxide, hydrogen and methane.
- ⇒ used in boilers, gas engines and also for lighting and heating applications.
- ⇒ Calorific value is about 20110 kJ/m^3 .

Producer gas

- ⇒ Producer gas is obtained by the partial burning of coal or coke in a mixed air stream blast.
- ⇒ It consists of carbon monoxide, hydrogen and nitrogen.
- ⇒ Producer gas is mainly used for power generation in glass melting furnaces.
- ⇒ It has low calorific value due to high nitrogen content.

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L. value kJ/kg	g heat	lower
72	43710	
0	43166	
	43166	
	41366	

⇒ Its calorific value is 50.024 kJ/m^3

Water gas

⇒ It is also called as blue gas

⇒ It consists of carbon monoxide, carbon dioxide, hydrogen and Nitrogen.

⇒ It is used in heating furnaces.

⇒ Its calorific value is about 11700 kJ/m^3

Mond gas

⇒ It is produced by passing air and large amount of steam over waste coal at 650°C

⇒ It is used in power plants, gas engines and furnaces.

⇒ Its calorific value is 6490 kJ/m^3

Coke oven gas

⇒ The coke oven gas is obtained by the carbonization of coal in coke ovens.

⇒ It is also produced as by-product of coke ovens during the production of metallurgical coke.

⇒ It is used for power generation and industrial heating.

⇒ Its calorific value is about 17000 to 19250 kJ/m^3

Advantages

⇒ Easy combustion and better control.

⇒ Minimum air is required for complete combustion

⇒ Can be produced with low grade coal.

⇒ Clean to use and free from impurities.

⇒ Easily conveyed through pipelines

⇒ Burn without smoke.

⇒ Produce no ash.

⇒ They can be used directly in I.C engines.

Disadvantages of gaseous fuels

⇒ Requires large storage tanks.

⇒ Risk of fire and explosion are greater.

⇒ Tendency to leak.

Fuel	Volume analysis (%)						Calorific value kJ/m ³	
	H ₂	CO	CH ₄	C ₂ H ₄	CO ₂	N ₂	Higher	Lower
Coal gas	27	7	48	13	3	2	31950	28970
Producer gas	6	23	3	0.2	5	62	5025	4815
Water gas	49	42	0.5	-	5	3	11765	10802
Mond gas	25	12	4	0.3	16	43	6490	5820
Water gas	50	8	29	4	2	7	21420	19250
blast furnace gas	4	28	-	-	8	60	3440	3200

Merits of liquid fuels over Solid fuels

⇒ Relatively calorific value is high

⇒ Easy handling

⇒ Does not contain ash

⇒ Less space required for storage

⇒ Higher efficiency

⇒ The combustion can be easily controlled.

⇒ Better cleanliness and dust free,

Demerits of liquid fuels over Solid fuels

⇒ The cost of the fuel is high.

⇒ more risk of fire.

⇒ Requires costly containers for storage and trans-

-port.
⇒ may have higher sulphur content.

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merits of gaseous fuels over liquid fuels

- ⇒ The Combustion of fuel can be easily controlled
- ⇒ They are free from impurities.
- ⇒ They do not produce ash or smoke.
- ⇒ They require minimum air for complete Combustion.
- ⇒ They can be easily conveyed through pipe lines to furnaces.

⇒ Risk of fire and explosion are greater.

Demerits of gaseous fuels over liquid fuels

⇒ Requires large storage tanks.

⇒ Risk of fire and explosion are greater.

⇒ Greater tendency to leak.

Heating Values of fuel

⇒ The Calorific value or heat value of a fuel is defined as the total quantity of heat liberated by the complete combustion of unit quantity of fuel.

⇒ The calorific value of solid or liquid fuels is expressed in kJ/kg.

⇒ The calorific value of gaseous fuels is expressed in kJ/m³.

⇒ Thus the calorific value of fuel may be expressed by two values.

* Higher calorific value (H.C.V)

* Lower calorific value (L.C.V)

* Higher calorific value (H.C.V)

⇒ Higher calorific value is defined as the total amount of heat liberated when unit quantity of the fuel is completely burnt and the products of combustion are cooled to the initial temp. at which fuel and air are supplied usually taken as 15°C

Lower Calorific Value (L.C.V)

⇒ L.C.V is defined as the amount of heat liberated by complete combustion of unit quantity of fuel without the condensation of steam formed.

⇒ It is given by the difference betⁿ H.C.V and the latent heat absorbed by the water vapour.

$$L.C.V = H.C.V - m_s L \text{ kJ/kg}$$

where m_s = mass of water vapour formed per kg of fuel burnt = $9H_2$

H_2 = percentage of hydrogen by mass

L = Latent heat of water vapour, corrected for condensing to liquid

⇒ Thus the above equation can be written as $= 2466 \text{ kJ/kg}$

$$L.C.V = H.C.V - m_s 2466 \text{ kJ/kg}$$

$$L.C.V = H.C.V - 9H_2 \times 2466 \text{ kJ/kg}$$

⇒ The value of L depends on temperature. At 25°C its value is taken as 2442 kJ/kg .

Dulong's formula for H.C.V and L.C.V $\downarrow$ 587 calories

⇒ Dulong suggested a formula for the calculation of the calorific value of the solid or liquid fuels from their chemical composition is given below.

$$H.C.V = 33800 C + 144000 \left(H_2 - \frac{O_2}{8} \right) + 9270 S \text{ kJ/kg}$$

where C, H_2, O_2 and S are carbon, hydrogen, oxygen and Sulphur in percentage respectively in kg of fuel.

$$L.C.V = H.C.V - m_s L$$

$$= H.C.V - (9H_2) 2442 \text{ kJ/kg of fuel}$$

Since 1 kg of H_2 forms 9 kg of steam and latent heat of vaporisation of water at standard temp.

15°C is 2466 kJ/kg

* The numerical values 33800, 144000 and 9270 represent heat evolved due to combustion of unit quantity of C, H_2 and Sulphur in kJ/kg

Engine

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Engine fuels

Common fuels used in auto engines are gasoline (Petrol) and diesel.

However other fuels such as alcohol, methanol, benzol, ethanol, liquefied, Petroleum gas (LPG) and compressed natural gas (CNG) are also being used as engine fuels.

Petrol

It is a mixture of hydrocarbons and is obtained by a process called fractional distillation of crude petroleum.

Properties are:-

- ⇒ Cleanliness - good flowability
- ⇒ High volatility i.e., it vaporises quickly
- ⇒ High calorific value
- ⇒ Good anti-knock quality.
- ⇒ Least sulphur content, thus anti corrosive.
- ⇒ Petrol provides better rate of combustion and high velocity flame propagation.
- ⇒ It does not cause gumming effect in engine parts. It mixes very easily with air.

Diesel

It is widely used in heavy duty automobiles because of its cheapness and better thermal efficiency.

As petrol, diesel is also obtained from petroleum. It has a high boiling range. (180°C to 300°C)

It is less volatile than petrol.

It has a calorific value of 40,000 kJ/kg.

Sulphur content in diesel is slightly more than that in gasoline.

Diesel readily ignites in the presence of highly compressed air.

It provides even burning throughout the combustion chamber.

- Alcohol
⇒ It is extracted from wood by the process of distillation.

⇒ It is extracted from alcohol as an additive because of distillation.

- benzol

Benzol
 ⑤ It is obtained by the distillation of coal tar.
 ⑥ It is used as a blending fuel with motor fuel.
 ⑦ It is not used in cold climates due to its high freezing point.

- L. P. G.

⇒ Liquefied of butane and Propane.
⇒ It is extremely economical and modern.
Petrol cars are adopting L.P. Gas as their fuel
thus doing away costly petrol.
⇒ Elimination of fuel pump

- thus doing away costly repairs
- ⇒ Advantages are (i) elimination of fuel pump
(ii) No carbon deposits
(iii) Low specific fuel consumption
(iv) Easy and effective maintenance
⇒ Less engine wear.

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* Compressed natural gas (CNG)

- ⇒ It is the substitute for the fossil fuels like diesel, petrol and propane.
- ⇒ It is made by compressing the natural gas.

Importance of CNG

- ⇒ It is likely less ignitable on hot substance because it has high auto ignition temp. 5400° and small range of flexibility.
- ⇒ It is cheaper than other fuels.
- ⇒ It is dispersed quickly when released.
- ⇒ It is lighter than air.
- ⇒ It releases less carbon into the atm.

Advantages of CNG

- ⇒ Less pollution and more efficiency.
- ⇒ Due to absence of lead, lead fouling of spark plug is eliminated.
- ⇒ Low maintenance cost than other vehicles.
- ⇒ It increases the life of lubricating oils.

Octane number

- ⇒ Fuels differ in their ability to resist the knocking and detonation in S.I. engines.
- ⇒ They are rated in terms of octane number. For this purpose, a standard fuel is chosen with which any given fuel can be compared.
- ⇒ Standard fuel is the combination of iso-octane and n-heptane by volume.
- ⇒ Arbitrarily the iso-octane is assigned a rating of 100 octane number and n-heptane is assigned a rating of zero octane.

- ⇒ It may be noted that iso-octane has minimum knocking tendency and the n-heptane has high tendency to knock.
- ⇒ The percentage volume of iso-octane in the mixture of iso-octane and n-heptane in any given fuel represents octane number.
- ⇒ For example of a given fuel has 80% iso-octane and 20% n-heptane by volume, it is rated as having a knocking rate of 80.
- ⇒ That is octane number of this fuel is 80.
- ⇒ Hence octane number rating of fuel is an expression which indicates the ability of a fuel to resist knocking or detonation in S.I. engines.

