E-Learnig Materials
On

Thermal Engg. II

Branch –Mechanical
4th Semester

Preapared
By

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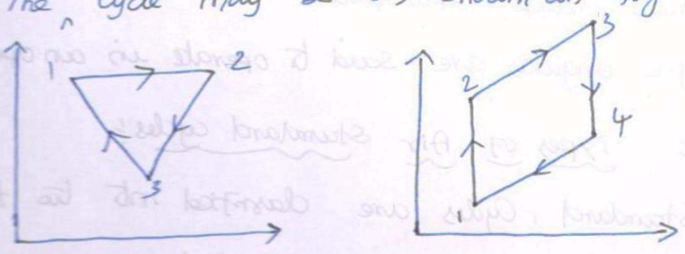
Thermal Engineering

Unit-I : Gas power Cycles:

Cycle: (what is meant by Cycle)

* It is defined as a repeated Series of operations occuring in a Certain order
* (ii) It may be repeated by repeating the process in the Same order

The DIFF TYPES OF Cycle may be as shown in Fig below.



The Cycle may be of

(1) imaginary perfect Engine → ideal cycle

(2) Actual engine → Actual Cycle.

Thermodynamic Cycle: (First law & Second law Suggests)

* The method of producing mechanical power by transforming heat from reservoir to a working fluid is done through a thermodynamic cycle.
* A part of heat received by fluid is rejected to the Sink. These cycles are termed as power Cycles.

Power Cycles are Classified as follows:

(1) Vapour power Cycles

(2) Gas power Cycles.

unit - II . IC Engines:

2.1 Classification :-

Ic engines may be Classified on following basi

(a). According to type of fuel used.
i) Petrol engine.
ii) diesel "
iii) Gas turbine .

(B). According to method of ignition.
i) Spark ignition.
ii) Compression ignition.
iii) hot - Spot ignition.

(c). According to number of Strokes Per Cycle.
i) Four Stroke engine.
ii) Two " "

(d). Working Cycle:
i) otto Cycle engine.
ii) Diesel Cycle "
iii) Dual Combustion "

(e). number of Cylinder used.
i) Single Cylinder
ii) multi Cylinder.

(f). Arrangement of Cylinder :
i) horizontal Engine.
ii) Vertical "
iii) Radial "
iv) opposed Cylinder Engine .
v). V- Engine.

(g). fuel Injection.
i) Carburettor
ii) Air injection
(iii) airless injection

(h) · Cooling System.
i) air Cooled engine.
ii) Water Cooled engine .

(i) Valve location : (i) Over head Valve engine.
(ii) Side Valve engine.

2.2 Components & function:

The Main Parts of an I.C engines are.

Cylinder: It is the main body of the engine in which the Piston reciprocates to develop power. The Cylinder has to withstand very high pressure and temperature because there is a direct Combustion inside the engine Cylinder. Heavy duty engines are made of alloy Steel. Sleeves (or) lines inserted into Cylinder when the Engine block is heavy.

Cylinder head: one end of the Cylinder is closed by Cylinder head. The Cylinder head Contains inlet & exhaust valve through which the fresh charge is admited inside the engine Cylinder and burnt gases are exhausted from the Cylinder to atmosphere.

Piston: It is the heart of the engine It is a gas tight movable Cylinder disc which slides up & down in the Cylinder. It's function is to compress the fresh charge during the Compression stroke & to transmit the force produced due to Combustion of the charge to the Connecting rod & then to the Crank during the Power stroke.

Crank gear: It is the Principal Mechanism of the reciprocating engine. The Mechanism Consists of piston assembly, Connecting rod, Crank shaft and flywheel.

The Crank gear transmits the force of explosion, Produced by Combustion of fuel with air in the engine Cylinder to the output Shaft.

Valves and Valves Operating Mechanism:

It Permits at the right moment the entry of fresh Charge into the Cylinder and exhaust the Products of Combustion into the atmosphere.

In the Case of SI engines, Correct Quantity of air fuel mixture is supplied to the Cylinder by Carburetor.

Fuel Filters:

It filter the foregin Particles that may be Present in the fuel.

Air filter: It removes dust, dirt and other foregi Particles Present in the air supplied to the engi

Lubricating system: It supplies lubricating oil to the vaiour Parts of an engine where there is relative motion. This reduce friction between the Parts and wear and there by increase engine life.

Cooling system: It's used to abstracts excess heat from the Variour Parts of engine which are heated due to Combustion. The Coolants are air (or) liquid (or) it may be Cooled by lubricating oil.

2.3. Engine timing & Valve timing diagram:

A diagram of the actual Pressure Variation with respect to the Volume Changes of the Cylinder Contents as the piston moves from BDC to TDC and from TDC to BDC is also obtained. This diagram is called an Indicator diagram.

Let us Consider the valve timing diagrams one by one.

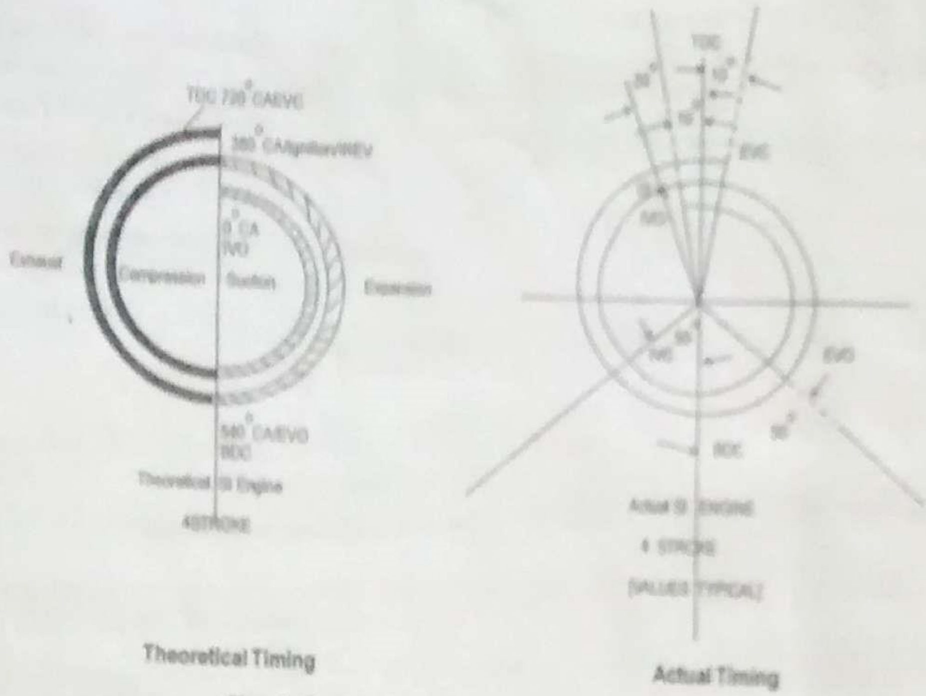
1. Theoritical Diagram.
   - i) Valve timing diagram of a 4 Stroke Petrol Engine.
   - ii) Valve timing diagram of a 4 Stroke Diesel Engine.

2. Actual Engine Diagram
   - i) Actual Engine Valve timing diagram for 4 Stroke Petrol engine.
   - ii) Actual Engine Valve timing diagram for a 4 Stroke Diesel engine.

3. Theoritical Valve timing & P-V Diagram.
   - i) For a 2 Stroke Petrol engine
   - ii) For a 2 Stroke Diesel engine.

4. Actual Engine P-V, P-t
   - i) For a 4 Stroke & 2 Stroke Petrol engine.
   - ii) for a 4 Stroke & 2 Stroke Diesel engine

3.5.7 Valve Timing Diagram – SI Engine



Figs. 3.12 : Valve Timing Diagram - 4 Stroke SI Engine

Table 3.3 : Comparison between Theoretical and Actual Valve Timing-4S SI Engine

	Theoretical	Actual	
IVO [Inlet Valve Open]	TDC	10° Before TDC	[Typical]
IVC [Inlet Valve Close]	BDC	50° After BDC	[I Rev]
IS [Ignition Start]	TDC	20° Before TDC	[Typical]
EVO [Exhaust Valve Open]	BDC	50° Before BDC	[II Rev]
EVC [Exhaust Valve Close]	TDC	10° After TDC	[Typical]
Value Overlap	O	20° [10° + 10].	

Let us take Inlet valve first

It is Opening 10° BDTC and close 50° CA after BDC.

Inlet valve opens earlier than TDC:

The Purpose is to get max. air-fuel mixture inside the Cylinder within the available time The Inlet valve is opened early so that the air charge is given time to gain moment

Extending beyond the BDC for intake Valve closing:

The Purpose of this action Can be explained as the means to utilize the kinetic energy of the following air charge into the Cylinder

Start of Ignition Earlier:

The spark is advanced well before TDC to allow enough time for the air - fuel mixture for flame development and entering into rapid burning Stage. Since flame development & flame Propagation are functions of time, Spark advance is restored to. The spark advance Can be even 35°CA before TDC. The burning process is dependent on the mixture Quality (ie) air fuel ratio, its homogenity, residual gas Present in the cylinder etc.

Depending on all the Factors and the speed the spark is advanced (or) retarded.

Advance Spark discharge - Introducing Spark discharge earlier to TDC.

Retarded Spark discharge - Spark discharge taking place closer to TDC

Exhaust Valve:

Opening early: In a theoritical engine exhaust valve opens at BDC in the second revolution. Refering to the actual engine valve diagram we find valve opens much early.

The Purpose of exhaust valve early is to ensure efficient expulsion of all the Products of Combustion. When exhaust valve opens, the working fluid is at a higher Pressure than atmosphere. This enables exhaust gases to be discharged easily.

Closing of exhaust valve after TDC:

When the Piston is nearing TDC, has attained Considerable kinetic energy keeping the exhaust valve open even beyond TDC there is a means of Providing an uninterupted flow Path for the Combustion Products & there by increases the η of exhaust.

Overlap: This is the duration, in degree Crank angle in which both inlet & exhaust valve are open

Valve timing diagram for CI Engine:

2. Valve Timing Diagram – Compression Ignition or Diesel Engine:

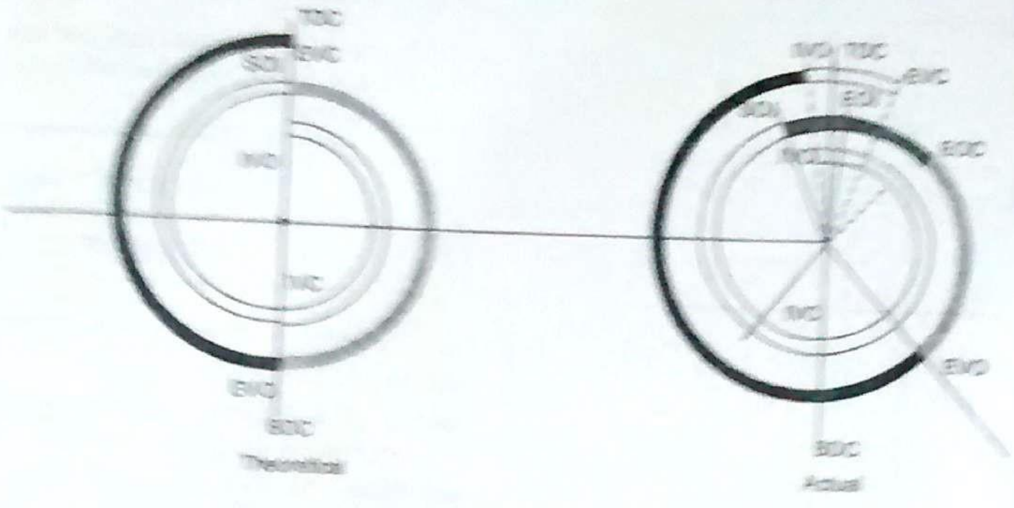


Fig. 3.15 : Valve Timing Diagram (Upright) Diesel Engine

BDC – Bottom Dead Centre
TDC – Top Dead Centre
IVO – Inlet Valve Open
IVC – Inlet Valve Close
EVO – Exhaust Valve Open
EVC – Exhaust Valve Close
SOI – Start Of Injection
EOI – End of Injection
EOC – End of Combustion
Valve Overlap – IVO to EVC.

Events	Theoretical	Actual.
IVO	TDC	10° BTDC
IVC	BDC	40° ABDC
SOI	TDC	20° BTDC
EVO	BDC	45° BBDC
EVC	TDC	20° ATDC
Valve overlap	0	30° CA

The Purpose of Inlet Valve opening before TDC, Closing after BOC and Exhaust Valve opening before BDC and Closing after TDC are nearly the same for the SI & CI engine.

The Process of Combustion of Petrol fuel in the CI engines are entirely different while spark advances in the Case of the SI engine may be for allowing time for Pre-flame reactions to take Place, the SOI earlier in the CI engine is to allow enough time for the Combustion Process and to Complete ignition delay Period well in advance of TDC, in the Process or auto-ignition of delay in the CI engine. usually, the ignition delay is split into two Parts the Physical delay and the Chemical delay.

Port Timing diagram:

In a Crank Case two stroke Cycle engine, we had identified the three types of Ports as;

Scavenge Ports

Exhaust Port

Inlet Port.

Scavenge Ports as inlet Ports which Creates Confusion. It is better to refer to the port filling air/air-fuel mixture into the Cylinder as Scavenge Ports and the Port filling air/air fuel mixture into the Crank Case as Inlet Ports.

Port timing diagram for Carank Case Scavenged symmetrical two stroke Cycle. SI & CI engine.

In the Case of SI engine, the spark discharge initiates the Process of Combustion & the Case of CI engines SOI in the high temperature air of the Cylinder initiates the Process of Combustion.

The end of Combustion Occurs more or less about 35° ADTC in both the engines.