Cetane number

- ⇒ Cetane number in the case of diesel fuel is similar to the octane number for gasoline.
- ⇒ It is percentage of cetane in a mixture of cetane and ~~a~~ methyl naphthalene which has the same diesel knock characteristics as the fuel under test.
- ⇒ Cetane number expresses the ignition quality of the diesel fuel.
- ⇒ A fuel with shorter ignition delay period will have higher cetane number and vice versa.
- ⇒ The cetane number affects cold starting, warm up, roughness, acceleration, deposits and exhaust smoky density in a diesel engine.
- ⇒ Most diesel fuels have cetane numbers from 40 to 50.

Rating of fuels for C.I. engines

- ⇒ Increased delay period promotes the phenomenon of knocking in C.I. engines.
- ⇒ When delay period is reduced, the fuel ignites quickly.
- ⇒ Fuels of different chemical composition show different delay tendencies.
- ⇒ Ignition quality of a fuel and its suitability for use in C.I. engines for use in C.I. engines is rated in terms of CETANE number.
- ⇒ The knock rating of a diesel fuel is found by comparing it with a reference fuels.
- ⇒ The reference fuels are normal cetane $C_{16}H_{34}$, which is arbitrarily assigned a cetane number of 100, and alpha methyl naphthalene, $C_{10}H_{10}$ which is assigned a cetane number of 0.
- ⇒ The former has a very good ignition quality and the latter has a poor ignition quality.
- ⇒ The cetane number of a given fuel is defined as the percentage of volume of cetane in a mixture of cetane and alpha methyl naphthalene that produces the same delay periods as the fuel being tested under the same operating conditions on the same engine.
- ⇒ Higher the cetane number, better is the ignition quality of a fuel is more suitable for use in C.I. engines.
- ⇒ Ignition delay being the primary factor in controlling the initial auto ignition in the C.I. engines, it may be concluded that knock should be directly related to the ignition delay of the fuel.

Highest useful compression ratio (HUCR)

→ The highest useful compression ratio is the highest compression ratio at which a fuel can be used without detonation in a specified test engine under specified operating conditions and the ignition and mixture strength adjusted to give best efficiency.

Fuel	C.R
iso-octane	10.96
n-heptane	3.25
Toluene	15
cyclohexane	8.20

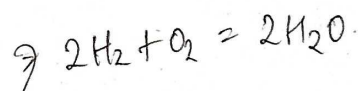
$$HCV = 8080C + 34500\left(H_2 - \frac{O_2}{8}\right) + 2240S \quad \text{Kilo Calorie/kg}$$

Where C = mass of carbon present in 1 kg of fuel
% of carbon

H_2 = mass of Hydrogen present in 1 kg of fuel
% of H_2

O_2 = " " oxygen " " 1 kg of fuel
% of O_2

S = " " Sulphur " " 1 kg of fuel
% of S



⇒ ~~4x1 + 2x16~~

$$\Rightarrow 4x1 + 2x16$$

$$\Rightarrow 4 + 32 = 36$$

IF 4 gm ~~hydrogen~~ ^{water} = 36

$$1 \text{ gm Hydrogen} = \frac{36}{4} = 9 \text{ gm}$$

1 gm oxygen = 8 gm
1 gm Hydrogen = 1 gm

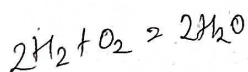
class work

$$\eta = \frac{o/p}{i/p} = \frac{W_{net}}{Q_{input}} = \frac{W_{net}}{H_{AV}} = \frac{Q_{net}}{H_{AV}} = \frac{H_{AV} - H_{RV}}{H_{AV}}$$

$$\Rightarrow 1 - \frac{H_{RV}}{H_{AV}} = 1 - \frac{\int_1^4 C_v dT}{\int_2^3 C_v dT}$$

$$\left(\because \frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} \right) = \frac{1 - \int_1^4 C_v dT}{\int_2^3 C_v dT}$$

$$= \frac{1 - C_v [T]_1^4}{C_v [T]_2^3}$$



$$= \frac{1 - C_v [T_4 - T_1]}{C_v [T_3 - T_2]}$$

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

in terms of T_1

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = R_p^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_2 = T_1 \cdot R_p^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_3}{T_2} = \frac{P_3}{P_2} \Rightarrow T_3 = T_2 \cdot \left(\frac{P_3}{P_2} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_3 = T_2 \left(\frac{P_3}{P_2} \right)^{\frac{\gamma-1}{\gamma}} = T_1 R_p^{\frac{\gamma-1}{\gamma}} \cdot \left(\frac{P_3}{P_2} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} = 1 \Rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$$

$$\Rightarrow T_4 =$$

$$\Rightarrow T_2 = T_1 r^{\gamma-1}$$

$$\Rightarrow \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\Rightarrow T_3 = T_4 r^{\gamma-1}$$

$$\Rightarrow \frac{T_2}{T_1} = r^{\gamma-1} = \frac{T_3}{T_4}$$

~~substituting T_2 and T_3 value in Net cycle~~

$$1 - \frac{T_4 - T_1}{T_3 - T_2}$$

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

$$= 1 - \frac{T_1(n-1)}{T_2(n-1)}$$

$$\Rightarrow 1 - \frac{T_1}{T_2} \Rightarrow 1 - \frac{1}{\frac{T_2}{T_1}}$$

$$\eta_{\text{otto}} = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \Rightarrow 1 - \frac{1}{r^{\gamma-1}}$$

$\eta =$

$=$

$\frac{\text{DTC}}{n}$

$\frac{\eta}{n}$

$$\eta = 1 - \left(\frac{1}{8}\right)^{\gamma-1} = 1 - \left(\frac{1}{8}\right)^{1.4-1}$$

$$= 0.56$$

Diesel cycle

$$\eta = \frac{Q_p}{Q_p} = \frac{W_{net}}{Q_p} = \frac{W_{net}}{W_{Ap}} = \frac{Q_{net}}{W_{Ap}} = \frac{W_{Ap} - W_{Rv}}{W_{Ap}}$$

$$= 1 - \frac{W_{Rv}}{W_{Ap}} = 1 - \frac{\int_1^4 C_v dT}{\int_2^3 C_p dT} = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$\Rightarrow \frac{V_3}{V_2} = (\text{row}) \text{ cutoff ratio} = 1 - \frac{T_4 - T_1}{\gamma(T_3 - T_2)}$$

$$\Rightarrow r = \frac{V_1}{V_2}$$

$$\Rightarrow r_c = \frac{V_4}{V_3} = \frac{V_1}{V_3} \quad \left(\because \frac{V_1}{V_2} = r, \frac{V_1}{V_3} = r_c \right)$$

$$\Rightarrow r_c = \frac{r}{\beta}$$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1} \Rightarrow \boxed{T_2 = T_1 r^{\gamma-1}}$$

$$\Rightarrow \frac{T_3}{T_2} = \left(\frac{V_3}{V_2}\right)^{\gamma-1} = \beta^{\gamma-1} \Rightarrow \boxed{T_3 = T_2 \times \beta^{\gamma-1} = T_1 r^{\gamma-1} \beta^{\gamma-1}}$$

$$\Rightarrow \frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{1}{r_c}\right)^{\gamma-1} = \left(\frac{\beta}{r}\right)^{\gamma-1}$$

Isentropic expansion

(Expansion ratio = r_c)

$$\Rightarrow T_4 = T_3 \left(\frac{\beta}{r}\right)^{\gamma-1}$$

$$= T_1 r^{\gamma-1} \beta^{\gamma-1} \left(\frac{\beta}{r}\right)^{\gamma-1}$$

$$= T_1 \cdot n^{r-1} \cdot s \left(\frac{s}{n} \right)^{r-1}$$

$$\Rightarrow T_4 = T_1 \cdot n^{r-1} \cdot s \cdot \frac{s^{r-1}}{n^{r-1}}$$

$$\Rightarrow T_4 = T_1 \cdot s^{1+r-1}$$

$$\boxed{\Rightarrow T_4 = T_1 \cdot s^r}$$

$$\eta_{\text{Diesel cycle}} \Rightarrow 1 - \frac{T_4 - T_1}{\gamma (T_3 - T_2)}$$

$$\Rightarrow 1 - \frac{(T_1 s^r - T_1)}{\gamma (T_1 n^{r-1} s - T_1 n^{r-1})}$$

$$= 1 - \frac{T_1 (s^r - 1)}{\gamma T_1 n^{r-1} (s - 1)}$$

$$\Rightarrow \frac{1 - (s^r - 1)}{\gamma (n^{r-1} s - n^{r-1})} = \frac{1 - (s^r - 1)}{\gamma n^{r-1} (s - 1)}$$