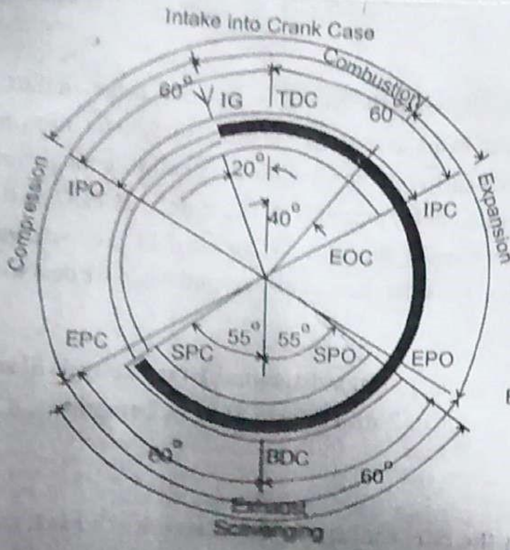


Fig. 3.16 (a): Typical port timing diagram
2 stroke SI engine

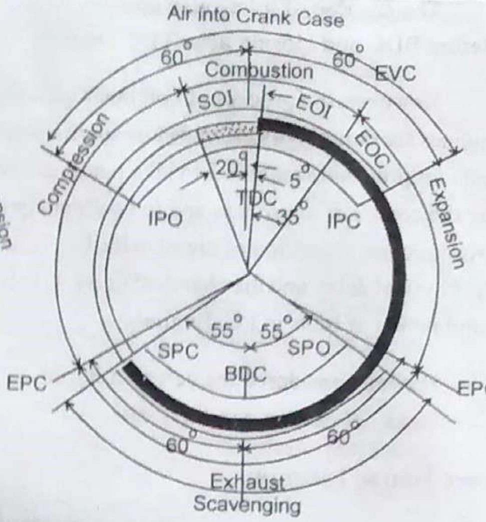


Fig. 3.16 (b): Typical port timing diagram
2 stroke CI engine

Legend:

TDC – Top Dead Centre
BDC – Bottom Dead Centre
SPO – Scavenge Port Open
SPC – Scavenge Port Close
IG – Ignition Start
EOC – End of Combustion

EPO – Exhaust Port Open
EPC – Exhaust Port Close
IPO – Inlet Port Open
IPC – Inlet Port Close
SOI – Start of Injection
EOI – End of Injection

Since it is a Case of Symmetrical Crank Case Scavenged engines Port opening & Closing are symmetrical about BDC/TDC Exhaust Port opens 60° before BDC and closes 55° after BDC and likewise inlet Port to fill Case opens 60° before TDC and close 60° after TDC.

2.4. Actual and Theoritical P-V diagram:

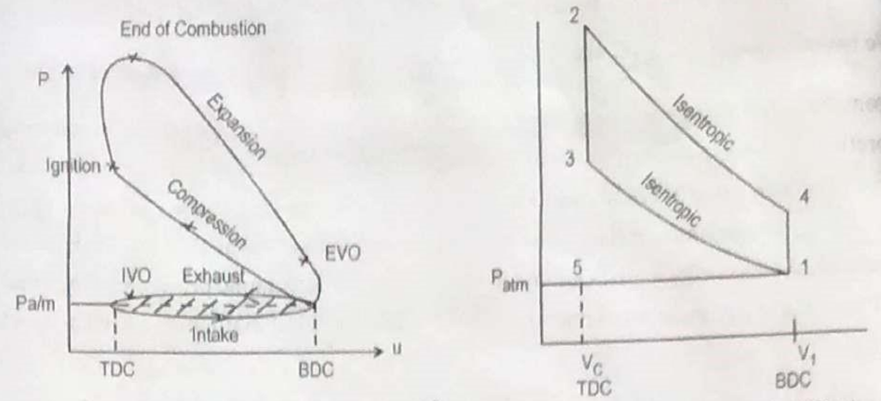
From the above discussion on the Valve timing diagram it is Clear that there is departure from the theoritical process in the actual engine. More over we have Observed during our Consideration of engine operation, that there Should be Pressure difference for fresh Charge to fill up the Cylinder during intake & Similarly Pressure difference across exhaust Valve to discharge the Products of Combustion efficiently. our a understa of thermodynamics Principles State that work. is done by an agency to Push a volume of a fluid at a Pressure.

$$P(V_f - V_1)$$

P = the Pressure in N. ; V_1 = the initial Volume.

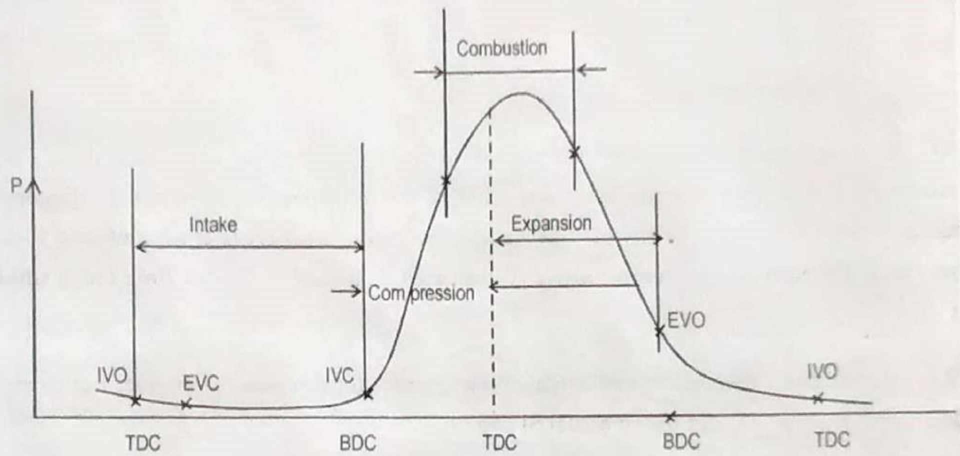
V_f = the final volume

Comparison of theoritical P-V diagram with actual pv. diagram.



Typical Actual Engine p-V diagram — Theoretical p-V diagram for SI Engine

Figs. 3.13 : Theoretical and Actual p-v Diagram for SI Engine–4S.



Figs. 3.14 : Typical p–t Diagram for Actual 4-S SI Engine

When the drum is given a reciprocating movement, it records the p – v diagram.

We obtained a Complete history of the Pressure existing in the Cylinder at any instant and with this details of a complete Cycle is drawn. Such a diagram which gives the instaneous Value of the Pressure inside the Cylinder with respect to the Piston of the Piston is known as Indicator diagram.

3.5.8 *p* – *v* and *p* – *t* Diagrams

We shall now consider the $p - v$ diagrams of theoretical and actual engine cycles of SI and CI engines.

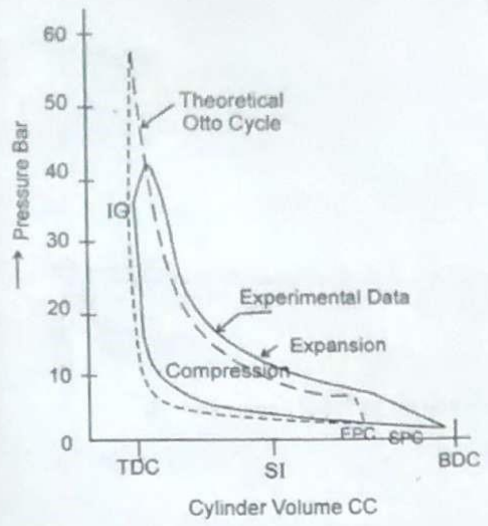


Fig. 3.17 (a) : 2S SI Engine Experimental data compared with OTTO cycle (Typical)

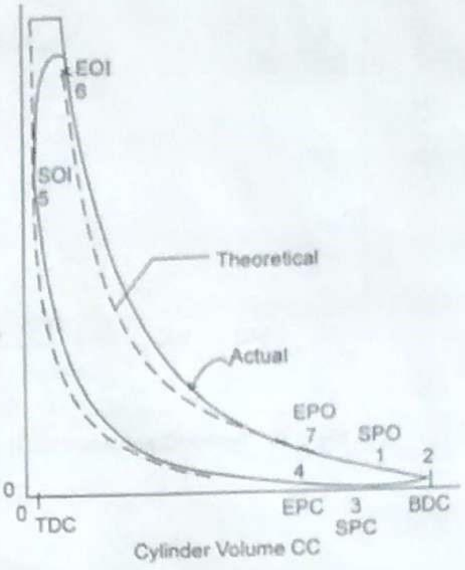


Fig. 3.17 (b) :2S CI Engine Indicator diagram compared with theoretical Diesel cycle (Typical)

Theoritical and experimental data for the Presure more (or) less look similar and the Values do approach the theoritical values. Compresion & the expansion Curve do not follow the $\gamma = 1.4$ value for the ideal otto Cycle.

Similar Comments will hold good for the Compression ignition engines also. It Can be Obsaved from the figure that there is a Constant Presure movement of the Piston between Point 5 and Point 6 from where the expansion takes Place upto the Point 7 when the exhaust Port open.

25 Carburettor:

A mixture of air and fuel in which the fuel is mixed with the chemically correct quantity of air is known as stoichiometric mixture.

b. A mixture in which air is in excess of the chemically correct requirement is known as lean (fuel) mixture.

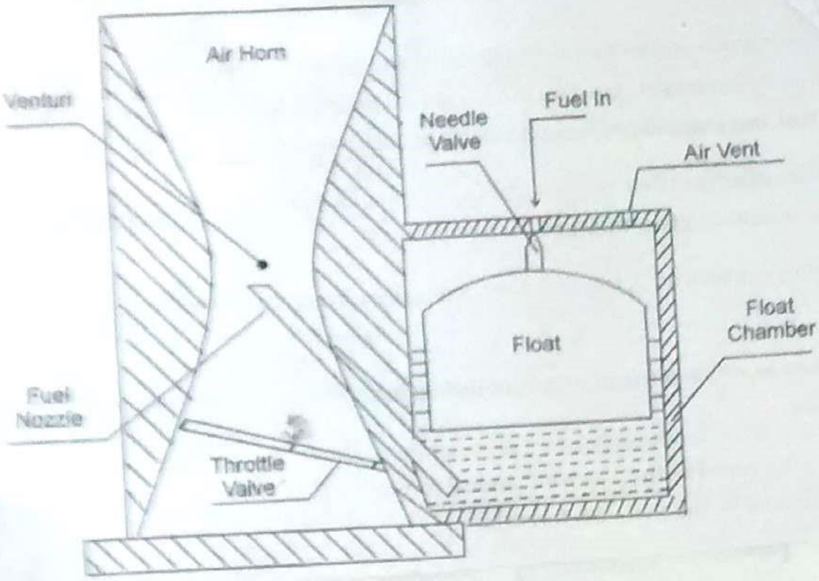
Considering Petrol as fuel whose chemical formula is C_8H_{18}, it can be worked out to find the oxygen requirement by the chemical formula.

$$C_8H_{18} + 12.5O_2 = 8CO_2 + 9H_2O$$

$$C_{10}H_{22} + 15.5O_2 = 10CO_2 + 11H_2O.$$

There is a limit within which the mixture burns and sustain combustion. That is if the ratio is too rich will not sustain combustion it will not find fuel to carry the flame forward.

Principle of a Carburettor:



The Components are
i) air duct (or) air horn
ii) Float Chamber.
iii) throttle body.

A venturi is Created inside the air duct the venturi is a restriction in the air flow Passage. By applying Continuity eqn it Can be found that the velocity increases at the Venturi and because of this Pressure drop. Petrol in the float Chamber is Connected by a fuel nozzle to the Venturi through a metering when the Pressure drop below atmosphere the Petrol in the float Chamber is forced by the atmospheric Pressure. towards the venturi space.

The mixture Passages through the throttle valve fixed in the throttle body.

2.5 Battery Ignition System:

It is known as the Coil-ignition System.

It can also be Considered as the Magnetic Discharge ignition System. The Principle is that when the ignition Switch is inserted, the Primary Circuit of MIS close & the Primary gets charged and as a result the magnetic field in the iron Core also build up. This Process is not instantaneous but takes few micro seconds.

The system Consists of a 6 or 12 V ammeter, ignition switch, ignition Coil, with a Primary and Secondary winding as a fund in a Step up transformer, Contact breaker, Capacitor distributor rotor, distributor Contact Point. But it works on mutual electromagnetic induction Principle.

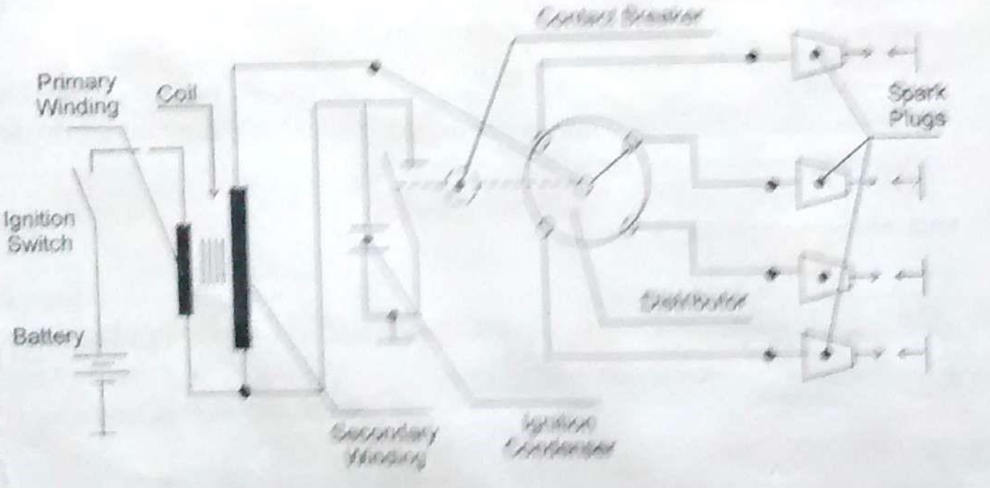


Fig. 3.48 : Wiring Diagram for a Typical Battery Ignition System (Conventional)

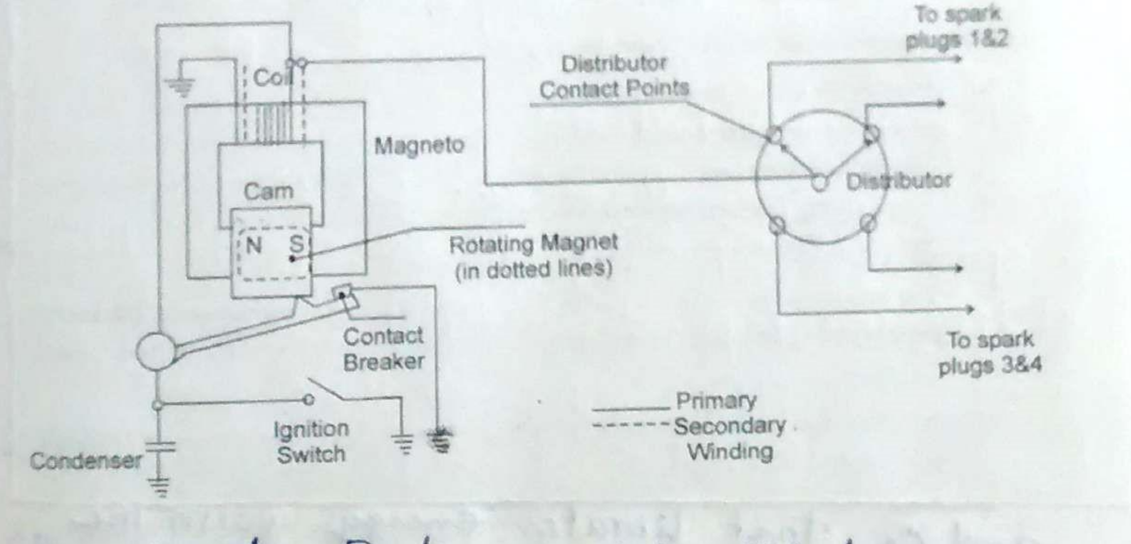
It has two Circuits.

i) a Primary Circuit. ; ii) Secondary Circuit.

Primary Circuit Consists of 6 (or) 12 V battery, ammeter ignition switch, Primary winding, Contact breaker. Secondary Circuit consists of secondary winding, distributor rotor, Contact Points

Magneto ignition system:

In magneto ignition, the magneto works as an energy Source and Produces and supplies the required Current to the Primary winding. Two type of magneto are available, a rotating magneto fixed Coil (or) a rotating Coil with fixed magneto It also works on same Principle.



The breaker Points are subjected to wear required frequent maintenance. Because of arcing, Pitting of Contact breaker Point takes place which leads to regular maintenance schedule.

2.6 Combustion and knock:

The Process of Combustion takes place in a SI engine is differ from that in the CI engine. In a Conventional SI engine, Petrol is inducted into the Cylinder during the suction stroke and around the end of Compression Stroke a spark discharge is made of take Place in the Combustion Chamber

So, in a normal Combustion in the SI engine spark discharge signals the start of the Combustion Process.

The Combustion Process in a CI engi Comprises four phases.

i) Ignition delay Period.
ii) Premixed Combustion.
iii) mixing Controlled Combustion.
iv) late Combustion Phase.

SI engine Combustion:

It Contains four phases.

i) Spark ignition; ii) development of early flame for
iii) Flame Propagation iv) flame termination.

Flame is the evidence of a Chemical reaction takes place between fuel and O_2 that librates energy with the subsequent increase in Pressure and temp Combustion begins at the spark plug where the fuel molecule are energized by the spark to a level where reaction becomes self sustaining. Here the reaction zone is establi and once the reaction zone is being established the turbulent spherical flame front & burned gas is behind the flame front.

Abnormal Combustion has been divided into two categories.

i) Knock &

ii) Surface ignition.

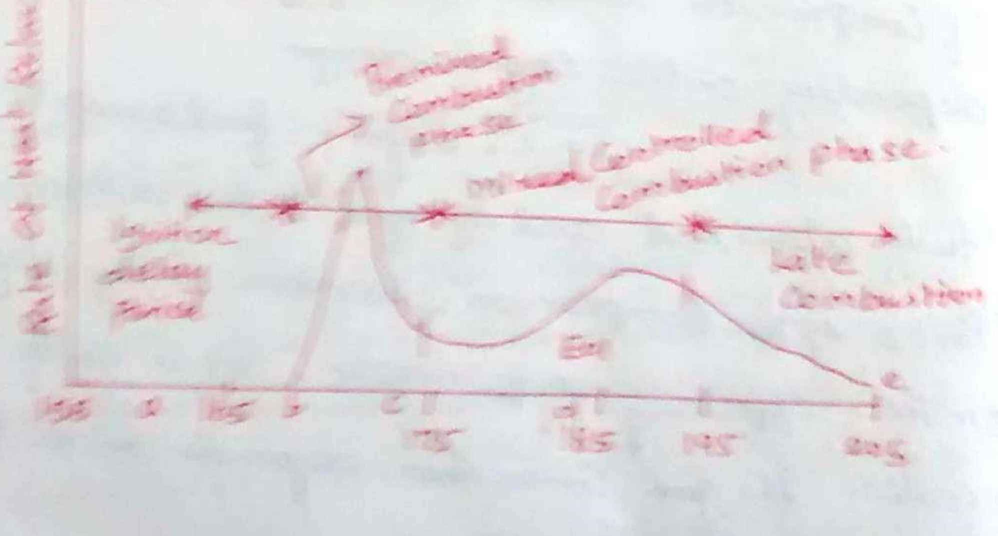
The foremost criterion for good combustion is that it must occur very near the TDC so that full work output is realized. It has been found that spark advances plays a critical role in developing the max. torque from an given engine.

CI Engine Combustion:

In CI engine air alone compressed and raised to a high temperature. Near the end of compression stroke, jets of fuel, the nor of depending on the engine design.

In CI engine fuel needs to be fully atomized and sprayed to the different parts of the compression chamber solely depend on the efficiency of the nozzle. It is easily to realize the good combustion depends on the η of the nozzle.

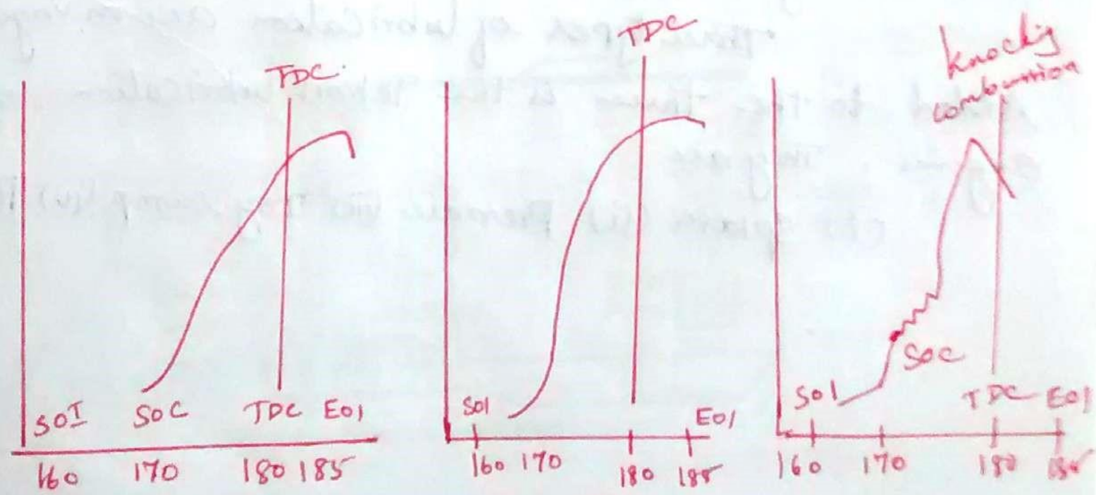
The spray from an nozzle Creates an envelope of fuel surrounded by fuel. The temperature of air is Conducted for auto-ignition and oxidization of fuel become imminent. This Period when the fuel is atomized, vaporized, find enough air is mixed with air and is raised in temperature is the Physical delay Period. In the next Phase called chemical delay reaction starts slowly and accelerating until inflammation (or) ignition takes Place. This Period that elapse between the injection of diesel fuel and the start of Combustion is known as ignition delay. Ignition delay is the Combustion of Physical delay and Chemical delay Periods.



Knock in CI engine & SI engine:

In the CI engine injection Process is time bound. Injection is Continuing as the first few drops are injected and are Passing through the Period of ignition delay If the ignition delay is sort, for by the time the additional fuel droplets arrive actual burning would have started. And the accumlate fuel is likely to be a small amount. this means the mass rate of mixed burned will be such as to Produce a smooth force on the piston. On the other hand if the ignition delay is longer on more fuel will accumlate and burn resulting in too rapid a pr. rise Causing a jaming action on the piston. If the ignition delay is still longer than the quality of accumlate fuel will also gives rise to extreme pressure diff & violent variation evidence by an audible knock.

SI engine occurs later in knock but CI engine occur earlier in the Combustion.



2.7 Lubrication and Cooling System:

i. Lubrication System

Lubrication system is to reduce the wear between the two metals (or) the to reduce the friction loss due to relative motion.

Lubrication method and systems can be classified as follows:

For bearing and bushes:

i) Gravity feed.
ii) By wicks and
iii) By a ring.

Gravity feed is employed for a shaft rotating in stationary bearings.

Wick (or) siphon lubrication is also installing a cup filled with lubricating oil over the hole in the bearing housing.

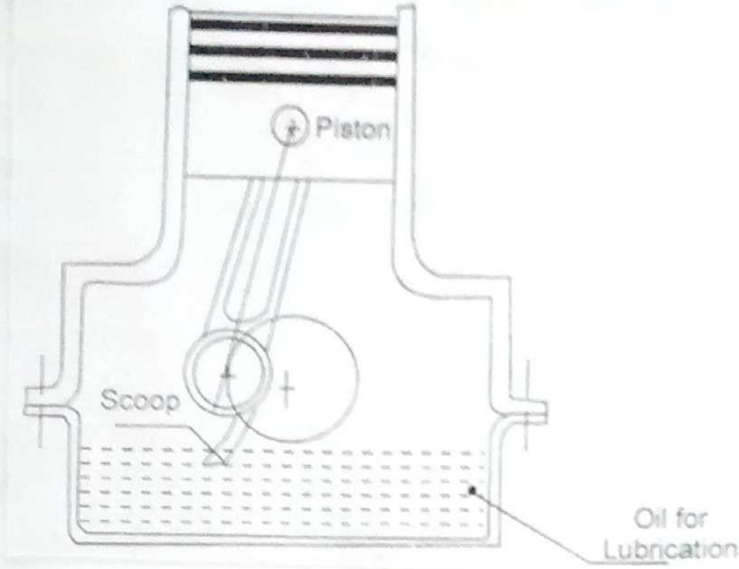
For other Engine Parts,

Three types of lubrication are in vogue. Added to the three is the Petroil lubrication for 2S Engines. They are:

(i) Splash (ii) Pressure (iii) Dry sump (iv) Petroil.

Splash lubrication :

A Scoop is attached to the lower Part of the big end of the Connecting rod. A trough of oil is Stored below the Connecting rod. when the engine runs, the Scoop Collects the oil & splashes over the Piston, wrist pin, big end bearings etc.



Pressure lubrication:

In this a Pump is employed to acheive required Pressure to lubrication. A Strainer/filter is employed for the Pressure lubrications.

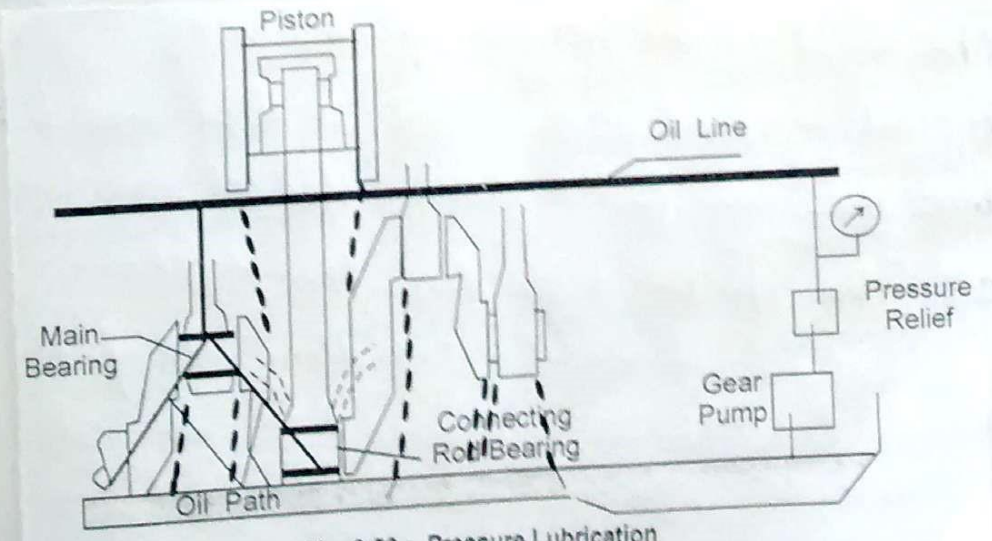
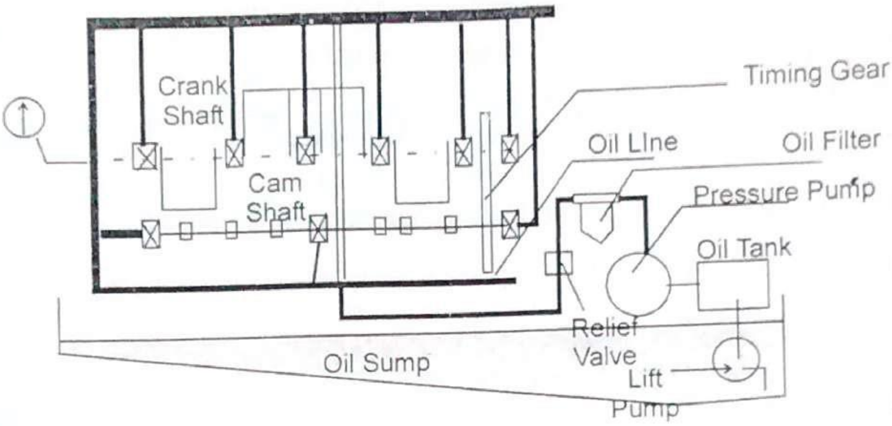


Fig. 3.56 : Pressure Lubrication

Dry Sump Method:

when a Vehicle is moving up a gradiant (or) Climbing a steep Slope, there is all the likehood of the Pump suction not finding oil level. In such situation two Pumps employed One Pump is to lift oil from the lowest level Another Pump is to Main gallery.



Petroil Method:

Petrol + oil makes Petroil. This type is used for SI engines. Since Crank ~~gas~~ Case cannot be used as the oil sump. 3-6% of lubricating oil is mixed with Petrol and is introduce along with the air-fuel mixture. The oil serve to lubricate the Piston & Cylinder. This system Consume lot of oil since it burns along with fuel.

Cooling System:

It is about 30 to 35% of heat Supplied to the IC engine wasted as heat Carried away by Cooling medium. Normal Cooling medium used is water. The Cooling system in use we know is Air Cooled and water cooled.

Air Cooling Method:

The basic air Cooling methods are.

i) Cooling fins and (ii) Blast of air Provided by a blower(or) moving vehicle.

Cooling fins increase the area of exposure of the heated surface to the blast of air there by increase the η of Cooling.

water Cooling Method:

In the water Cooling System, the Cooling water is Circulated around the engine so the absorbs the heat from the engine Compounds, mainly the engine cylinder & head.

Types:

i) Non-Return System.
ii) Thermo sypon.
iii) Impeller Thermo syphon.
iv) Full Pump Circulation and
v) Evoprative Cooling.

Thermosyphon:

When we boil the water in a vessel the bottom layer of water heated up and rise upwards and Cooler water Goes down. This is known as Convection Current In such a way that Cylinder Jacket and Radiator Connected. hot water rises up and flows into Radiator where it cooled and naturally flows into the Cylinder jacket.