Dual

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Dual Cycle

$$\eta = \frac{Q/P}{L/P} = \frac{W_{net}}{Q_{i/P}} = \frac{W_{net}}{H_{Ap} + H_{Av}} = \frac{Q_{net}}{H_{Ap} + H_{Av}}$$

$$= \frac{(H_{Ap} + H_{Av}) - H_{Rv}}{H_{Ap} + H_{Av}}$$

$$\Rightarrow 1 - \frac{H_{Rv}}{H_{Ap} + H_{Av}} = 1 - \frac{\int_1^5 C_v dt}{\int_1^3 C_v dt + \int_3^4 C_p dt}$$

$$= \frac{1 - C_v(T_5 - T_1)}{C_v(T_3 - T_1) + C_p(T_4 - T_3)}$$

$$\Rightarrow \eta = \frac{V_1}{V_2}$$

$$\beta = \frac{V_4}{V_3} = \frac{V_4}{V_2}$$

$$\eta_c = \frac{V_5}{V_4} = \frac{V_5/V_2}{V_4/V_2} = \frac{V_1/V_2}{V_4/V_2} = \frac{\eta}{\beta}$$

$$\text{Explosion Ratio} = \alpha = \frac{P_3}{P_2}$$

$$\Rightarrow T_2 = T_1 \eta^{\gamma-1}$$

$$\Rightarrow T_3 = \left(\frac{P_3}{P_2}\right) T_2 = \alpha \cdot T_1 \cdot \eta^{\gamma-1}$$

$$\frac{T_4}{T_3} = \left(\frac{V_4}{V_3}\right) = \beta \cdot \frac{T_1 \cdot \eta^{\gamma-1}}{\alpha \cdot T_1 \cdot \eta^{\gamma-1}}$$

$$\Rightarrow T_4 = \alpha \cdot T_1 \cdot \eta^{\gamma-1} \cdot \beta$$

$$\Rightarrow \frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{\beta}{\eta}\right)^{\gamma-1}$$

$$\Rightarrow T_5 = \alpha \cdot T_1 \cdot \eta^{\gamma-1} \cdot \beta \cdot \left(\frac{\beta}{\eta}\right)^{\gamma-1}$$

$$\Rightarrow T_5 = T_1 \cdot \alpha n^{r-1} \beta \left(\frac{\beta}{n}\right)^{r-1}$$

$$\Rightarrow T_5 = T_1 \cdot \alpha n^{r-1} \beta \left(\frac{\beta^{r-1}}{n^{r-1}}\right)$$

$$\Rightarrow T_5 = T_1 \cdot \alpha \cdot \beta^{r-1}$$

$$T_5 = T_1 \cdot \alpha \cdot \beta^r$$

$$\frac{1 - C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$\eta_{\text{dual}} = \frac{1 - C_v(T_1 \cdot \alpha \cdot \beta^r - T_1)}{C_v(T_1 \cdot \alpha \cdot n^{r-1} \beta - T_1 n^{r-1}) + C_p(T_1 \alpha n^{r-1} \beta - T_1 \alpha n^{r-1})}$$

$$= \frac{1 - C_v T_1 (\alpha \beta^r - 1)}{C_v T_1 (\alpha n^{r-1} \beta - n^{r-1}) + C_p T_1 (\alpha n^{r-1} \beta - \alpha n^{r-1})}$$

$$= \frac{1 - C_v (\alpha \beta^r - 1)}{C_v n^{r-1} (\alpha - 1) + C_p \alpha n^{r-1} (\beta - 1)}$$

$$= \frac{1 - C_v (\alpha \beta^r - 1)}{C_v n^{r-1} (\alpha - 1) + C_p \alpha n^{r-1} (\beta - 1)}$$

$$= \frac{1 - (\alpha \beta^r - 1)}{n^{r-1} (\alpha - 1) + \alpha n^{r-1} (\beta - 1)}$$

$$= \frac{1 - (\alpha \beta^r - 1)}{n^{r-1} [\alpha - 1 + \alpha (\beta - 1)]}$$

$$= \frac{1 - (\alpha \beta^r - 1)}{n^{r-1} [\alpha - 1 + \alpha (\beta - 1)]}$$

$$= \frac{1 - (\alpha \beta^r - 1)}{n^{r-1} [\alpha - 1 + \alpha (\beta - 1)]}$$

$$= 1 - \left[\left(\frac{1}{n} \right)^{r-1} \times \frac{\alpha \beta^r - 1}{(\alpha - 1) + \alpha (\beta - 1)} \right]$$

$$\eta_{\text{otto}} = 1 - \left(\frac{1}{r}\right)^{\gamma-1}$$

$$\eta_{\text{diesel}} = 1 - \frac{(\beta^{\gamma}-1)}{r^{\gamma-1} \gamma (\beta-1)} = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \times \frac{(\beta^{\gamma}-1)}{\gamma(\beta-1)}$$

$$\eta_{\text{dual}} = 1 - \left[\left(\frac{1}{r}\right)^{\gamma-1} \times \frac{\alpha \beta^{\gamma}-1}{(\alpha-1) + \gamma \alpha (\beta-1)} \right]^{\frac{1}{\gamma(\beta-1)}}$$

Carnot cycle (Ideal cycle)

Carnot cycle efficiency is not 100%, but it is maximum efficiency for other cycle

$$Q_{12} = W_{12}$$

$$Q_{1-2} = P_1 V_1 \log_e \left(\frac{V_2}{V_1} \right) = mRT_1 \log_e \left(\frac{V_2}{V_1} \right)$$

$$Q_{2-3} = 0$$

$$r_e = \frac{V_2}{V_1} = \text{expansion ratio}$$

$$Q_{3-4} = P_3 V_3 \log_e \left(\frac{V_3}{V_4} \right) = mRT_3 \log_e \left(\frac{V_3}{V_4} \right)$$

$$\Rightarrow mRT_3 \log_e r_c = \text{Compression ratio} = \frac{V_3}{V_4} \quad (P.V = mRT)$$

$$Q_{4-1} = 0$$

$$T_1 = T_2$$

$$T_3 = T_4$$

$$\begin{aligned} \text{Workdone} &= \text{Heat Supplied} - \text{Heat rejected} \\ &= mRT_1 \log_e(r) - mRT_2 \log_e(r) \end{aligned}$$

$$\text{efficiency of the cycle} = \frac{\text{workdone}}{\text{Heat supplied}}$$

$$\eta_{\text{Carnot}} = \frac{mRT_1 \log_e(r) - mRT_3 \log_e(r)}{mRT_1 \log_e(r)}$$

$$\eta_{\text{Carnot}} = \frac{T_1 - T_3}{T_1}$$

$$= 1 - \frac{T_3}{T_1} = 1 - \frac{T_L}{T_H}$$

Important formula

$$\eta_{\text{otto, diesel, dual}} = 1 - \left\{ \left(\frac{L}{r_c} \right)^{\gamma-1} \times \frac{\alpha \beta - 1}{(\alpha-1) + \alpha \beta (\alpha-1)} \right\}$$

Example - 11.1

Calculate the ideal air-standard cycle efficiency of a petrol engine operating on otto cycle. The cylinder bore is 50mm, a stroke is 75mm and the clearance volume is 21.3 cm³.

Sol $d = 50 \text{ mm} = 5 \text{ cm}$

$L = 75 \text{ mm} = 7.5 \text{ cm}$

$V_c = 21.3 \text{ cm}^3$

$\eta_{\text{otto}} = ?$

$\gamma = 1.4$

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

Scrub Volume
 $= \frac{\pi}{4} \times (5 \text{ cm})^2 \times 7.5 \text{ cm}$
 $= 147.26 \text{ cm}^3$

Total Volume

$V_1 = V_s + V_c$

$= 147.26 + 21.3 = 168.56 \text{ cm}^3$

The compression ratio of the engine

$r_c = \frac{V_1}{V_c} = \frac{168.56 \text{ cm}^3}{21.3 \text{ cm}^3} = 7.913$

$\eta_{\text{otto}} = 1 - \frac{1}{r_c^{\gamma-1}}$
 $= 1 - \frac{1}{(7.913)^{1.4-1}} = 1 - \frac{1}{2.287} = 0.5628$
 $= 56.28\%$

Q2 In an engine working on an ideal Otto cycle, the temperature at the beginning and at the end of compression are 27°C and 327°C . Find the compression ratio and air standard efficiency of the engine.

Sol $T_1 = 27^{\circ}\text{C} = 300\text{K}$
 $T_2 = 327^{\circ}\text{C} = 600\text{K}$

(i) The compression ratio is expressed as $r = \frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}} = \left(\frac{600}{300}\right)^{\frac{1}{1.4-1}} = (2)^{2.5}$

(ii) Thermal efficiency of Otto cycle $\eta_{\text{Otto}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(5.65)^{1.4-1}} = 0.5$
 $\approx 50\%$

Q3 In an air-standard Otto cycle the pressure ratio during the compression is 15. The temperature of air at the beginning of compression is 37°C and maximum temp. attained in the cycle is 1950°C .

Determine (a) compression ratio,
(b) Thermal efficiency of the cycle
(c) work done

Take $\gamma = 1.4$, $C_v = 0.717 \text{ kJ/kg.k}$.

Given $P_2 = 15P_1$ $\gamma = 1.4$
 $T_1 = 37^{\circ}\text{C} = 310\text{K}$
 $T_3 = 1950^{\circ}\text{C} = 2223\text{K}$

Sol Compression ratio

$$r = \frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} = (15)^{\frac{1}{1.4}} = 6.919$$

(ii) Thermal efficiency of the cycle

$$\eta_{\text{otto}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(6.919)^{1.4-1}} = 0.5387 = 53.8\%$$

(iii) Work done

$$T_2 = T_1 r^{\gamma-1} = 310 \times (6.919)^{0.4} = 672 \text{ K}$$

$$q_s = C_v (T_3 - T_2)$$

$$= 0.717 \times (2223 - 672) = 1112 \text{ kJ/kg}$$

$$\text{work done} = \eta_{\text{otto}} \times q_s$$

$$\text{Diesel cycle} = 0.538 \times 1112 = 598.3 \text{ kJ/kg}$$

Ex-1

Determine the air-standard efficiency of the Diesel engine having a cylinder with a bore of 250 mm, a stroke of 375 mm and a clearance volume of 1500 cc, with fuel cutoff occurring at 5% of the stroke. Assume $\gamma = 1.4$.