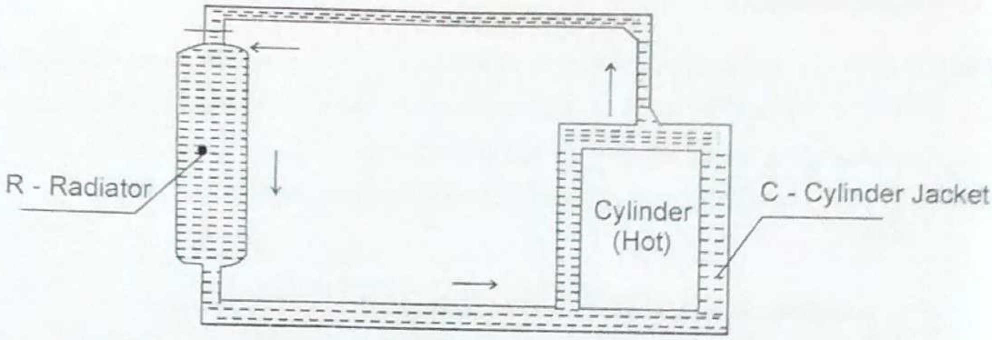


Fig. 3.61 : Simple Thermosyphon

Impeller Thermo syphon:

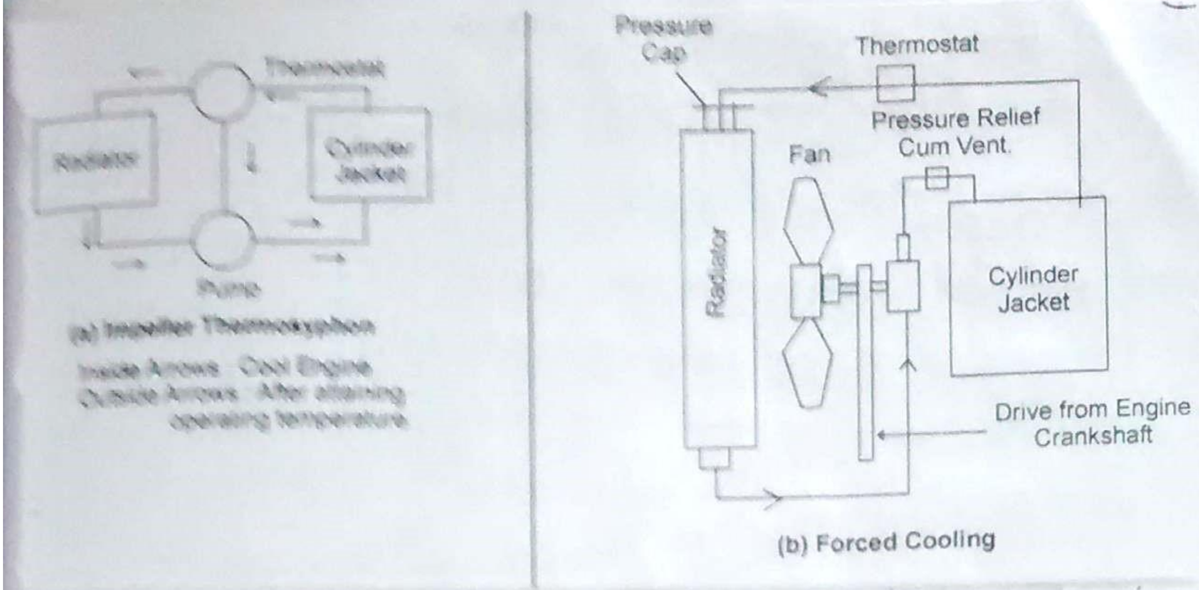
The water Circulation is Still by Convection tough assisted by a Pump.

The radiator Cools the hot water from the engine Cylinder, Jacket:

i) Tubular type

ii) Cellular type.

Tubular Core Consits of tinned tube Convered with brass fins to increase the heat Area

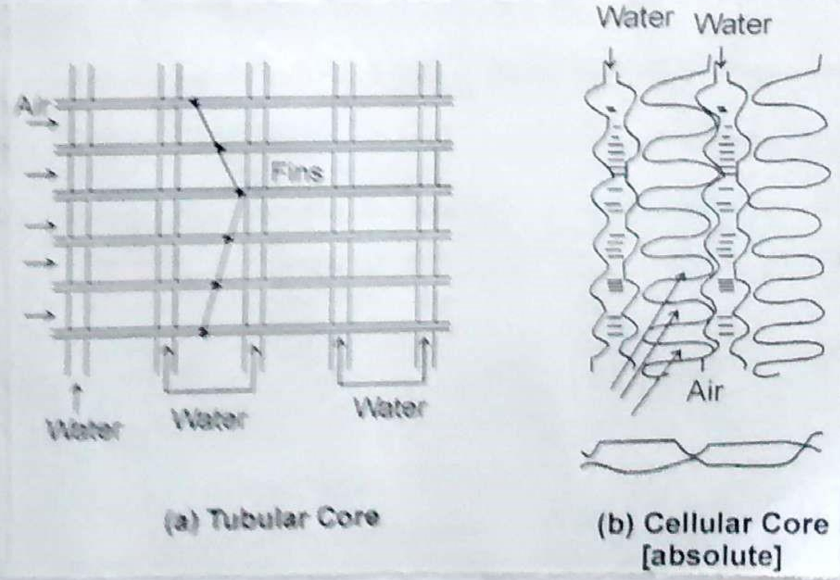


(a) Impeller Thermosyphon

(b) Forced Cooling

The materials for radiators must have good Corrosion resistance and thermal Conductivity. Copper and brass are Common materials and aluminium is used when weight is of Consideration.

Radiators are associated with the fans. The fans blow air across the Crores for faster Cooling. Thermostat Controls the water flow blow a given temperature

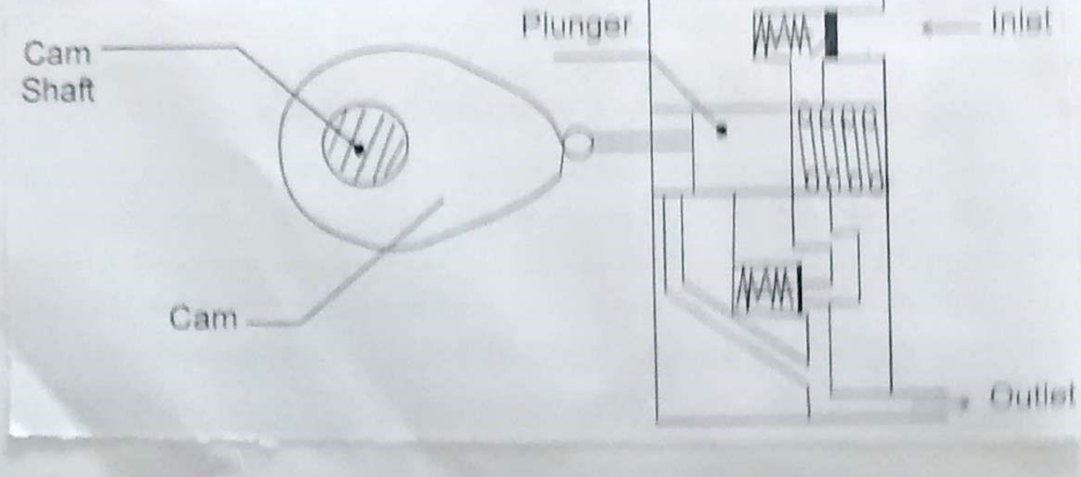


(a) Tubular Core

(b) Cellular Core [absolute]

28. Diesel Pump

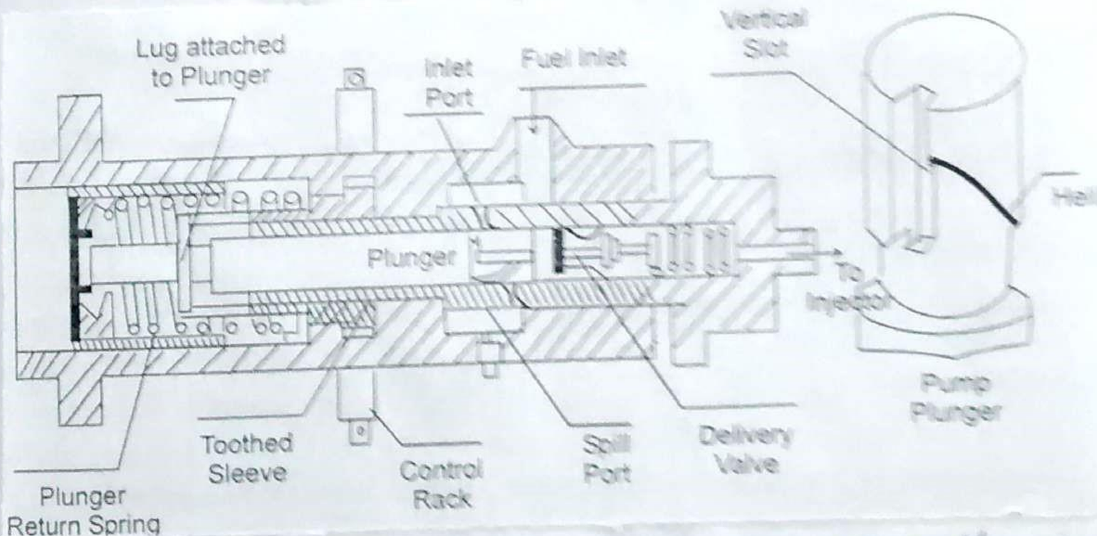
There are many methods of erecting and many types of feed pumps (or) it may be erected seperately outside the injection pump. It may be driven from the main engine camshaft (or) by the cam in the injection pump drive. The type of pumps include gear pumps, vane pumps, diaphragm pumps, plunger pump etc. Since we are familiar with the other type of pumps let us describe the plunger pump briefly. In this plunger pump one movement i.e. forward moment for the plunger is provided by the minimum position of the cam on the camshaft. The return movement is effected by the spring. The forward movement lets fuel inside the cylinder of the pump body through a suction valve & the backward movement lets fuel inside the cylinder of the spring forces the fuel out through the delivery valve.



Jerk type Injection Pump:

A Pump must have suction, delivery, a Pressurizing Mechanism and a drive. Additionally the injection mechanism must have a metering device to allow correct amount of fuel for the speed & load on the engine.

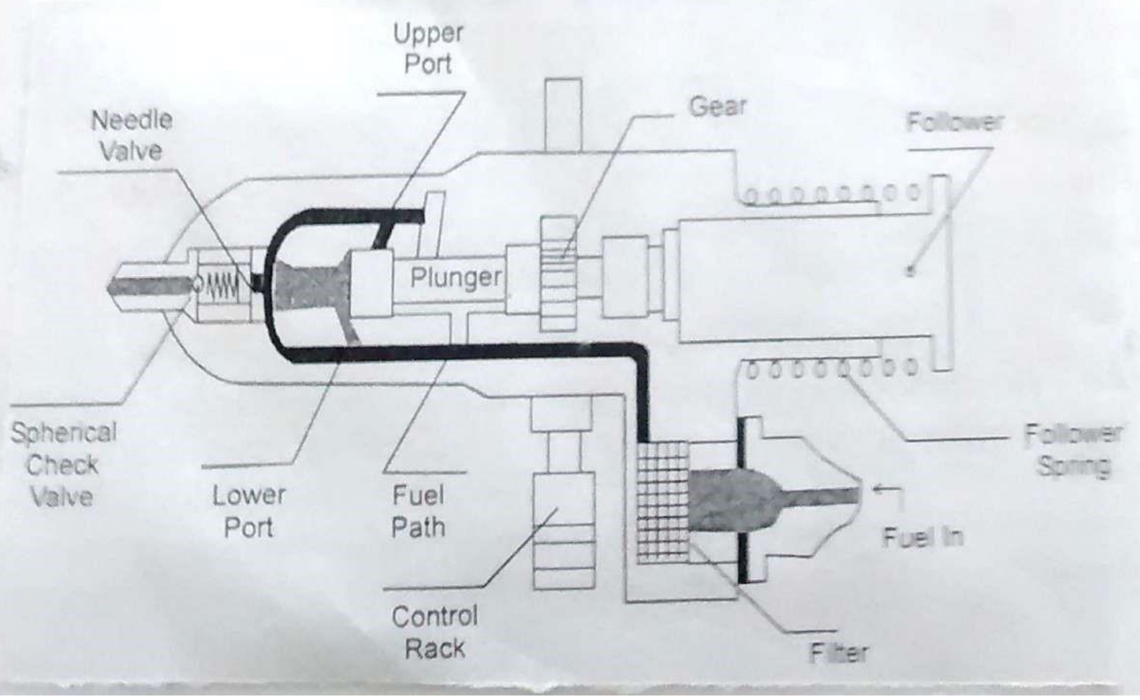
In a Jerk pump, a plunger operates inside a cylinder with an inlet Port and a spill way Port. Inlet port admits fuel from the feed Pump and the spill way offers Passage to excess fuel back to the tank.



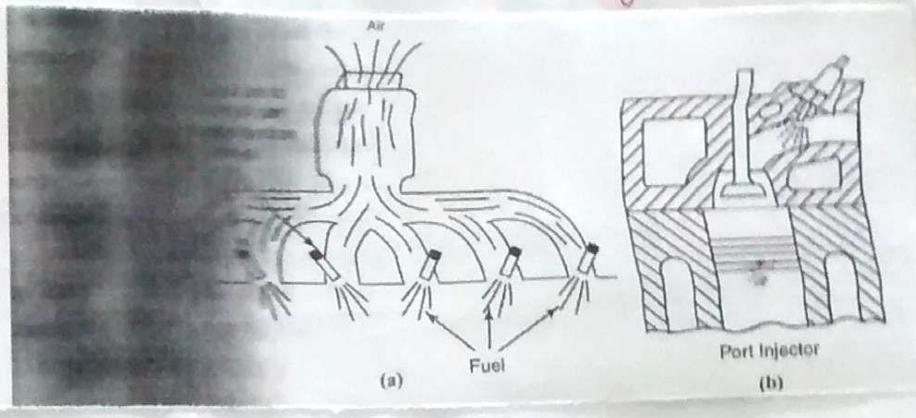
when the fuel is Pressurized the specially designed to deliver valve operating against a spring force and supplies fuel at high Pressure to the injector.

2.9. Fuel Injector:

It's been the heart of the IC engine. The Injector Consits of a fuel supply arrangement, a spring loaded well valve and a nozzle. The spring loaded needle Valve Performs the function of allowing and stopping the flow of fuel. into droplets is to increase the area for mixing and heat transfer and ultimately aimed to acheive good Combustion. At the time of injection fuel at a high Pressure acts against the spring force and moves the needle upwards. The upward movement of the needle allows the Port to be open for fuel to escape through nozzle in a fine spray. Lubrication of the nozzle valve and Guided are by leakage fuel.



2.10. MPFI (or) Multi port fuel Injection system: 47



A low pressure fuel transfer pump, a fuel injection pump and a nozzle are the essential components of the system. usually injection takes place duing the early stage of suction mode. Modern fuel injection system use sensors, computer and solenoid operated injector for acheiving metered fuel injection. There electronic device from part of an Electronic fuel injection system. The computer is also known as ECU and receives signals from the sensors. The data so received are processed and are used to operate the injectors and other device. The typical sensors used in EFI is O_2 sensor, air flow sensor.

It injects in the individual manifold if it is an 8 cylinder engine there has to be 8 injectors for the cylinder 1 injector for each cylinder.

UNIT – 3

STEAM NOZZLES AND TURBINES

Nozzle:

Nozzle is a duct of varying cross-sectional area in which the velocity increases with corresponding drop in pressure.

Its main function is to produce a jet of steam with high velocity.

SHAPES OF NOZZLE:

The following three types of nozzles are important.

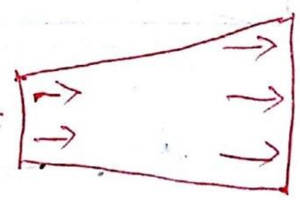
1. Convergent nozzle:

In Convergent nozzles, cross sectional area decreases from inlet section to outlet section.

CONVERGENT NOZZLE

2. Divergent nozzle:

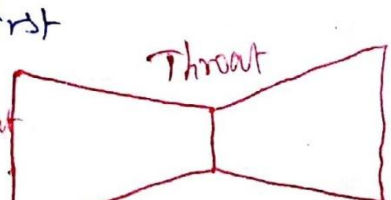
In divergent nozzles, cross sectional area increases from inlet section to outlet section.



DIVERGENT NOZZLE

3. Convergent divergent nozzle:

When the cross section of a nozzle first decreases from the inlet section to throat and then it increases from its throat to outlet section. It is called a Convergent - divergent nozzle.



STEAM FLOW THROUGH NOZZLES:

Steam flow through nozzle may be assumed as adiabatic flow. Since no heat is supplied (or) rejected by steam during flow through a nozzle and there is no workdone during flow of steam.

i.e, $Q = 0$ and $W = 0$

Velocity of steam:

Steam enters nozzle with high pressure and low velocity, and leaves with high velocity and low pressure.

The outlet velocity (V_2) of steam can be found as follows.

Consider a small unit mass flow of steam through a nozzle.

Let, V_1 – Velocity of steam at entrance of nozzle – m/s
V_2 – Velocity of steam at any section – m/s.
h_1 – Enthalpy of steam entering nozzle – KJ/kg.
h_2 – Enthalpy of steam at any section – KJ/kg.

For steady flow process:

The steady flow energy equation can be written as,

$$h_1 + \frac{1}{2} m V_1^2 = h_2 + \frac{1}{2} m V_2^2 + \text{Losses} \quad [\because Q = 0, W = 0]$$

W.K.T, for unit mass flow rate of steam,

$m = 1$, and neglecting losses in nozzle.

$$\text{So, } h_1 + \frac{1}{2} V_1^2 = h_2 + \frac{1}{2} V_2^2$$

$$h_1 + \frac{V_1^2}{2000} = h_2 + \frac{V_2^2}{2000} \quad [\because h \text{ unit is KJ/kg}]$$

$$(h_1 - h_2) = \frac{1}{2000}\left[V_2^2 - V_1^2\right]$$

$$V_2^2 - V_1^2 = 2000(h_1 - h_2)$$

$$V_2^2 = V_1^2 + 2000(h_1 - h_2)$$

$$V_2 = \sqrt{V_1^2 + 2000(h_1 - h_2)}$$

Inlet velocity V_1 is negligible as compared to outlet velocity V_2. So,

$$V_2 = \sqrt{2000\, h_1 - h_2}$$

$$\boxed{V_2 = 44.72 \sqrt{h_1 - h_2}}$$

MASS OF STEAM DISCHARGED THROUGH NOZZLES :

The isentropic process in nozzle may be approximately represented by an n^{+} equation.

$$PV^n = \text{constant.}$$

Where, $n = 1.135$ for Saturated steam

$n = 1.3$ for Superheated Steam.

Let, P_1 - Inlet Pressure of Steam.

v_1 - Specific Volume of steam at entry.

P_2 - Pressure of steam at throat (or) Exit.

v_2 - Sp. Volume of Steam at Pressure P_2.

V_1 - Velocity of Steam at Entry.

V_2 - Velocity of Steam at exit

As Steam passes through the nozzle, its pressure is dropped. So Enthalpy is also reduced. This reduction in enthalpy must be equal to increase in K.E. Hence workdone by steam is equal to

The workdone is given by equation $\frac{n}{n-1}(P_1 v_1 - P_2 v_2)$

Gain in K.E = Workdone during Isentropic process.

$$\frac{V_2^2}{2} - \frac{V_1^2}{2} = \frac{n}{n-1}(P_1 v_1 - P_2 v_2)$$

Since, V_1 is very less than compared to V_2. It canbe neglected. So, the eqn reduces to

$$\frac{V_2^2}{2} = \frac{n}{n-1} P_1 v_1 \left[1 - \frac{P_2 v_2}{P_1 v_1}\right]$$

$$P_1 v_1^n = P_2 v_2^n$$

$$\frac{v_2}{v_1} = \left(\frac{P_1}{P_2}\right)^{1/n}$$

Substituting $\frac{v_2}{v_1}$ value in above eqn,

$$\frac{V_2^2}{2} = \frac{n}{n-1} P_1 v_1 \left[1 - \frac{P_2}{P_1}\left(\frac{P_1}{P_2}\right)^{1/n}\right]$$

$$\frac{V_2^2}{2} = \frac{n}{n-1} P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)\left(\frac{P_2}{P_1}\right)^{-1/n}\right]$$

$$\frac{V_2^2}{2} = \frac{n}{n-1} P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]$$

$$V_2 = \sqrt{\frac{2n}{n-1} P_1 v_1 \left(1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right)}$$

W.K.T,

Mass of steam ~~discharged~~ through nozzle per second.

$$m = \frac{\text{Volume of steam flowing per sec}}{\text{Specific volume of steam.}}$$

Volume of steam flowing per sec = Area × velocity of steam
= $A \times V_2$

Specific volume of steam = v_2

$$\therefore m = \frac{A \times V_2}{v_2}$$

Substituting V_2 value in above equn,

$$\dot{m} = \frac{A}{V_2}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$$

W.K.T,

Specific volume, $V_2 = V_1\left(\frac{P_1}{P_2}\right)^{1/n}$

$$m = \frac{A}{V_1\left(\frac{P_1}{P_2}\right)^{1/n}}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$$

$$m = \frac{A}{V_1}\left(\frac{P_1}{P_2}\right)^{-1/n}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$$

$$m = \frac{A}{V_1}\times\left(\frac{P_2}{P_1}\right)^{1/n}\sqrt{\frac{2n}{n-1} P_1 V_1\, 1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}$$

$$= \frac{A}{V_1}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{2/n}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]\right]}$$

$$= \frac{A}{V_1}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{2/n} - \left(\frac{P_2}{P_1}\right)^{2/n+\frac{n-1}{n}}\right]}$$

$$= \frac{A}{V_1}\sqrt{\frac{2n}{n-1} \cdot P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{2/n} - \left(\frac{P_2}{P_1}\right)^{\frac{n+1}{n}}\right]}$$

$$= A\sqrt{\frac{2n}{n-1} \frac{P_1 \cdot V_1}{V_1^2} \left[\left(\frac{P_2}{P_1}\right)^{2/n} - \left(\frac{P_2}{P_1}\right)^{\frac{n+1}{n}}\right]}$$

$$\boxed{m = A\sqrt{\frac{2n}{n-1} \frac{P_1}{V_1} \left[\left(\frac{P_2}{P_1}\right)^{2/n} - \left(\frac{P_2}{P_1}\right)^{\frac{n+1}{n}}\right]}}$$

EFFECT OF FRICTION IN A NOZZLE:

When the steams flow through a nozzle, the final velocity of steam for a given pressure drop is reduced due to following reasons.

1. Due to friction between nozzle surface & steam.
2. Due to internal fluid friction in steam.
3. Due to shock losses.

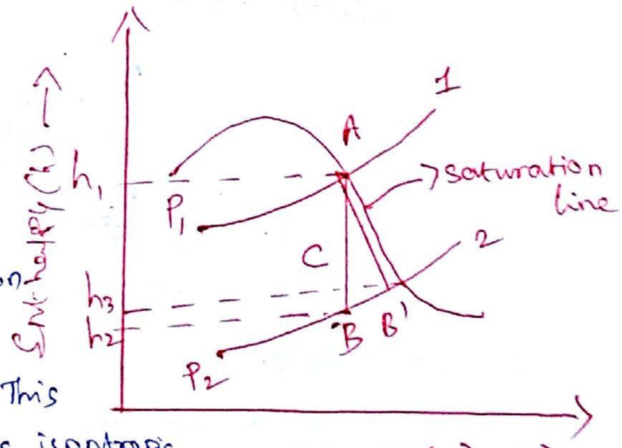
Most of these frictional losses occur bet throat & exit in a convergent - divergent nozzle.

The effects of these frictional losses are lited below

1. The expansion is no more isentropic and enthalpy drop is reduced by resulting lower exit velocity.

2. The final dryness fraction of steam is increased as part of K.E gets converted into heat due to friction and absorbed by steam with increase in enthalpy.

3. The specific volume of steam is increased as steam becomes drier due to this frictional reheating.



The point A represents initial condition of steam. It is a point where the saturation line meets initial pressure (P_1) line.

If friction is neglect, the expansion of steam from entry to throat is represented by vertical line AB. This is done, as flow through nozzle is isentropic.

The enthalpy drop $(h_1 - h_2)$ is known as isentropic enthalpy drop.

NOZZLE EFFICIENCY.

$$\eta = \frac{\text{Actual Enthalpy drop}}{\text{Isentropic enthalpy drop}} = \frac{AC}{AB} = \frac{h_1 - h_3}{h_1 - h_2}$$

CRITICAL PRESSURE RATIO:

There is only one value of ratio (P_2/P_1) which produces the maximum discharge from nozzle. This ratio is called critical pressure ratio.

where, P_1 – Inlet pressure

P_2 – Throat pressure

i) For saturated steam, $n = 1.135$

The critical pressure ratio is given by

$$\frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} = \left(\frac{2}{1.135+1}\right)^{\frac{1.135}{1.135-1}}$$

Critical pressure ratio, $\boxed{\frac{P_2}{P_1} = 0.577}$

(ii) For superheated steam $n = 1.3$,

$$\frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} = \left(\frac{2}{1.3-1}\right)^{\frac{1.3}{1.3-1}}$$

Critical pressure ratio, $\boxed{\frac{P_2}{P_1} = 0.546}$

(iii) For gases, $n = 1.4$,

Critical pressure ratio, $\frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$

$$\frac{P_2}{P_1} = \left(\frac{2}{1.4+1}\right)^{\frac{1.4}{1.4-1}}$$

$$\boxed{\frac{P_2}{P_1} = 0.5282}$$

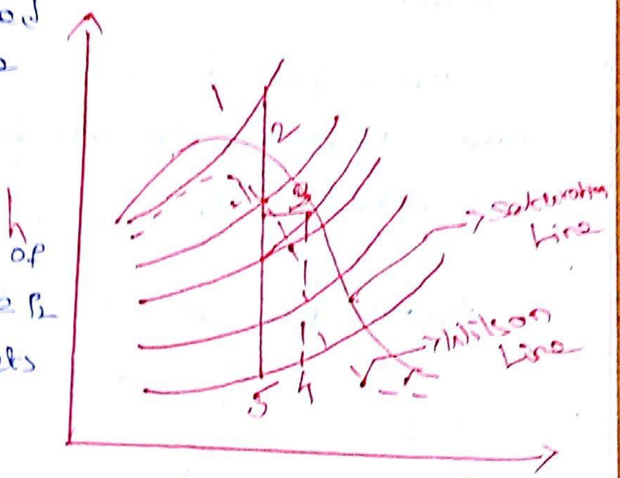
SUPERSATURATED FLOW (or) METASTABLE FLOW OF STEAM IN A NOZZLE:

When the superheated steam expands in nozzle, the condensation will occur in nozzle. Since, the steam has more velocity, the condensation will not take place at the expected rate. So equilibrium between liquid and vapour phase is delayed and steam continues to expand in a dry state.

The steam in such set of condition is said to be ~~superheated~~ "Supersaturated" (or) "Metastable flow".

The ideal expansion of superheated steam from pressure P_1 to P_4 can be represented by a line 1-5 on mollier diagram.

During the expansion, the change of phase must start to occur at pressure P_2 as shown where expansion line meets the saturation line (Point 2).



SUPERSATURATED FLOW.

But in nozzles under certain conditions, this phenomenon of condensation does not occur at point 2 as time available is very short due to high velocity of steam passing through nozzle.

The equilibrium bet liquid & vapour phase is therefore delayed and vapour continues to expand in dry state even beyond point (2).

The vapour bet pressure P_2 & P_3 is said to be "supersaturated" and this type of flow in nozzle known as "supersaturated (or) metastable flow of steam". A limit to supersaturated state was observed by Wilson & a line drawn on chart through observed point is known as Wilson line.

The flow is also called as supercooled flow because at as pressure bet P_2 & P_3 the temp of vapour is always lower than saturation temp corresponding to pressure. The diff in this temp is known as degree of "under-cooling".

Problem:

Dry saturated steam at a pressure of 11 bar enters a convergent - divergent nozzle and leaves at a pressure of 2 bar. If flow is adiabatic and frictionless, determine:

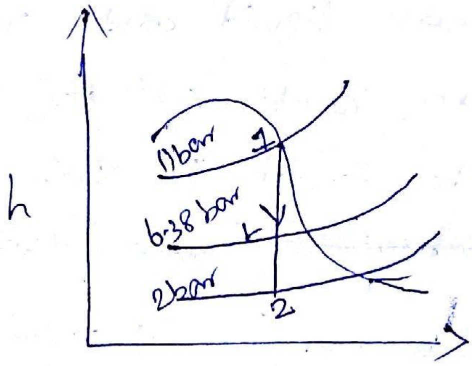
(i) Exit velocity of steam

(ii) ratio of cross-section of exit and that at throat.

Given:

$P_1 = 11$ bar

$P_2 = 2$ bar



h-s diagram.

Soln:

The critical pressure ratio when steam is initially dry saturated, $\frac{P_t}{P_1} = 0.577$

∴ Throat pressure of steam,

$P_t = 0.577 \times P_1 = 0.577 \times 11$

$P_t = 6.38$ bar.

Properties of steam at 20 bar and 250°C

$h_1 = 2780$ KJ/kg.

Since, expansion is isentropic, from $h_1 = 2780$ KJ/kg, a vertical line is drawn in mollier diagram up to 6.38 bar pressure line. Now, following values are noted at point:

$h_t = 2679$ KJ/kg, $v_t = 0.285$ m³/kg.