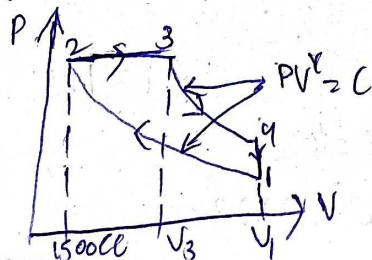
Given $d = 250 \text{ mm} = 25 \text{ cm}$

$$L = 375 \text{ mm} = 37.5 \text{ cm}$$

$$V_c = V_2 = 1500 \text{ cc}$$

$$\gamma = 1.4$$

Fuel cut-off = 5% of stroke



$$V_s = \left(\frac{\pi}{4}\right) d^2 L$$

$$= \left(\frac{\pi}{4}\right) \times (2.5)^2 \times (7.5) = 18408 \text{ cc}$$

$$\text{Total Volume } V_1 = V_s + V_c = 18408 + 1500 = 19908 \text{ cc}$$

$$\text{Compression ratio, } r_c = \frac{V_1}{V_2} = \frac{19908}{1500} = 13.27$$

$$V_3 = V_2 + 0.05 V_s = 1500 + 0.05 \times 18408$$

$$\text{Cut off volume } V_3 = 2420.4$$

$$\text{Cut off ratio } \rho = \frac{V_3}{V_2} = \frac{2420.4}{1500} = 1.613$$

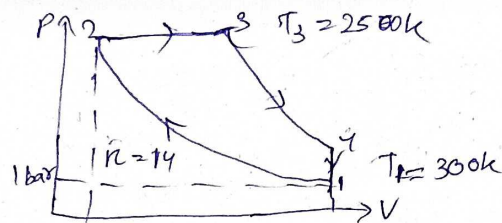
$$\eta_{\text{diesel}} = 1 - \frac{1}{r_c^{\gamma-1}} \left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)} \right]$$

$$= 1 - \frac{1}{(13.27)^{1.4-1}} \times \left[\frac{(1.613)^{1.4}-1}{1.4 \times (1.613-1)} \right]$$

$$= 0.6052 = 60.52\%$$

Q2) An air-standard Diesel cycle has a compression ratio of 14. The pressure at the beginning of the compression stroke is 1 bar and the temp. is 300K. The maximum cycle temperature is 2500K. Determine the cut off ratio and thermal efficiency.

Sol. $T_1 = 300\text{K}$ $P_1 = 1\text{ bar}$
 $r_c = 14$ $T_3 = 2500\text{K}$



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

$$= 300 \times (14)^{1.4-1} = 862.13 \text{ K}$$

(i) The cutoff ratio after constant-pressure heat addition $\beta = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{2500}{862.13}$

(ii) The thermal efficiency of an air standard Diesel cycle.

$$\eta_{\text{Diesel}} = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{\beta^{\gamma}-1}{\gamma(\beta-1)} \right]$$

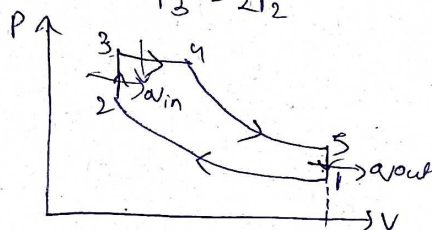
$$= 1 - \frac{1}{(14)^{1.4-1}} \times \left[\frac{2.9^{1.4}-1}{1.4 \times (2.9-1)} \right]$$

$$= 0.55 \text{ or } 55\%$$

Dual Cycle

(1) A high speed oil engine operating on a dual combustion cycle has a pressure of 1 bar and a temperature of 50°C before compression. Air is then compressed isentropically to $1/15^{\text{th}}$ of its original volume. The maximum pressure is twice the pressure at the end of isentropic compression. If the cut-off ratio is 2, determine the temperature at the end of each process and ideal efficiency of the cycle. Take $\gamma = 1.4$.

sol $P_1 = 1 \text{ bar}$ $T_1 = 50^\circ\text{C} = 323 \text{ K}$
 $r = 15$ $\beta = 2$
 $\gamma = 1.4$ $P_3 = 2P_2$



Specific Volume after compression;

$$V_2 = \frac{1}{15} V_1$$

Temperature after the isentropic compression;

$$T_2 = T_1 r^{\gamma-1} = 323 \times (15)^{1.4-1} \\ = 954.2 \text{ K or } 681.2^\circ\text{C}$$

$$P_2 = P_1 r^\gamma \\ = 1 \text{ bar} \times (15)^{1.4} = 44.312 \text{ bar}$$

$$T_3 = \left(\frac{P_3}{P_2}\right) T_2 = 2 \times 954.2 \\ = 1908.4 \text{ K or } 1635.4^\circ\text{C}$$

$$P_3 = P_{\text{max}} = 2P_2 = 2 \times 44.312 = 88.625 \text{ bar}$$

$$T_4 = \beta T_3 = 2 \times 1908.4 \\ = 3816.8 \text{ K or } 3543.8^\circ\text{C}$$

$$T_3 = T_4 \left(\frac{\beta}{r}\right)^{\gamma-1} \\ = 3816.8 \times \left(\frac{2}{15}\right)^{1.4-1} \\ = 1704.8 \text{ K or } 1431.8^\circ\text{C}$$

$$(ii) q_{in} = C_v (T_3 - T_2) + C_p (T_4 - T_3)$$

$$q_{out} = C_p (T_5 - T_1)$$

$$\eta_{diesel} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{C_p (T_5 - T_1)}{C_v (T_3 - T_2) + C_p (T_4 - T_3)}$$

$$= 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)}$$

$$= 1 - \frac{1794.8 - 323}{(1908.4 - 954.2) + 1.4 \times (3816.8 - 1982)}$$

$$= 0.6189 \text{ or } 61.9\%$$

Diesel cycle (3)

A Diesel engine has a compression ratio 18 and cut off takes place at 5% of the stroke calculate the air standard efficiency. Take $\gamma = 1.4$.

Sol $r = 18$

Cut off = 0.05 of stroke

$$\gamma = 1.4$$

$$R = \frac{V_1}{V_2}$$

$$\Rightarrow r = RV_2$$

$$= 18V_2$$

Swept volume

$$V_s = V_1 - V_2 = 18V_2 - V_2 = 17V_2$$

Cut off volume

$$V_3 = V_2 + 0.05V_s$$

$$\Rightarrow V_2 + 0.05 \times 17V_2 = 1.85V_2$$

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cut off ratio $r = \frac{V_1}{V_2} = 1.85$

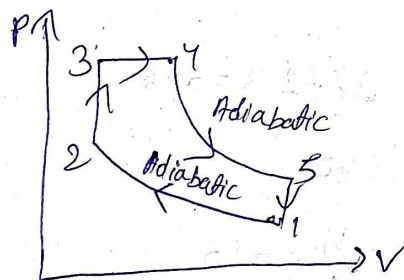
$\eta_{\text{diesel}} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{\beta^{\gamma}-1}{\gamma(\beta-1)} \right]$
 $= 1 - \frac{1}{(1.8)^{1.4-1}} \times \left[\frac{(1.85)^{1.4}-1}{1.4 \times (1.85-1)} \right]$
 $= 0.6387 \text{ or } 63.87\%$

Dual cycle

- (2) An oil engine working on the dual combustion cycle has a compression ratio 14 and the explosion ratio obtained from an indicator card is 1.4. If the cut-off occurs at 6% of stroke, find the ideal efficiency. Take γ for air = 1.4.

Given data

Compression ratio, $r = 14$
 Explosion ratio, $\beta = 1.4$



If β is the cut off ratio, then

$$\frac{\beta-1}{r-1} = \frac{6}{100} = 0.06$$

$$\therefore \beta = 1.78$$

$$\text{Ideal efficiency } \eta_{\text{dual}} = 1 - \frac{1}{n^{\gamma-1}} \left[\frac{\beta \cdot \beta^{\gamma} - 1}{(\beta - 1) + \beta \gamma (\beta - 1)} \right]$$

$$= 1 - \frac{1}{(1.4)^{1.4-1}} \left[\frac{1.4 \times (1.78)^{1.4} - 1}{(1.4 - 1) + 1.4 \times 1.4 (1.78 - 1)} \right]$$

$$= 1 - 0.348 \left[\frac{3.138 - 1}{0.4 + 1.528} \right]$$

$$\eta_{\text{dual}} = 0.614 \text{ or } 61.4\%$$

Q(3) In an I.C engine operating on dual cycle the temp. of the working fluid at the beginning of compression is 27°C . The ratio of the max and min. pressures of the cycle is 70 and compression ratio is 15. The amounts of heat added at constant volume and at constant pressure are equal. Compute the air standard thermal efficiency of the cycle. Take γ for air = 1.4.

Given data

$$T_1 = 27 + 273 = 300\text{K}$$

$$\frac{P_3}{P_1} = 70$$

$$\frac{V_1}{V_2} = \frac{V_1}{V_3} = 15$$

Consider 1 kg of air

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} = (15)^{1.4-1} = 2.954$$

$$T_2 = 300 \times 2.954 = 886.2\text{K}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\gamma = (11.3)^{1.4}$$

$$\Rightarrow P_2 = 49.2 P_1$$

constant pressure $\frac{P_2}{P_1} = \frac{V_2}{V_1}$

$$T_3 = T_2 \times \frac{V_2}{V_1}$$

$$= 886.2 \times 70 P_1 = 1400 K$$

$$\Rightarrow C_V (T_3 - T_2) = C_P (T_4 - T_3)$$

$$\Rightarrow T_3 - T_2 = \gamma (T_4 - T_3)$$

$$\Rightarrow T_4 = T_3 + \frac{T_3 - T_2}{\gamma}$$

$$= 1400 + \frac{1400 - 886.2}{1.4}$$

$$= 1767 K$$

Constant Volume: $\frac{V_3}{T_3} = \frac{V_4}{T_4} \Rightarrow \frac{V_4}{V_3} = \frac{T_4}{T_3}$

$$= \frac{1767}{1400} = 1.26$$

$$\frac{V_4}{V_3} = \frac{V_4}{(V_1/15)} = 1.26$$

$$\Rightarrow V_4 = 0.084 V_1$$

$$\Rightarrow V_5 = V_1$$

Adiabatic expansion: $\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1} = \left(\frac{V_1}{0.084 V_1}\right)^{1.4}$

$$= 2.69$$

$$T_5 = \frac{T_4}{2.69} = \frac{1767}{2.69} = 656.9 \text{ K}$$

$$\begin{aligned} \Rightarrow \eta_{\text{air standard}} &= 1 - \frac{C_v (T_5 - T_1)}{C_v (T_3 - T_2) + C_p (T_4 - T_3)} \\ &= 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)} \\ &= 1 - \frac{656.9 - 300}{(1400 - 886.2) + 1.4(1767 - 1400)} \end{aligned}$$

$$\Rightarrow \eta_{\text{dual}} = 0.653 \text{ or } 65.3\%$$

(9) The swept volume of a diesel engine working on dual cycle is 0.0053 m^3 and clearance volume is 0.00035 m^3 . The maximum pressure is 65 bar , fuel injection ends at 5% of the stroke. The temp. and pressure at the start of the compression are 80°C and 0.9 bar . Determine the air standard efficiency of the cycle. Take γ for air 1.4 .

Given Swept Volume, $V_s = 0.0053 \text{ m}^3$

Clearance Volume, $V_c = V_3 = V_2 = 0.00035 \text{ m}^3$

Maximum pressure, $P_3 = P_4 = 65 \text{ bar}$

Initial temp. $T_1 = 80 + 273 = 353 \text{ K}$

Initial pressure, $P_1 = 0.9 \text{ bar}$

$\eta_{\text{dual}} = ?$

$$\eta_{\text{dual}} = 1 - \frac{1}{(\gamma)^{\gamma-1}} \left[\frac{\beta \cdot \gamma - 1}{(\beta - 1) + \beta \gamma (\gamma - 1)} \right] \quad \text{--- (i)}$$

$$\text{Compression ratio } r = \frac{V_1}{V_2} = \frac{V_s + V_c}{V_c}$$

$$= \frac{0.0053 + 0.00035}{0.00035}$$

$$r = 16.14$$

Cut off ratio

$$\beta = \frac{V_4}{V_3} = \frac{\frac{5}{100} V_s + V_c}{V_c} = \frac{0.05 V_s + V_c}{V_c}$$

$$\Rightarrow \beta = \frac{0.05 \times 0.0053 + 0.00035}{0.00035} = 1.757$$

$$= 1.76$$

Compression operation

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^\gamma = (16.14)^{1.4}$$

$$= 99.14$$

$$P_2 = P_1 \times 99.14$$

$$\Rightarrow 0.9 \times 99.14 = 89.22 \text{ bar}$$

Pressure or explosion ratio

$$\beta = \frac{P_3}{P_2} = \frac{65}{49.22} = 1.47$$

Put the value eqn(i)

$$\eta_{\text{dual}} = 1 - \frac{1}{(16.14)^{1.4-1}} \left[\frac{1.47 \times (1.76)^{1.4} - 1}{(1.47-1) + 1.4(1.76-1)} \right]$$

$$= 1 - \left[\frac{3.243-1}{0.47+1.564} \right] = 0.6383 \text{ or } 63.83\%$$

$$\Rightarrow \eta_{\text{dual}} = 0.6383 \text{ or } 63.83\%$$

fuel can be ^{fuel} substance which a burning of oxygen in the atmospheric air produces a large amount ~~heat~~ heat.
→ most of the fuel contains carbon and hydrogen as main constituents. So these are known as hydrocarbon fuel.

→ Calorific Value is defined as the amount of heat ~~to be~~ produced by complete combustion of 1 kg of fuel. S.I unit kJ/kg

① H.C.V = Gross calorific value

L.C.V = Net calorific value

→ In case of gaseous fuel unit of calorific value is kJ/m^3

Carnot cycle Problem Assignment

Q1 A Carnot engine working between 650K and 310K, produces 150kJ of work. Find thermal efficiency and heat added during the process.

Sol Given $T_1 = 650\text{K}$

$$T_3 = 310\text{K}$$

$$W = 150\text{kJ}$$

$$\eta_{\text{Carnot}} = \frac{T_1 - T_3}{T_1} = \frac{650 - 310}{650} = 1 - \frac{310}{650} = 0.523$$

$$= 52.3\%$$

Heat added during the process

$$Q_{1-2} = \frac{W}{\eta} = \frac{150}{0.523} = 286.8\text{kJ}$$

Q2 A Carnot engine operates between two reservoirs at temperatures T_1 and T_3 . The work output of the engine is 0.6 times the heat rejected. The difference in temp. between the source and the sink is 200°C . Calculate the thermal efficiency, source temp. and the sink temp.

Sol Given $W = 0.6 \times \text{Heat rejected} = 0.6Q_{3-4}$

$$T_1 - T_3 = 200^\circ\text{C}$$

Thermal efficiency:-

$$\eta = \frac{\text{Workdone}}{\text{Heat Supplied}} = \frac{\text{Workdone}}{\text{Workdone} + \text{Heat rejected}}$$

$$= \frac{0.6}{0.6 + 1} = \frac{0.6}{1.6} = 0.375 \text{ or } 37.5\%$$

$$\eta = 0.375 = \frac{T_1 - T_3}{T_1} = \frac{200}{T_1}$$

$$T_1 = 200 / 0.375 = 533.3\text{K} = 260.3^\circ\text{C}$$

$$T_3 = T_1 - 200 = 260.3 - 200 = 60.3^\circ\text{C}$$

(3) An engineer claims his engine to develop 3.75 kW. on testing, the engine consumes 0.44 kg of fuel per hour having a calorific value of 42,000 kJ/kg. The maximum temperature recorded in the cycle is 1400°C and minimum is 350°C. Find whether the engineer is justified in his claim.

Sol Given $P = 3.75 \text{ kW}$

fuel consumed = 0.44 kg/h

Calorific value = 42000 kJ/kg

$$T_1 = 1400^\circ\text{C} = 1400 + 273 = 1673 \text{ K}$$

$$T_3 = 350^\circ\text{C} = 350 + 273 = 623 \text{ K}$$

$$\eta_{\text{Carnot}} = \frac{T_1 - T_3}{T_1} = \frac{1673 - 623}{1673} = 0.627 \text{ or } 62.7\%$$

The heat supplied to the engine by the fuel
 $= \text{Fuel consumed} \times \text{Calorific value of fuel}$
 $= 0.44 \times 42000 = 18,480 \text{ kJ/h} = 5.13 \text{ kW}$

and work done by the engine = 3.75 kW

$$\therefore \text{Efficiency claimed} = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{3.75}{5.13} = 0.731 \text{ or } 73.1\%$$

(4) What is the maximum percentage of heat that can be converted into work by a heat engine, when the heat is available at 127°C and the atmospheric temp. is 27°C?

Sol Given Heat available temp. = $T_H = 127^\circ\text{C}$

$$T_H = 127 + 273 = 400 \text{ K}$$

Atmosphere

Temperature

(5) The air is at 10°C and 11

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Atmospheric temperature :- $T_L = 27^\circ\text{C}$
 $= 27 + 273 = 300\text{K}$

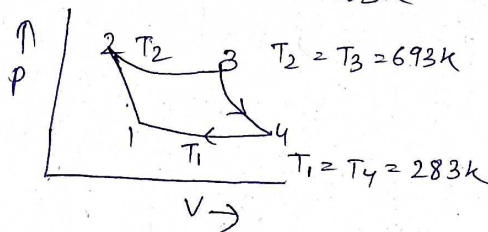
$$\eta_{\text{Carnot}} = \frac{T_H - T_L}{T_H} = \frac{400 - 300}{400} = 0.25 \text{ or } 25\%$$

5) The temp. limits for a Carnot cycle using air as a working substance are 420°C and 10°C . Calculate the efficiency of the cycle and ratio of adiabatic expansion. Take $\gamma = 1.4$ for air.

Given

$$\text{max. } T_H = 420^\circ\text{C} = 420 + 273 = 693\text{K}$$

$$\text{min. } T_L = 10^\circ\text{C} = 10 + 273 = 283\text{K}$$



$$\eta_{\text{Carnot}} = \frac{T_H - T_L}{T_H} = \frac{T_2 - T_4}{T_2} = \frac{693 - 283}{693} = 0.5916 \text{ or } 59.16\%$$

adiabatic expansion process 3-4,

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$\Rightarrow T_3 = T_2 ; T_4 = T_1$$

$$\Rightarrow \frac{T_2}{T_1} = (r)^{\gamma-1}$$

$$\text{Expansion ratio, } r = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}} = \left(\frac{693}{283}\right)^{\frac{1}{1.4-1}} = 9.38$$

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OTTO cycle

- ① In an Otto cycle, the temperature at the beginning and end of the isentropic compression are 316 K and 596 K respectively. Determine the air standard efficiency and the compression ratio. Take $\gamma = 1.4$.

Sol $T_3 = 316 \text{ K}$ $\gamma = 1.4$
 $T_4 = 596 \text{ K}$ $r = \frac{V_3}{V_4}$

Isentropic compression 3-4

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} = \frac{1}{(r)^{0.4}}$$

$$= (r)^{0.4} = \frac{T_4}{T_3} \quad \text{or} \quad r = \left(\frac{T_4}{T_3}\right)^{\frac{1}{0.4}} = \left(\frac{596}{316}\right)^{2.5}$$

$$= 4.885$$

air standard efficiency

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(4.885)^{1.4-1}} = 1 - \frac{1}{1.886}$$

$$= 1 - 0.53$$

$$= 0.47 \text{ or } 47\%$$

- ② An engine, working on the Otto cycle, has a cylinder diameter of 150 mm and a stroke of 225 mm. The clearance volume is ~~1.25~~ $1.25 \times 10^{-3} \text{ m}^3$. Find the air standard efficiency of this engine. Take $\gamma = 1.4$

Given $d = 150 \text{ mm} = 0.15 \text{ m}$

$$l = 225 \text{ mm} = 0.225 \text{ m}$$

$$V_c = 1.25 \times 10^{-3} \text{ m}^3$$

$$\gamma = 1.4$$

$$V_3 = 1$$

$$r =$$

$$\eta =$$

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$$V_s = \frac{\pi}{4} \times d^2 \times l = \frac{\pi}{4} (0.15)^2 (0.225) = 3.976 \times 10^{-3} \text{ m}^3$$

$$r = \frac{V_c + V_s}{V_c} = \frac{1.25 \times 10^{-3} + 3.976 \times 10^{-3}}{1.25 \times 10^{-3}} = 4.18$$

we know that air standard efficiency

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(4.18)^{1.4-1}} = 1 - \frac{1}{1.772} = 1 - 0.564 = 0.436$$

(3) A certain quantity of air at a pressure of 1 bar and temperature 70°C is compressed reversibly and adiabatically until the pressure is 7 bar in an Otto cycle engine. 460 kJ of heat per kg of air is now added at constant volume. determine: ~~ratio~~

- (1) Compression ratio of the engine
- (2) Temperature at the end of compression
- (3) Temperature at the end of heat addition.