Velocity of steam at throat,

$V_t = \sqrt{2000(h_1 - h_t)} = \sqrt{2000(2780 - 2679)}$

$V_t = 449.44$ m/s

mass flow rate of steam/nozzle. $m = \frac{A_1 V_t}{v_t}$

Throat Area, $A_t = \frac{m v_t}{V_t}$

$$A_t = \frac{m \times 0.285}{449.44}$$

$$A_t = 6.34 \times 10^{-3} \, m$$

Similarly, a vertical line is drawn in mollier diagram up to 2 bar pressure line from $h_1 = 2780$ KJ/kg. Now following values are noted at that point.

$$h_2 = 2480 \text{ KJ/kg}$$

$$v_2 = 0.7965 \, m^3/kg$$

Velocity of steam at exit, $= \sqrt{2000(h_1 - h_2)}$

$$= \sqrt{2000(2780-2480)}$$

$$V_2 = 774.6 \, m/s$$

Exit Area, $A_2 = \frac{m \cdot v_2}{V_2} = \frac{m \times 0.7965}{774.6}$

$$A_2 = 1.028 \times 10^{-3} \, m$$

Ratio of exit area to throat area:

$$\frac{A_2}{A_1} = \frac{1.028 \times 10^{-3} \, m}{6.34 \times 10^{-3} \, m} = 0.162$$

$$\frac{A_2}{A_1} = 0.162$$

Problem

A convergent - divergent nozzle is required to discharge 2kg of steam per sec. The nozzle is supplied with steam at 7 bar and 180°c and discharge takes place against a back pressure of 1bar. The expansion up to throat is isentropic and friction resistance bet throat and exit is equivalent to 63 KJ/kg of steam. Taking approach velocity of 75m/s and throat 4 bar. estimate:

(i) suitable areas for throat & Exit and

(2) overall efficiency of nozzle based on enthalpy drop between the actual inlet pressure and temp and exit pressure.

Given data:

$m = 2kg/s$, $P_1 = 7bar$, $T_1 = 180°c$, $P_t = 4 bar$, $P_2 = 1 bar$

$h_2 - h_{2s} = 63 KJ/kg$, $V_1 = 75m/s$.

Soln:

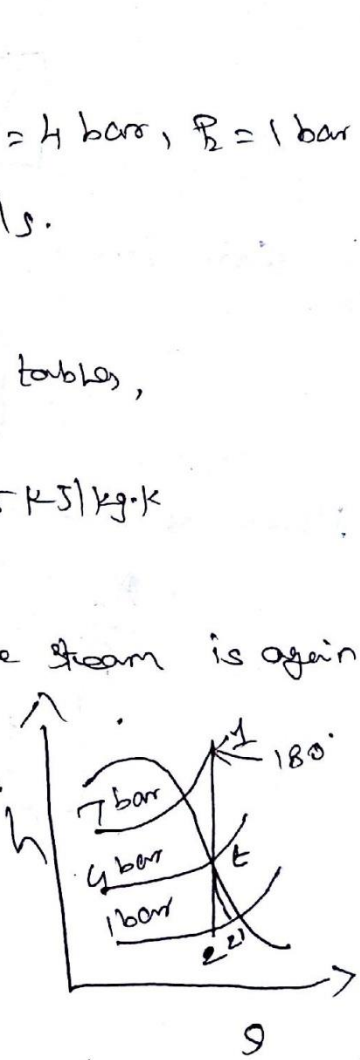
Properties of steam from steam tables,

At 7 bar and 180°c

$h_1 = 2888.5 KJ/kg$; $S_1 = 6.975 KJ/kg.K$

$v_1 = 0.3146 m^3/kg$.

S_1 is more than S_{gt}. Therefore ; the steam is again in superheated condition.



h-s diagram

From mollier diagram, corres to 4 bar.

$h_t = 2780 KJ/kg$, $v_t = 0.462455 m^3/kg$.

At 1 bar,

$h_f = 417.4 KJ/kg$, $h_g = 2675 KJ/kg$

$S_f = 1.303 KJ/kg.K$ $S_g = 7.359 KJ/kg.K$

$v_f = 0.001043 m^3/kg$, $v_g = 1.694 m^3/kg$.

1-2 ⇒ Isentropic Expansion

$s_1 = s_2 = 6.975 \ kJ/kg.$

$s_2 = s_{f2} + x_2 \cdot s_{fg2}$

$6.975 = 1.303 + x_2 \times (7.359 - 1.303)$

$x_2 = 0.937$

$h_2 = h_{f2} + x_2 \cdot h_{fg2}$

$= 417.4 + 0.937 \times (2675 - 417.4)$

$h_2 = 2532.77 \ kJ/kg$

But, $h_2' - h_2 = 63 \ kJ/kg.$

$h_2' = 2532.77 + 63 = 2595.77 \ kJ/kg.$

Velocity of steam at throat,

$$V_t = \sqrt{2000(h_1 - h_t) + \frac{V_1^2}{2000}}$$

$$= \sqrt{2000(2888.5 - 2780) + \frac{75^2}{2000}}$$

$V_t = 465.62 \ m/s.$

Throat Area, $A_t = \frac{m \cdot v_t}{V_t} = \frac{2 \times 0.462455}{465.62}$

$A_t = 0.0001986 \ m^2$

Velocity of steam at throat,

$$V_2 = \sqrt{2000(h_1 - h_2') + \frac{V_1^2}{2000}}$$

$$= \sqrt{2000(2888.5 - 2469.77) + \frac{75^2}{2000}}$$

$V_2 = 915.13 \ m/s$

To calculate x_2',

$h_2' = h_{f2} + x_2' \cdot h_{fg2}$

$$W_{max} = 2V_b\left[V_1 \cdot \frac{2V_b}{V_1} - V_b\right]$$

$$= 2V_b(2V_b - V_b)$$

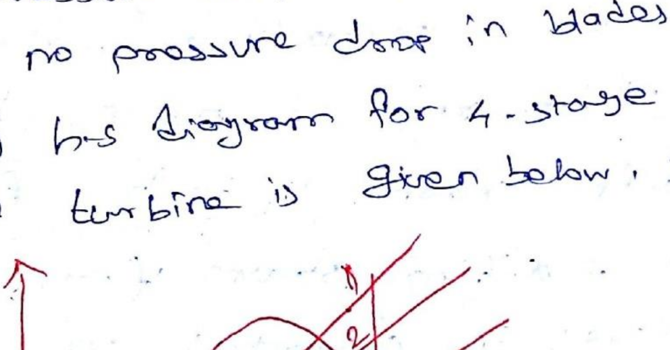
$$\boxed{W_{max} = 2V_b^2}$$

-x-

VELOCITY DIAGRAM FOR MULTISTAGE TURBINES:

Pressure Compounding:

When four simple impulse turbines are connected in series, the total enthalpy drop is divided equally among stages. So, the pressure drop only occurs in nozzle whereas there is no pressure drop in blades. Therefore, the corresponding h-s diagram for 4-stage pressure compounding steam turbine is given below.



h-s diagram.

Enthalpy drop in each stage will be equal.

$h_1 - h_2 = h_2 - h_3 = h_3 - h_4 = h_4 - h_5$

so, $h_1 - h_2 = \frac{h_1 - h_5}{4}$

The velocity of steam at exit from first row of nozzle is given by,

$$V_1 = \sqrt{2000(h_1 - h_2)}$$

$$= \sqrt{2000\left(\frac{h_1 - h_5}{4}\right)}$$

$$= \frac{1}{2}\sqrt{2000(h_1 - h_5)}$$

But for a single stage turbine, the velocity of steam at exit of nozzle, $V_1 = \sqrt{2000(h_1 - h_5)}$.

For n-stage, enthalpy drop per stage will be

$$(\Delta h)_{Stage} = \frac{(\Delta h)_{Total}}{n} = \frac{h_1 - h_2}{n}$$

(or)

$$\text{No. of stages} = \frac{(\Delta h)_{Total}}{(\Delta h)_{Stage}}$$

Pressure Compounding:

Velocity Compounding :-

The K.E of steam jets $(\frac{1}{2}mv_1^2)$ at nozzle exit is partially converted into work in 1st row of moving blades with velocity diff from V_1 to V_2. Again K.E $(\frac{1}{2}mV_3^2)$ of exiting steam from first row of moving blades in converted into work in next row of moving blades and so on.

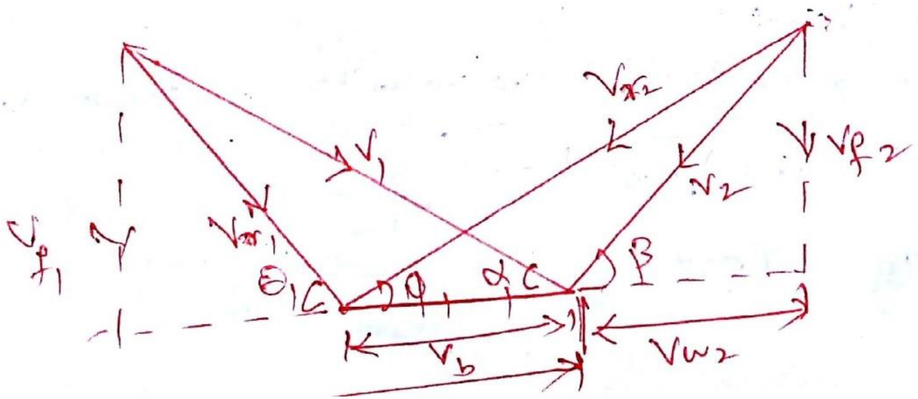
$$\frac{V_{r2}}{V_{r1}} = K.$$

$$\text{Work done,} = m(V_{w_1} + V_{w_2})V_b$$

$$\text{Axial Thrust} = m(V_{f_1} - V_{f_2})$$

K.E of steam supplied for first stage,

$$K.E_1 = \frac{1}{2}mv_1^2.$$



Same friction factor is considered for next row of moving blades.

$$\frac{V_3}{V_2} = K \text{ and also } \frac{V_{r4}}{V_{r3}} = K.$$

$$\text{Work done}_{II} = m(V_{w3} + V_{w4}) V_b.$$

$$\text{Axial Thrust} = F_{y_{II}} = m(V_{f3} - V_{f4})$$

$$K.E = \frac{1}{2} m V_3^2$$

∴ Total efficiency of steam turbine,

$$\eta = \frac{\text{Workdone}_I + \text{Workdone}_{II}}{K.E_I + K.E_{II}}$$

$$= \frac{m(V_{w1} + V_{w2}) V_b + m(V_{w3} + V_{w4}) V_b}{\frac{1}{2} m V_1^2 + \frac{1}{2} m V_3^2}$$

$$\eta = \frac{2V_b(V_{w1} + V_{w2} + V_{w3} + V_{w4})}{V_1^2 + V_3^2}$$

$$\text{Total axial Thrust, } F_y = F_{y_I} + F_{y_{II}}$$

$$= m(V_{f1} - V_{f2} + V_{f3} - V_{f4})$$

$$= m[(V_{f1} + V_{f3}) - (V_{f2} + V_{f4})]$$

— x —

Problem:-

The following data refer to a single stage impulse turbine: Isentropic nozzle enthalpy drop = 200 kJ/kg

Nozzle efficiency = 90%, Nozzle angle = 25°.

Ratio of blade speed to whirl component of steam speed = 0.5

Blade co-eff = 0.9, The velocity of steam entering the nozzle 30 m/s.

Find (i) the blade angles at inlet and outlet if steam enters blade without shock & leaves the blade in axial direction.

(ii) blade efficiency.

(iii) power developed.

(iv) axial thrust if steam flow rate is 10 kg/s.

Given data:

$h_1 - h_e' = 200$ kJ/kg, $\eta_N = 90\%$, $\alpha = 25°$, $\frac{V_b}{V_{w1}} = 0.5$

$\frac{V_{r2}}{V_{r1}} = 0.9$, $V_i = 30$ m/s, $V_2 = V_{f2}$, $V_{w2} = 0$, $\beta = 90°$

Soln:

Actual enthalpy drop,

$h_i - h_e = (h_i - h_e') \times \eta_N$

$h_i - h_e = 200 \times 0.9 = 180$ kJ/kg.

Exit velocity of nozzle,

$V_e = \sqrt{2(h_i - h_e) + V_i^2}$

$= \sqrt{2(1000 \times 180) + 30^2}$

$V_e = 600.75$ m/s.

Inlet velocity of steam to turbine,

$V_1 = V_e = 600$ m/s.

From $\triangle$ BCE, $V_{w1} = V_1 \cos 25° = 600.75 \cos 25° = 544.46$ m/s.

$V_{f1} = V_1 \sin 25° = 600.75 \sin 25° = 253.89$ m/s.

$V_b = 0.5$

$\therefore V_b = 0.5 \times 544.46 = 272.23$ m/s.

From ΔACE, $V_{r_1} = \sqrt{V_{f_1}^2 + (V_{w_1} - V_b)^2}$

$= \sqrt{253.89^2 + (544.76 - 272.23)^2}$

$= 372.25$ m/s.

$\tan\theta = \frac{V_{f_1}}{V_{w_1} - V_b} = \frac{253.89}{544.46 - 272.23}$

$\boxed{\theta = 43^\circ.}$

$V_{r_2} = 0.9 \times V_{r_1} = 0.9 \times 372.25 = 335.03$ m/s.

From ΔADB, $\cos\phi = \frac{AB}{AD} = \frac{V_b}{V_{r_2}} = \frac{272.23}{335.03}$

$\boxed{\phi = 35^\circ 39'}$

$V_2 = \sqrt{V_{r_2}^2 - V_b^2} = \sqrt{335.03^2 - 272.03^2} = 195.28$ m/s

$\therefore V_f = V_2 = 195.28$ m/s.

Power developed, $P = m(V_{w_1} + V_{w_2}) \times V_b$

$= 10(544.46 + 0) \times 272.23$

$\boxed{P = 1482.18 \text{ kW}}$

Blade efficiency, $\eta_b = \frac{(V_{w_1} + V_{w_2})V_b}{\frac{1}{2} V_1^2}$

$\boxed{\eta_b = 82.14\ \%}$

Axial Thrust, $F_y = m(V_{f_1} - V_{f_2})$

$= 10(253.89 - 195.28)$

UNIT-4

AIR COMPRESSORS

INTRODUCTION.

The process of increasing the pressure of air, gas or vapour by reducing its volume is called Compression and device used to carry out this process is called a Compressor.

Compressed air is mostly used in pneumatic brakes, pneumatic drills, Pneumatic Jacks, Pneumatic lifts, spray painting, Shop Cleaning, injecting fuel in diesel engines. etc.

CLASSIFICATION OF AIR COMPRESSOR:

(1) According to design & principle of operation
- (a) Reciprocating Compressors
- (b) Rotary Compressors.

(2) According to action
- (a) Single acting compressors
- (b) Double acting compressors.

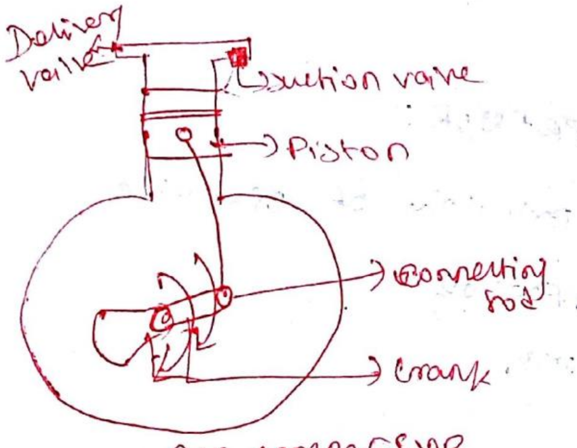
... to no. of stages.