Take for air, $C_p = 1 \text{ kJ/kg K}$ and $C_v = 0.707 \text{ kJ/kg K}$

Sol Given: $P_3 = 1 \text{ bar}$

$$T_3 = 70^\circ\text{C} = 70 + 273 = 343 \text{ K}$$

$$P_4 = 7 \text{ bar}$$

$$Q_{4-1} = 460 \text{ kJ}$$

$$m = 1 \text{ kg}$$

$$C_p = 1 \text{ kJ/kg K}$$

$$C_v = 0.707 \text{ kJ/kg K}$$

That ratio of specific heats,

$$\gamma = C_p / C_v = \frac{1}{0.707} = 1.41$$

① Compression ratio

$$r = V_3/V_4$$

$$P_3 V_3^\gamma = P_4 V_4^\gamma$$

$$\frac{V_3}{V_4} = \left(\frac{P_4}{P_3}\right)^{\frac{1}{\gamma}} \text{ or } r = \left(\frac{7}{1}\right)^{\frac{1}{1.41}} = (7)^{0.709} = 3.97$$

(ii) Temp. at the end of compression

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{1}{r}\right)^{\gamma-1} = \left(\frac{1}{3.97}\right)^{1.41-1} = (0.252)^{0.41} = 0.568$$

$$T_4 = \frac{T_3}{0.568} = \frac{343}{0.568} = 604 \text{ K} = 331^\circ\text{C}$$

(iii) Temp. at the end of heat addition

$$Q_{4-1} = 460$$

$$Q_{4-1} = 460 = m c_v (T_1 - T_4)$$

$$= 1 \times 0.707 (T_1 - 604) \text{ kJ}$$

$$T_1 - 604 = \frac{460}{0.707} = 651 \text{ or } T_1 = 1255 \text{ K} = 982^\circ\text{C}$$

④ In an Otto cycle operation the compression ratio is changed from 4.5 to 8.5. determine the increase in air standard efficiency of the cycle

sol given $r_1 = 4.5$

$$r_2 = 8.5$$

$$\eta_2 = \eta_1 = ?$$

$$\eta_1 = 1 - \frac{1}{(r_1)^{\gamma-1}} = 1 - \frac{1}{(4.5)^{1.41-1}} = 0.4521 \text{ or } 45.21\%$$

$$= 3.97$$

Stroke

$$\frac{1.4}{1.4-1}$$

$$)^{0.4} = 0.568$$

31°C

ation

4) n_2

$$T_1 = 1255K$$

$$T_2 = 982^\circ C$$

increase
cycle

T

$$45.21\%$$

$$\eta_2 = 1 - \frac{1}{(r^2)^{\gamma-1}} = 1 - \frac{1}{(8.5)^{1.4-1}}$$

$$= 0.5752 \text{ or } 57.52\%$$

$$\text{increase efficiency} = \eta_2 - \eta_1$$

$$= 57.52 - 45.21$$

$$= 12.31\%$$

5) An engine working on Otto cycle has an efficiency of 51%. It has a stroke length of 150mm and diameter of 100mm. Find the clearance volume of the engine?

Given $\eta = 51\%$,

Piston diameter, $d = 100\text{mm} = 0.1\text{m}$.

Stroke, $l = 150\text{mm} = 0.15\text{m}$

$$\gamma = 1.4$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$\Rightarrow 0.51 = 1 - \frac{1}{r^{1.4-1}}$$

$$\Rightarrow 1 - \frac{1}{r^{0.4}} = 0.51$$

$$\Rightarrow \frac{1}{r^{0.4}} = 1 - 0.51$$

$$= 0.49$$

$$\Rightarrow r^{0.4} = \frac{1}{0.49}$$

$$= 2.04$$

$$\Rightarrow r = (2.04)^{\frac{1}{0.4}} = 5.94$$

Stroke volume, $V_s = \frac{\pi d^2 \cdot l}{4}$

$$= \frac{\pi \times (0.1)^2 \times 0.15}{4}$$

$$\Rightarrow \frac{\pi \times 0.01 \times 0.15}{4}$$

$$V_s = 0.0018\text{m}^3$$

Compression ratio,

$$r = \frac{V_s + V_c}{V_c} = 5.94$$

$$5.94 V_c = 0.0018 + V_c$$

clearance volume

$$V_c = \frac{0.0018}{4.94}$$

$$= 0.000239\text{m}^3$$

Diesel cycle

- ① Find the air standard efficiency of a diesel cycle engine if the cut off is 6% of the stroke and clearance is $\frac{1}{13}$ th of the stroke.

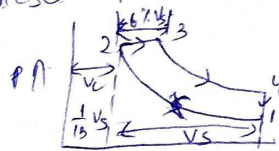
Take $\gamma = 1.4$

Given cut-off = 6% V_s

$$\text{Cut-off volume, } V_3 = V_c + 6\% V_s \\ = V_c + 0.06 V_s$$

$$\text{Clearance volume, } V_c = \frac{1}{13} V_s$$

$$\eta_{\text{diesel}} = ?$$



$$\text{clearance volume, } V_c = V_2 = \frac{1}{13} V_s$$

$$\begin{aligned} \text{Compression ratio } r &= R = \frac{V_1}{V_2} = \frac{V_c + V_s}{V_c} \\ &= \frac{\frac{1}{13} V_s + V_s}{\frac{1}{13} V_s} \\ &= \frac{V_s \left(\frac{1}{13} + 1 \right)}{\frac{1}{13} V_s} = \frac{\left(\frac{14}{13} \right)}{\left(\frac{1}{13} \right)} \\ &= 14 \end{aligned}$$

Cut off ratio

$$\begin{aligned} \beta &= \frac{V_3}{V_2} = \frac{V_c + 0.06 V_s}{V_c} \\ &= \frac{\frac{1}{13} V_s + 0.06 V_s}{\frac{1}{13} V_s} \end{aligned}$$

7 of a
6% of
the stroke

$$= \frac{V_s \left(\frac{1}{13} + 0.06 \right)}{V_s \left(\frac{1}{13} \right)}$$

$$\Rightarrow \rho = 13 \left(\frac{1}{13} + 0.06 \right) = 1.78$$

$$\Rightarrow \eta_{\text{diesel}} = 1 - \frac{1}{\gamma(\rho)^{\gamma-1}} \left[\frac{\rho^{\gamma}-1}{\rho-1} \right]$$

$$= 1 - \frac{1}{1.4 \times (1.78)^{1.4-1}} \times \left[\frac{(1.78)^{1.4}-1}{1.78-1} \right]$$

$$= 0.6043 \text{ or } 60.43\%$$

(2) In an engine working on a diesel cycle has compression ratio of 15:1 and expansion ratio 8:1 the pressure and temp. at beginning of compression are 2 bar and 50°C respectively pressure before the heat rejection is 4 bar.

Determine

- (i) Air standard efficiency of the cycle
- (ii) maximum temp. and pressure in the cycle.

Assume $\gamma = 1.4$

Sol Given $r = \frac{V_1}{V_2} = 15$

expansion ratio $\Rightarrow r_e = \frac{V_4}{V_3} = 8$

$P_1 = 2 \text{ bar}$

$T_1 = 50 + 273 = 323 \text{ K}$

Heat rejection $= 4 \text{ bar}$

$\gamma = 1.4$

$$= \left(\frac{\frac{14}{13}}{\frac{1}{13}} \right)$$

= 14

$$\eta_{\text{diesel}} = 1 - \frac{1}{r(r)^{\gamma-1}} \left[\frac{\beta^{\gamma}-1}{\beta-1} \right]$$

$$\Rightarrow \beta = \frac{r_c}{r_e} = \frac{15}{8} = 1.875$$

$$= 1 - \frac{1}{1.4(15)^{1.4-1}} \left[\frac{(1.875)^{1.4}-1}{1.875-1} \right]$$

$$\eta_{\text{diesel}} = 0.61 = 61\%$$

maximum temp. and pressure.
(P.V relation)

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^{\gamma}$$

$$P_2 = 2 \times (1.5)^{1.4}$$

$$= 88.66 \text{ bar}$$

T-S relation

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1}$$

$$T_2 = 323 (15)^{1.4-1}$$

$$T_2 = 954.2 \text{ K}$$

from process 2-3

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \beta$$

$$T_3 = T_2 \beta$$

$$= 954.2 \times 1.875$$

$$= 1789.12 \text{ K}$$

$$\text{maximum temp} = 1789.12 \text{ K}$$

$$\text{maximum pressure} = 88.66 \text{ bar}$$

(3)

r

8

e

So

4
-1
-1

(3) In a diesel engine, the compression ratio is 13:1 and the fuel is cut off at 8% of the stroke, find the air standard efficiency of the engine. Take $\gamma = 1.4$