WORKING OF SINGLE STAGE RECIPROCATING AIR COMPRESSOR:

In a single stage compressor, the compression of air from the initial pressure to final pressure is carried out in one cylinder only.

It consist of a cylinder, piston, connecting rod, crank, inlet & discharge valves.

When the piston moves downwards i.e during suction stroke, the pressure of air inside the cylinder falls below atm pressure.



AIR COMPRESSOR

So, the inlet valve opens and air from atm is sucked into cylinder until piston reaches bottom dead centre.

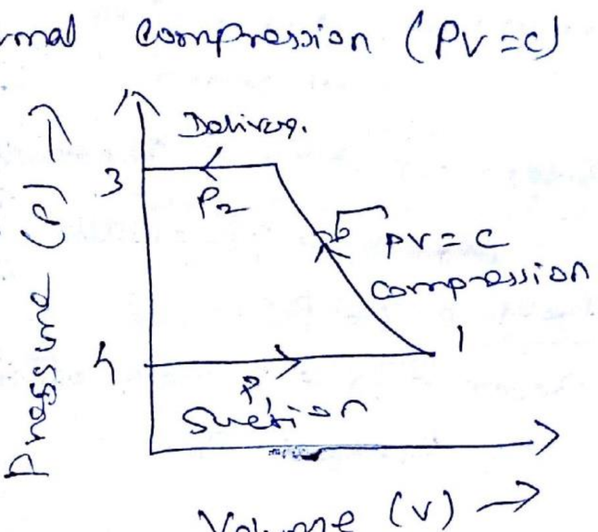
During this stroke, the delivery valves remains closed. When piston moves upwards, both valves are closed. So, the pressure inside the cylinder goes on increasing till it reaches required discharge pressure.

At this stage, discharge valve opens and compressed air is delivered through this valve. Thus cycle is repeated.

WORK DONE BY A SINGLE STAGE RECIPROCATING AIR COMPRESSOR WITHOUT CLERANCE VOLUME.

(a) Work done during Isothermal compression ($PV = C$)

P-V diagram for it:



Isothermal compression.

Process 4-1 - Suction of air @ pressure P_1

Process 1-2 - Isothermal compression

Process 2-3 - Discharge of air @ Pressure P_2

Work done = Area 1-2-3-4-1

$W = W_{comp} + W_{Del} + W_{Suc}$

$= P_1V_1 \ln\left(\frac{V_1}{V_2}\right) + P_2V_2 - P_1V_1$

$= P_1V_1 \ln\left(\frac{V_1}{V_2}\right) + P_2V_2 - P_1V_1$

[$\because P_1V_1 = P_2V_2$ for isothermal process.]

$\therefore W = P_1V_1 \ln\left[\frac{V_1}{V_2}\right]$

$\frac{V_1}{V_2} = \frac{P_2}{P_1}$ [$\because P_1V_1 = P_2V_2$]

$\therefore W = P_1V_1 \ln\left(\frac{P_2}{P_1}\right)$

W.K.T, $PV = mRT$

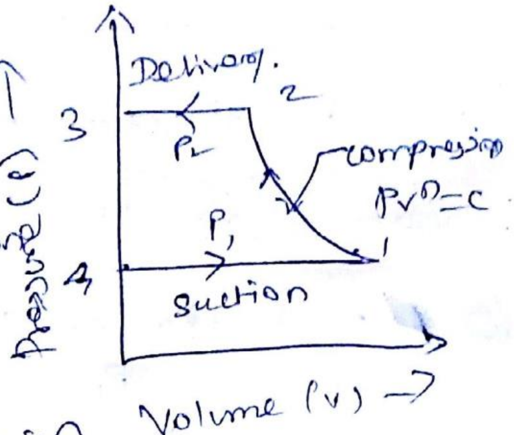
$W = mRT_1 \ln\left(\frac{P_2}{P_1}\right)$

(b) Work done during polytropic compression ($PV^n = C$)

Process 4-1 - Suction of air at pressure P_1

Process 1-2 represents compression of air polytropically from P_1 to P_2.

Process 2-3 - delivery of air @ pressure P_2.



POLYTROPIC COMPRESSION.

Work done = Area 1-2-3-4-1

$$W = W_{comp} + W_{Del} - W_{suc}.$$

$$W = \frac{P_2V_2 - P_1V_1}{n-1} + P_2V_2 - P_1V_1$$

$$= \frac{P_2V_2 - P_1V_1 + (n-1)P_2V_2 - (n-1)P_1V_1}{n-1}$$

$$= \frac{P_2V_2 - P_1V_1 + nP_2V_2 - P_2V_2 - nP_1V_1 + P_1V_1}{n-1}$$

$$= \frac{nP_2V_2 - nP_1V_1}{n-1} = \frac{n(P_2V_2 - P_1V_1)}{n-1}$$

$$\therefore W = \frac{n}{n-1}(P_2V_2 - P_1V_1)$$

$P_1V_1 = mRT_1$, $P_2V_2 = mRT_2$.

$$W = \frac{n}{n-1}\left[mRT_2 - mRT_1\right]$$

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

$$W = \frac{n}{n-1} mRT_1\left(\frac{T_2}{T_1} - 1\right)$$

For polytropic process, $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$$W = \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

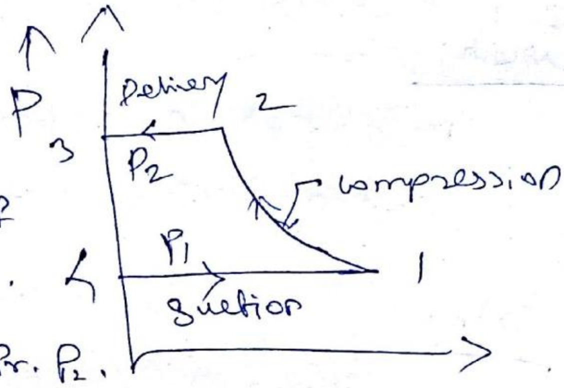
$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] \quad (\because PV = mRT)$$

c) Work done during isentropic compression: ($PV^{\gamma} = C$)

Process 4-1 - Suction of air at pressure P_1

Process 1-2 - isentropic comp of air from P_1 to P_2.

Process 2-3 - Delivery of air @ Pr. P_2.



Isentropic compression.

Workdone = Area 1-2-3-4-1

$$W = W_{comp} + W_{del} - W_{suc}$$

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

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

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

$$\therefore W = \frac{\gamma}{\gamma - 1} \left[P_2 V_2 - P_1 V_1\right]$$

$P_1 V_1 = mRT_1$, $P_2 V_2 = mRT_2$

$$W = \frac{\gamma}{\gamma - 1} (mRT_2 - mRT_1)$$

$$W = \frac{\gamma}{\gamma - 1} mRT_1 \left(\frac{T_2}{T_1} - 1\right)$$

$$W = \frac{\gamma}{\gamma - 1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right] \quad (\because P_1 V_1 = mRT)$$

Problem.

A single stage air compressor is required to compress 0.75 m³ of air from 1.2 bar to 9 bar at 27°C. The compression takes place according to law $pv^{1.35} = c$. Determine work done by compressor and temp at end of compression.

Given:

$V_1 = 0.75 m^3$, $P_1 = 1.2 bar = 120 KPa$.

$P_2 = 9 bar$, $T_1 = 300 K$, $n = 1.35$

Soln.

Work done on a single stage reciprocating air compressor without clearance volume.

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{1.35}{1.35-1} \, 120 \times 0.75 \left[\left(\frac{900}{120} \right)^{\frac{1.35-1}{1.35}} - 1 \right]$$

$$W = 238.15 \text{ KJ.}$$

W.K.T,
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

$$T_2 = 300 \times \left(\frac{900}{120} \right)^{\frac{0.35}{1.35}}$$

$$\boxed{T_2 = 505.812 K}$$

— x —

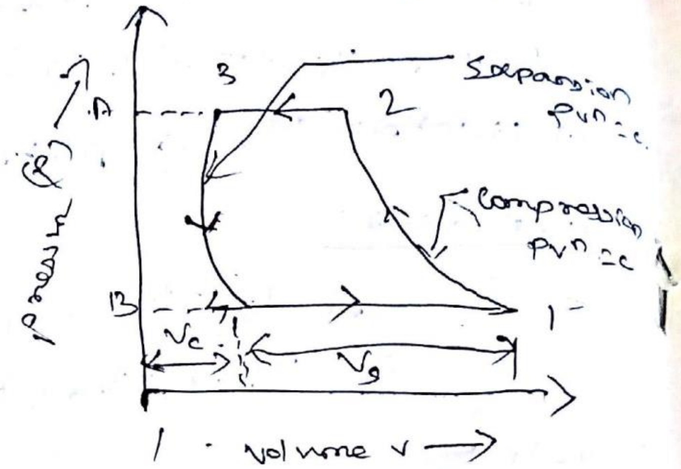
WORK DONE BY SINGLE STAGE RECIPROCATING AIR COMPRESSOR WITH CLERANCE VOLUME:

P_1, V_1, T_1 - Initial pressure, Temp & volume of air res.

P_2, V_2, T_2 - corresponding values for final condition.

V_c - clearance volume.

V_s - stroke volume $= V_1 - V_c$



Work done by compressor for cycle.

$$W = \text{Area } 1-2-3-4-1 = \text{Area }(1-2-A-B-1) - \text{Area }(3-A-B-4-3)$$

W = Work done during comp − Work done during Expansion

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] - \frac{n}{n-1} P_4 V_4 \left[\left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W = \frac{n}{n-1} P_1 \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right) (V_1 - V_4)$$

$$= \frac{n}{n-1} P_1 (V_1 - V_4) \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right)$$

$$= \frac{n}{n-1} P_1 V_a \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right)$$

$$\therefore W = \frac{n}{n-1} m R T_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right].$$

VOLUMETRIC EFFICIENCY:

It is defined as ratio of vol of free air sucked into compressor per cycle to stroke vol of cylinder.

$$\eta_{vol} = \frac{\text{Vol. of free air taken per cycle}}{\text{stroke vol. of cylinder}}$$

$\eta = \frac{V_a}{V_s}$ from P-V diagram

$V_a = V_s - x$

$x = V_4 - V_c$

$$\eta_{vol} = \frac{V_s - x}{V_s} = \frac{V_s - (V_4 - V_c)}{V_s}$$

$$= \frac{V_s - V_c\left[\frac{V_4}{V_c} - 1\right]}{V_s}$$

$$\eta_{vol} = 1 - \frac{V_c}{V_s}\left[\frac{V_4}{V_c} - 1\right]$$

Both compression & expansion follow the law $pv^n = c$

$P_3 V_3^n = P_4 V_4^n$.

from P-V diagram, $V_3 = V_c$, $P_4 = P_1$, $P_3 = P_2$

$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{1/n}.$$

$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{1/n}.$$

$$\frac{V_4}{V_c} = \left(\frac{P_2}{P_1}\right)^{1/n}.$$

$$\eta_{vol} = 1 - \frac{V_c}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right].$$

Clerance ratio, $C = \frac{V_c}{V_s}$

$$\eta_{vol} = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right]$$

$$\eta_{vol} = 1 + C - C\left[\left(\frac{P_2}{P_1}\right)^{1/n}\right]$$

at 1.K, T1

$$\eta_{vol} = \frac{V_a}{V_s}$$

$$0.75 = \frac{25}{V_s}$$

$$V_s = 33.33 \ m^3/min.$$

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

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

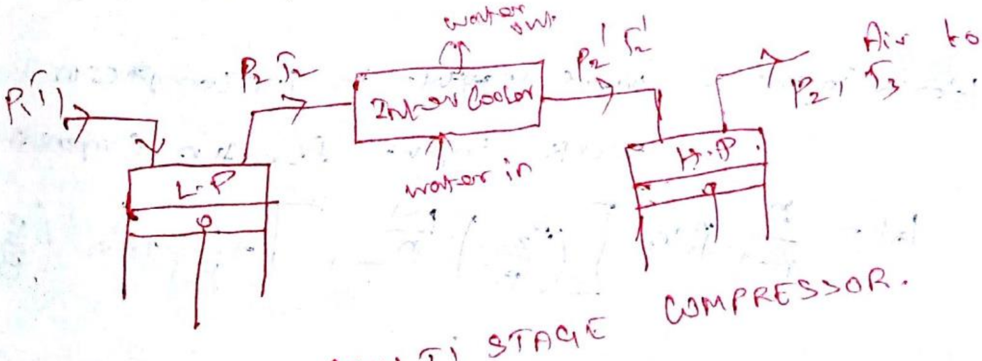
$$T_2 = 288 \times \left(\frac{1500}{100}\right)^{\frac{0.35}{1.35}}$$

$$\boxed{T_2 = 581.17 K}$$

MULTI STAGE AIR COMPRESSOR WITH INTERCOOLING

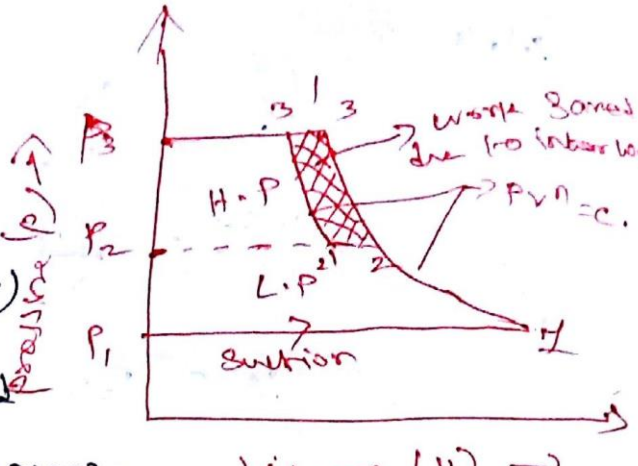
In a multistage compressor, compression of air from initial pressure, to final pressure is carried out in more than one cylinder.

It is used to get high-Pressure air. In a compressor, when compression ratio exceeds 5.



MULTI STAGE COMPRESSOR.

It consists of a low-pressure cylinder (LP) an inter cooler and a high-pressure cylinder (HP).



The fresh air is sucked from atm in low-pressure cylinder during its suction stroke at intake pressure P_1 and temp T_1.

The air after compression in LP cylinder is delivered to intercooler at pressure P_2 and temp T_2.

In intercooler, the air is cooled at constant pressure by circulating cold water. The cooled air from intercooler is then taken to high-pr cylinder.

In high pressure cylinder, air is further compressed to final delivery pressure (P_3) and discharged to receiver.

WORK DONE BY A TWO-STAGE COMPRESSOR WITH INTERCOOLER

Work input = Work input in L.P compressor + Work input for H.P compressor.