Sol Given $r = \frac{V_4}{V_1} = 13$

$\gamma = 1.4$

Volume cut off $= V_2 = V_1 + 8\% (V_4 - V_1)$
 $= V_1 + 0.08(V_4 - V_1)$

Clearance volume $V_1 = 1 \text{ m}^3$

$V_4 = 13 \text{ m}^3$ ($\because \frac{V_4}{V_1} = 13$)

Stroke volume $V_4 - V_1 = 13 - 1 = 12 \text{ m}^3$

Volume at cut-off

$V_2 = V_1 + 0.08(V_4 - V_1)$
 $= 1 + 0.08 \times 12 = 1.96 \text{ m}^3$

Cut off ratio $\beta = \frac{V_2}{V_1} = \frac{1.96}{1} = 1.96$

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{\beta^{\gamma}-1}{\gamma(\beta-1)} \right]$$

$$= 1 - \frac{1}{(13)^{1.4-1}} \left[\frac{(1.96)^{1.4}-1}{1.4(1.96-1)} \right]$$

$$= 1 - 0.417 = 0.583 \text{ or } 58.3\%$$

(4) In an ideal diesel cycle, the temp. at the beginning and end of compression are 57°C and 603°C respectively. The temp. at the beginning and end of expansion are 1950°C and 870°C respectively. Determine the ideal efficiency of the cycle $\gamma = 1.4$
 If the compression ratio is 14 and the pressure at the beginning of the compression is 1 bar. Calculate the maximum pressure in the cycle

Sol Given $T_4 = 57^\circ\text{C} = 57 + 273 = 330\text{K}$
 $T_1 = 603^\circ\text{C} = 603 + 273 = 876\text{K}$
 $T_2 = 1950^\circ\text{C} = 1950 + 273 = 2223\text{K}$
 $T_3 = 870^\circ\text{C} = 870 + 273 = 1143\text{K}$
 $\gamma = 1.4$
 $r = \frac{V_4}{V_1} = 14$
 $P_4 = 1\text{ bar}$

Ideal efficiency of the cycle

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

$$= 1 - \frac{1}{1.4} \left(\frac{1143 - 330}{2223 - 876} \right)$$

$$= 1 - 0.431 = 0.569 \text{ or } 56.9\%$$

Let reversible adiabatic compression,

$$P_1 V_1^\gamma = P_4 V_4^\gamma$$

$$P_1 = P_4 \left(\frac{V_4}{V_1} \right)^\gamma = 1 (14)^{1.4} = 40.23 \text{ bar}$$

(5) An ideal Diesel engine has a diameter 150mm and stroke 200mm. The clearance volume is 10 percent of the swept volume. Determine the compression ratio and the air standard efficiency of the engine if the cut-off takes place at 6 percent of the stroke.

Sol Given $d = 150\text{mm} = 0.15\text{m}$
 $l = 200\text{mm} = 0.2\text{m}$
 $V_c = 10\% \text{ of } V_s$
 $= 0.1 V_s$

330k
823k
2223k
= 1143k

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Compression Ratio

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

$$= \frac{\pi}{4} (0.15)^2 \times 0.2$$

$$= 3.53 \times 10^{-3} \text{ m}^3$$

$$V_c = 0.1 V_s = 0.1 \times 3.53 \times 10^{-3}$$

$$= 0.353 \times 10^{-3} \text{ m}^3$$

Compression ratio

$$\eta = \frac{V_c + V_s}{V_c} = \frac{0.353 \times 10^{-3} + 3.53 \times 10^{-3}}{0.353 \times 10^{-3}}$$

Efficiency

= 11

Volume at cut off Since cut off takes place at 6%

$$V_2 = V_1 + 0.06 V_s$$

$$= V_c + 0.06 V_s$$

$$= 0.353 \times 10^{-3} + 0.06 \times 3.53 \times 10^{-3}$$

$$= 0.565 \times 10^{-3} \text{ m}^3$$

$$\text{Cut off ratio } \gamma = \frac{V_2}{V_1} = \frac{V_2}{V_c} = \frac{0.565 \times 10^{-3}}{0.353 \times 10^{-3}}$$

$$= 1.6$$

$$\eta = 1 - \frac{1}{(\gamma)^{\gamma-1}} \left[\frac{\beta^{\gamma}-1}{\gamma(\beta-1)} \right]$$

$$= 1 - \frac{1}{(1.6)^{1.4-1}} \left[\frac{(1.6)^{1.4}-1}{1.4(1.6-1)} \right]$$

$$= 1 - \frac{1}{2.61} \times 1.11 = 1 - 0.4246$$

$$= 0.5753 \text{ or } 57.53\%$$

Dual cycle

① An oil engine, working on the dual combustion cycle, has a compression ratio 10 and cutoff takes place at $1/10$ of the stroke. If the pressure at the beginning of compression is 1 bar and maximum pressure 40 bar, determine the air standard efficiency of the cycle. Take $\gamma = 1.4$

Sol given $r = \frac{V_4}{V_5} = 10$

cutoff = $\frac{1}{10}$ of stroke

$P_4 = 1 \text{ bar}$

$P_1 = P_2 = 40 \text{ bar}$

$\gamma = 1.4$

Volume at cut-off,

$V_2 = V_1 + \frac{1}{10} \text{ of stroke volume}$

$= V_1 + \frac{1}{10} (V_4 - V_1)$

$= V_5 + 0.1 (V_4 - V_5)$

Cut-off ratio, $\rho = \frac{V_2}{V_5} = 1 + 0.1 \left(\frac{V_4}{V_5} - 1 \right)$

($\therefore$ Dividing both side by V_5) $= 1 + 0.1 (10 - 1) = 1.9$

Isentropic Compression process 4-5

$P_4 V_4^\gamma = P_5 V_5^\gamma$

$P_5 = P_4 \left(\frac{V_4}{V_5} \right)^\gamma = 1 (10)^{1.4} = 25.12 \text{ bar}$

Pressure Ratio $\alpha = \frac{P_1}{P_5} = \frac{40}{25.12} = 1.59$

$\eta =$

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$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{\alpha p r - 1}{(\alpha-1) + \gamma \alpha (\beta-1)} \right]$$

$$= 1 - \frac{1}{(10)^{1.4-1}} \left[\frac{1.59(1.9)^{1.4} - 1}{(1.59-1) + 1.4 \times 1.59(1.9-1)} \right]$$

$$= 1 - \frac{1}{2.512} \left[\frac{3.9-1}{0.59+2} \right] = 1 - 0.446 = 0.554$$

or 55.4%

(2) In a compression ignition engine working on a dual combustion cycle, pressure and temp. at the start of compression are 1 bar and 300K respectively. At the end of compression, pressure reaches a value of 25 bar. 420 kJ of heat is supplied per kg of air during constant volume heating and pressure becomes 2.86 bar at the end of isentropic expansion. Estimate the ideal thermal efficiency.

Sol. Take $C_p = 1.005 \text{ kJ/kgK}$ and $C_v = 0.712 \text{ kJ/kgK}$

Given $P_1 = 1 \text{ bar}$

$T_1 = 300 \text{ K}$

$P_5 = 25 \text{ bar}$

$Q_{5-1} = 420 \text{ kJ/kg}$

$P_3 = 2.86 \text{ bar}$

$C_p = 1.005 \text{ kJ/kgK}$

$C_v = 0.712 \text{ kJ/kgK}$

Ratio of specific heats

$$\gamma = \frac{C_p}{C_v} = \frac{1.005}{0.712} = 1.4$$

Isentropic compression process 1-2

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

5.12 bar

5.9

Compression Ratio,

$$r = \frac{V_1}{V_5} = \left(\frac{P_5}{P_1}\right)^{\frac{1}{\gamma}} = \left(\frac{25}{1}\right)^{\frac{1}{1.4}} = (25)^{0.714} = 9.96$$

$$\Rightarrow \frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = (9.96)^{1.4-1} = 2.5$$

$$\Rightarrow T_5 = T_4 \times 2.5 = 300 \times 2.5 = 750 \text{ K}$$

Constant Volume heating process 5-1

$$420 = m c_v (T_1 - T_5) = 1 \times 0.712 (T_1 - 750)$$

$$T_1 - 750 = \frac{420}{0.712} = 590$$

$$T_1 = 590 + 750 = 1340 \text{ K}$$

Pressure ratio

$$\alpha = \frac{P_1}{P_5} = \frac{T_1}{T_5} = \frac{1340}{750} = 1.787$$

$$P_1 = P_5 \times 1.787 = 25 \times 1.787 = 44.7 \text{ bar}$$

Isentropic expansion 2-3

$$P_2 V_2^\gamma = P_3 V_3^\gamma$$

$$\Rightarrow \frac{V_2}{V_3} = \left(\frac{P_3}{P_2}\right)^{\frac{1}{\gamma}} = \left(\frac{2.8}{44.7}\right)^{\frac{1}{1.4}} = 0.138 \quad (\because P_2 = P_1)$$

$$\text{Cut off ratio } f = \frac{V_2}{V_1} = \frac{V_2}{V_5}$$

$$(\because V_1 = V_5 \text{ and } V_3 = V_4) = \frac{V_2}{V_3} \times \frac{V_3}{V_5} = \frac{V_2}{V_3} \times \frac{V_4}{V_5}$$

$$= 0.138 \times 9.96 = 1.37$$

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{\alpha \beta^{\gamma-1}}{(\alpha-1) + \gamma \alpha (\beta-1)} \right]$$

$$= 1 - \frac{1}{(9.96)^{1.4-1}} \left[\frac{1.787 (1.37)^{1.4}}{(1.787-1) + 1.4 \times 1.787 (1.37-1)} \right]$$

$$= 1 - \frac{1}{2.5} \left[\frac{2.78-1}{0.787+0.926} \right] = 1 - 0.414 = 0.586 \text{ or } 58.6\%$$

(3) An Otto cycle before compression original is twice isentropic ratio of the
Sol Given :-

We know

Comr

Tem

Com

$\frac{T_2}{T_1}$

$\Rightarrow$

Tem

$\frac{P_2}{P_1}$

$\frac{1}{\gamma}$

$$5) \frac{1}{1.4} = (25)^{0.24}$$

$$= 9.96$$

750k

5-1

(T₁ - 750)

$$\frac{40}{50} = 1.787$$

50

$$287 = 49.728$$

0.138

∴ P₂ = 9

$$\frac{1/2 \times V_4}{V_3 \times V_5}$$

$$= 1.37$$

$$287(1.37-1)$$

414

$$86 \text{ or } 58.6\%$$

(3) An engine working on a dual combustion cycle has a pressure of 1 bar and 50°C before compression. The air is then compressed isentropically to $\frac{1}{15}$ of its original volume. The maximum pressure is twice the pressure at the end of isentropic compression. If the cut off ratio is 2. determine the temp. at the end of each process and the ideal efficiency of the cycle, $\gamma = 1.4$.

Sol Given :- P₁ = 1 bar

$$T_1 = 50^\circ\text{C} = 50 + 273 = 323\text{K}$$

$$V_5 = \frac{V_4}{15}$$

$$P_1 = 2P_5$$

$$\beta = \frac{V_2}{V_1} = 2$$

We know that $\gamma = 1.4$

$$\therefore V_5 = V_4 / 15$$

Compression ratio, $R = V_4/V_5 = 15$

Temperature at the end of isentropic compression process

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = (15)^{1.4-1} = 2.954$$

$$\Rightarrow T_5 = T_4 \times 2.954 = 323 \times 2.954$$

$$= 954\text{K} = 681^\circ\text{C}$$

Temp. at the end of constant volume heating

$$\frac{P_5}{T_5} = \frac{P_1}{T_1} \Rightarrow T_1 = T_5 \times \frac{P_1}{P_5} = 954 \times 2$$

$$= 1908\text{K} = 1635^\circ\text{C}$$

Temp. at the end of constant pressure heating

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\Rightarrow T_2 = T_1 \times \frac{V_2}{V_1} = 1908 \times 2 = 3816 \text{ K} = 3543^\circ \text{C}$$

$$(\because \frac{V_2}{V_1} = 2)$$

Temp. at the end of isentropic expansion

$$\frac{T_2}{T_3} = \left(\frac{V_2}{V_3} \right)^{\gamma-1} = \left(\frac{V_2}{V_1} \times \frac{V_1}{V_3} \right)^{1.4-1} \left(\because \frac{V_1}{V_3} = \frac{V_1}{V_4} \times \frac{V_4}{V_3} = 1 \right)$$

$$= \left(2 \times \frac{1}{1.5} \right)^{0.4} = 0.447$$

$$\Rightarrow T_3 = T_2 \times 0.447 = 3816 \times 0.447 = 1706 \text{ K} = 1433^\circ \text{C}$$

$$\eta = 1 - \frac{T_3 - T_4}{\gamma (T_2 - T_1) + (T_1 - T_3)}$$

$$= 1 - \frac{1706 - 323}{1.4(3816 - 1908) + (1908 - 954)} = 1 - \frac{1383}{2671.494}$$

$$= 1 - 0.3815 = 0.6185 \text{ or } 61.85\%$$

(4) In an air standard dual cycle, the pressure and temp. are 0.1 MPa and 27°C. The compression ratio is 18. The pressure ratio for the constant volume part of heating process is 1.5 and the volume ratio for the constant pressure part of heating is 1.2, determine

(a) thermal efficiency

(b) mean effective pressure in MPa

Sol Given $P_1 = 0.1 \text{ MPa} = 100 \text{ kPa}$ $T_1 = 27^\circ \text{C} = 300 \text{ K}$

$$r_p = \frac{P_3}{P_2} = 1.5$$

$$r_v = \frac{V_1}{V_2} = 18$$

$$\beta = \frac{V_4}{V_3} = 1.2$$

Assump
Spec

(1) η_c

(ii) $\frac{m}{P_m}$

V_1

V

are heating

Assumptions

Specific heat ratio for air $\gamma = 1.4$

$$R = 0.287 \text{ kJ/kg.k}$$

$$C_p = 1.005 \text{ kJ/kg.k}$$

$$C_v = 0.718 \text{ kJ/kg.k}$$

$$\begin{aligned} (1) \eta_{\text{dual}} &= 1 - \frac{1}{r^{\gamma-1}} \left[\frac{r^{\gamma} \alpha^{\gamma} - 1}{(\alpha-1) + \gamma \alpha (\beta-1)} \right] \\ &= 1 - \frac{1}{(18)^{1.4-1}} \left[\frac{1.5 \times (1.2)^{1.4} - 1}{(1.5-1) + 1.4 \times 1.5 \times (1.2-1)} \right] \\ &= 1 - \frac{1}{3.178} \times \left[\frac{0.936}{0.5+0.42} \right] \\ &= 0.68 = 68\% \end{aligned}$$

(ii) mean effective pressure

$$P_m = \frac{\text{Net Work done}}{\text{Swept Volume}} = \frac{W_{\text{net}}}{V_s} = \frac{\eta_{\text{dual}} \times q_{\text{in}}}{V_1 - V_2}$$

$$V_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 300}{100} = 0.861 \text{ m}^3/\text{kg}$$

$$V_2 = \frac{V_1}{18} = 0.0478 \text{ m}^3/\text{kg}$$

$$T_2 = T_1 r^{\gamma-1} = 300 \times (18)^{1.4-1} = 953.3 \text{ K}$$

$$T_3 = T_2 r_p = 953.3 \times 1.5 = 1430 \text{ K}$$

$$T_4 = T_3 \beta = 1430 \times 1.2 = 1716 \text{ K}$$

$$\begin{aligned} q_{\text{in}} &= C_v (T_3 - T_2) + C_p (T_4 - T_3) \\ &= 0.718 \times (1430 - 953.3) + 1.005 \times (1716 - 1430) \\ &= 630.6 \text{ kJ/kg} \end{aligned}$$

$$P_m = \frac{0.68 \times 630.6}{0.861 - 0.0478} = 5.22 \text{ kPa} \approx 0.527 \text{ MPa}$$

iron

$$\frac{V_1}{V_3} = \frac{V_5}{V_4} = \frac{1}{15}$$

7

$$16 \text{ K} = 1433^\circ \text{C}$$

383

714959

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300k

1.5

(5) A four-cylinder, four-stroke engine has a displacement volume of 300 CC per cylinder. The compression ratio of the engine is 10 and operates at a speed of 3000 rpm. The engine is required to develop an output power of 40 kW at this speed. Calculate thermal efficiency of the cycle, assuming that the engine operates on the Otto cycle and that the pressure and temperature at the inlet condition are 1 bar and 27°C, respectively. If the above engine is operating on the Diesel cycle and receiving heat at the same rate, calculate thermal efficiency and maximum temp. of the cycle. Compare the efficiency of Otto and Diesel cycles.

Sol given = four stroke, four cylinder engine operates on Otto and Diesel cycles.

$$\eta = \frac{N}{2 \times 60}, \text{ Effective suction } k = 4$$

$$V_s = 300 \text{ CC}$$

$$r = 10$$

$$N = 3000 \text{ rpm}$$

$$P_1 = 1 \text{ bar}$$

$$W_{net} = 40 \text{ kW}$$

$$T_1 = 27^\circ\text{C} = 300 \text{ K}$$

$$\gamma = 1.4$$

$$C_p = 1.005 \text{ kJ/kg.K}$$

$$C_v = 0.72 \text{ kJ/kg.K}$$

$$\Rightarrow \eta_{Otto} = 1 - \frac{1}{r^{\gamma-1}}$$

$$= 1 - \frac{1}{(10)^{1.4-1}} = 0.60 \text{ or } 60\%$$

The efficiency is also given as

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

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Heat Supply rate

$$\dot{Q}_{in} = \frac{W_{net}}{\eta_{th}} = \frac{40 \text{ kW}}{0.6} = 66.67 \text{ kW}$$

(ii) Diesel cycle.

$$r = 10$$

$$P_1 = 1 \text{ bar}$$

$$T_1 = 300 \text{ K}$$

$$N = 3000 \text{ RPM}$$

Temperature isentropic compression

$$T_2 = T_1 r^{\gamma-1}$$

$$= 300 \times (10)^{1.4-1} = 753.56 \text{ K}$$

Compression ratio is given by

$$r = \frac{V_1}{V_2} = \frac{V_s + V_2}{V_2} = 1 + \frac{V_s}{V_2}$$

$$= \frac{V_s}{V_2} = 10 - 1 = 9$$

$$\Rightarrow V_2 = \frac{V_s}{9} = \frac{300}{9} = 33.33 \text{ CC}$$

$$\begin{aligned} \text{Total Volume } V_1 &= V_s + V_2 = 300 + 33.33 \\ &= 333.33 \text{ CC} \\ &= 333.33 \times 10^{-6} \text{ m}^3 \end{aligned}$$

mass of air in a cylinder/cycle

$$\begin{aligned} m &= \frac{P_1 V_1}{R T_1} = \frac{(100 \text{ kPa}) \times (333.33 \times 10^{-6} \text{ m}^3)}{(0.287 \text{ kJ/kg.K}) \times (300 \text{ K})} \\ &= 3.871 \times 10^{-4} \text{ kg} \end{aligned}$$

mass flow rate of four cylinders of the four stroke engine

$$\begin{aligned} \dot{m} &= m k n = 3.87 \times 10^{-4} \times 4 \times \frac{3000}{2 \times 60} \\ &= 0.0387 \text{ kg/s} \end{aligned}$$

heat supplied per second to the engine is given by $\dot{Q}_{in} = \dot{m} C_p (T_3 - T_2)$