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + \frac{n}{n-1} P_2' V_2' \left[\left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] + \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2\right]$$

Problem:

A Two stage single acting reciprocating air compressor takes $6 m^3$ of air at 1.1 bar & 23°c. and compresses it into 20 bar. The intermediate receiver cools the air to 25°c and 8.5 bar pressure. The law of comp. $PV^{1.35} = C$. calculate work done.

Given:

$V_1 = 6 m^3$, $P_1 = 1.1$ bar, $T_1 = 300 K$, $P_3 = 20$ bar,

$T_2' = 298 K$, $P_2' = 8.5$ bar, $n = 1.35$

Soln.:

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] + \frac{n}{n-1} P_2 V_2 \left[\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1\right]$$

$$V_2 = V_1 \left(\frac{P_1}{P_2}\right)^{1/1.35} = 6 \left(\frac{110}{850}\right)^{1/1.35} = 1.319 m^3.$$

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{0.35}{1.35}} = 300 \times \left(\frac{850}{110}\right)^{\frac{0.35}{1.35}} = 509.74 K.$$

$$\frac{V_2}{T_2} = \frac{V_2'}{T_2'} \Rightarrow V_2' = V_2 \times \frac{T_2'}{T_2}$$

$$V_2' = 1.319 \times \frac{298}{509.7} = 0.771 m^3.$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2' V_2'}{T_2'}$$

$$V_2' = \frac{P_1 V_1 T_2'}{P_2' T_1} = \frac{110 \times 6 \times 298}{850 \times 300} = 0.771\,m^3$$

$$W = \frac{1.35}{1.35-1} \times 110 \times 6 \times \left[\left(\frac{850}{110}\right)^{\frac{1.35-1}{1.35}} - 1\right]$$

$$+ \frac{1.35}{1.35-1} \times 850 \times 0.771 \times \left[\left(\frac{2000}{850}\right)^{\frac{0.35}{1.35}} - 1\right]$$

$$W = 2407.64\ kJ.$$

— x —

A three stage air compressor delivers 5.2 m^3 of free air per min. The suction pr & Temp are 1 bar and 30°C. The pressure & Temp are 1.013 bar and 20°C at free air condition. The air is cooled at 30°C after each stage of compression. The delivery pressure of compressor is 150 bar. Rpm of the compressor is 300. The clearance of L.P, I.P & H.P cylinders are 5% of respective strokes. The index of comp & expansion is 1.35. Neglecting fr. losses, find the B.P of motor required to run compressor. If mechanical efficiency is 80%.

Given

V_1

(

P_4

so

W

Given data :

$V_a = V_0 = 5.2\, m^3/min.$

$P_1 = 1\, bar$, $P_0 = 1.013\, bar$, $T_0 = 293\, K$, $T_1 = 303\, K$.

$P_4 = 150\, bar$, $N = 300\, rpm$, $C = 5\% = 0.05$

$n = 1.35$, $\eta_{mech} = 80\%$.

Soln :

Intermediate pressure $\left(\frac{P_2}{P_1}\right) = \left(\frac{P_4}{P_1}\right)^{1/3}$

$$\boxed{\left(\frac{P_2}{P_1}\right) = 5.31}$$

$$\therefore \frac{P_2}{P_1} = \frac{P_3}{P_2} = \frac{P_4}{P_3} = 5.31$$

W.K.T, $V_a = 5.2\, m^3/min = \frac{5.2}{60} = 0.0867\, m^3/s.$

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_0}{T_1}$$

$$\frac{103 \times 0.0867}{293} = \frac{100 \times V_{a1}}{303}$$

$$V_{a1} = 0.0923\, m^3/s.$$

$$\frac{P_0 V_0}{T_0} = \frac{P_2 V_{a2}}{T_2} \Rightarrow \frac{103 \times 0.0867}{293} = \frac{531 \times V_{a2}}{303}$$

$$\therefore V_{a2} = 0.0174\, m^3/s.$$

$$\therefore V_{a3} = 0.0328\, m^3/s.$$

$$W = \frac{n}{n-1} P_1 V_{a1}\left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right) + \frac{n}{n-1} P_2 V_{a2}\left[\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1\right] + \frac{n}{n-1} P_3 V_{a3}\left(\left(\frac{P_4}{P_3}\right)^{\frac{n-1}{n}} - 1\right)$$

$$W = \frac{1.35}{1.35-1} \times 103 \times 0.0923 \times \left[(5.71)^{\frac{0.35}{1.35}} - 1 \right]$$

$$+ \frac{1.35}{1.35-1} \times 531 \times 0.0177 \times \left((5.71)^{\frac{0.35}{1.35}} - 1 \right)$$

$$+ \frac{1.35}{1.35-1} \times 2819.61 \times 0.00328 \times \left((5.71)^{\frac{0.35}{1.35}} - 1 \right)$$

$$\boxed{W = 57.91 \text{ kW}}$$

Mechanical Efficiency,

$$\eta_m = \frac{BP}{IP}$$

$$0.8 = \frac{BP}{57.912}$$

$$\boxed{\therefore BP = 46.33 \text{ kW}}$$

— x —

Unit - V.

Refrigeration & Air Conditioning:

5.1 Refrigeration:

It is the Science of Producing an maintaining temperature below that of the Surr atmosphere. This means the removing of heat from a substance to be Cooled.

The equipment employed to main the system at a low temperature is termed a Refrigerating system.

Refrigeration is generally Produced in one of the following three ways

i) By melting of a solid.
ii) By Sublimation of a solid
iii) By Evaporation of a liquid

Major Components:

→ Evaporator.
→ Compressor.
→ Condenser.
→ Expansion Valve.

5.2. Refrigerants:

The Refrigerants is defined as any substance that absorbs heat through expansion (or) vapourisation and loses its through Condensation in a Refrigeration system.

Clarification:

i) Primary Refrigerants

ii) Secondary Refrigerants

Primary Refrigerants:

These are working mediums (or) heat Carries which directly take Part in the refrigeration system and Cool the substance by the absorption of laten heat. Eg: Ammonia, CO_2, NH_4, sulphur dioxide.

Properties:

- Completely non-toxic
- Completely safe.
- Low volumetric ~~d~~displacement
- Low weight of liquid Circulated Per tonne of refrigeration.
- They mostly have specific gravity (for liquid) of 1.38.
- works at low Pressure
- High efficiency (Ammonia).

Secondary Refrigeration:

There are first Cooled with the Primary Refrigerants and then they are employed for Cooling Purposes.

i) **HaloCarbon:**

In this they Contain one (or) more of three halogens, Chlorine and bromide.

R-10 - Carbon tetrachloride.

R-11 - Trichloro - monofluro methane.

ii) **Azeotropes:**

They Consists of mixture of different substances.

Ex: R-500. it Contains 73.8% of R-12 & 26.2% of R-152.

iii) **HydroCarbons:**

They Contains Organic Components several hydroCarbons are used successfully in Commercial & Industrial installation.

R-50 - Methane.

R-170 - Ethane.

R-290 - ProPane.

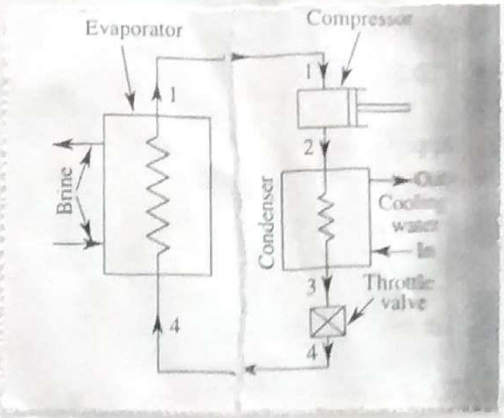
iv) **Inorganic Compounds:**

R717 - Ammonia(NH_3).

R718 - water

R729 - Air.

5.3: Vapour Compression System:



Compressor:

The function of a Compressor is to remove the Vapour from the evaporator. and to raise its temperature and Pressure to a Point.

Condenser:

The function of a Condenser is to provide a heat transfer surface through which heat Passes from the heat refrigerent Vapour to the Condensing Medium.

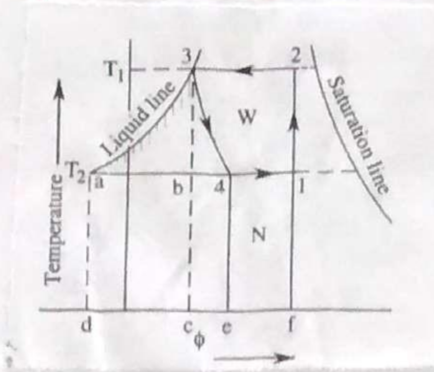
Expansion Valve:

Its function is to meter the proper amount of refrigerant to the evaporator and to reduce the Pressure of liquid entering the evaporator.

Evaporator:

An evaporator Provides a heat transfer through which heat can Pass from the refrigerated space into the Vapourizing refrigerant.

Vapour Compression Cycle:



At Point '2' the Vapour which is at low temperature (T_2) and low Pressure enters the Compressor's Cylinder and is Compressed adiabatically to '3' when its temperature increases to the temperature T_1. It is then Condensed in the Condenser (3-4). It then undergoes throttling expansion while Passing through the expansion Valve and its again Reduces to T_2. by the line 4-1.

Dryness fraction represented by $\frac{b_1}{b_2}$.

Work done by Compressor = W = Area '2-3-4-b-2'

Heat absorbed = N = Area '2-1-g-f-2'.

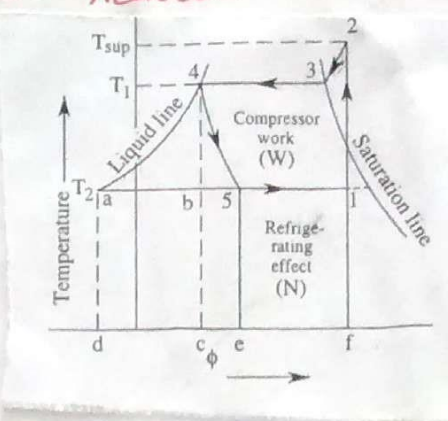
$$Cop = \frac{\text{Heat extracted (or) Refrigerating effect}}{\text{Workdone}}.$$

$$Cop = \frac{h_2 - h_1}{h_3 - h_2}.$$

$$= \frac{h_2 - h_4}{h_3 - h_2}.$$

$h_1 = h_4$ since during the throttling expansion 4-1 the total heat content.

When super heated:



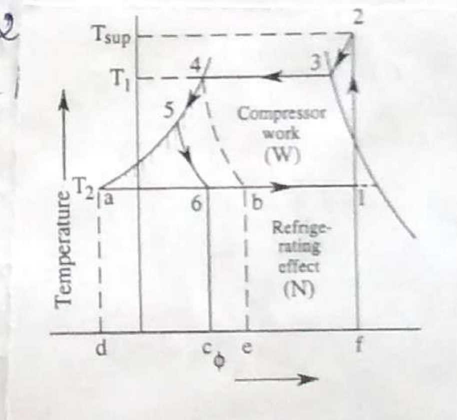
If the Compression of the Vapour is Continued after it become dry, the vapour will be superheated. The Vapour enters the Compressors at '2' and is Compressed to '3' where it is superheated to Temperature Tsup. Then it enters the Condenser. Firstly superheated Vapour Cools to T_1 and Condenses at const. temperature along the line 3'-4.

$$Cop = \frac{\text{heat extracted}}{\text{Work done}}$$

Work done = 2-3 $h_3 - h_2$

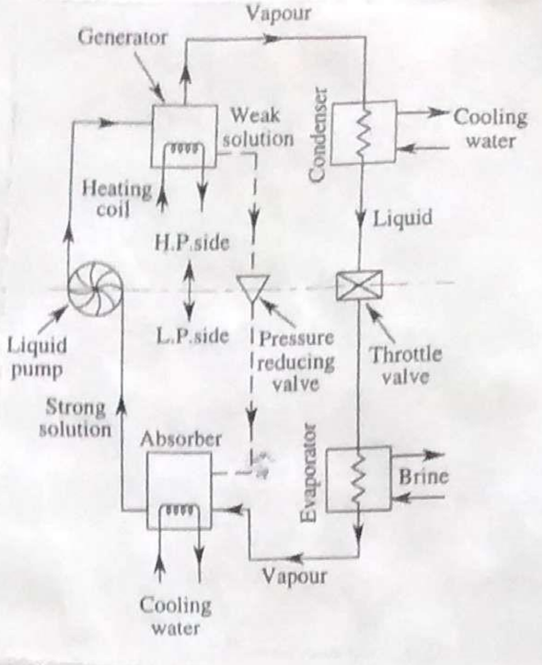
Heat extracted = $h_2 -$

Effect of subcooling:



The Process of Cooling the liquid refrigerant below the Condensing temperature for a given Pressure. It increases the Cop provided that no further energy has to be spent to obtain the extra Cold Coolant required.

5.4 Vapour Absorption System:



The solubility of Ammonia (or) lithium bromide (or) water. Can be used as Refrigerants [only refrigents differs but not the working Conditions & Process].

The Ammonia Vapour leaving the evaporator at point 2 is readily absorbed in the low temper hot solution in the absorber. The process is accombined by the rejection of heat. The ammonia is pumped to the higher pressure and is heated.

In this workdone on Compressor is less than vapour Compression Cycle.

$$\text{Cop} = \frac{\text{Heat extracted from the Evaporator}}{\text{Heat Supplied in the generator} + \text{Work done by the liquid Pump}}$$

prob on Vapour Compression, Superheat & Subcooled

prob: 5.1
pg: 813 (Rajput).

Given:

m = 6 kg/min ; $\eta_{relative}$ 50% ; x_2 = 0.6 ; C_{pw} = 4.187 kJ/kg

Laten heat of ice = 335 kJ/kg.

Soln:

h_{f_2} = 31.4 kJ/kg ; h_{fg_2} = 154.0 kJ/kg.

h_{f_3} = 59.7 kJ/kg. ; h_{fg_3} = 138 kJ/kg ; h_{f_4} = 59.7 kJ/kg.

$h_2 = h_{f_2} + x \cdot h_{fg_2}$.

$= 31.4 + 0.6 \times 154$

$h_2 = 123.8$ kJ/kg.

$s_3 = s_2$ (Isentropic)

$$s_{f_3} + x_3 \frac{h_{fg_3}}{T_3} = s_{f_2} + x_2 \frac{h_{fg_2}}{T_2}.$$

$$0.2232 + x_3 \times \frac{138}{298} = 0.1251 + 0.6 \times \frac{154}{268}$$

$= 0.4698$

$x_3 = 0.5325$.

$h_3 = h_{f_3} + x \cdot h_{fg_3}$

$= 59.7 + 0.5325 \times 138$.

$= 133.2$ kJ/kg.

Also, $h_1 = h_{f_4} = 59.7$ kJ/kg.

$$Cop = \frac{h_2 - h_1}{h_3 - h_2} = \frac{123.8 - 59.7}{133.2 - 123.8} = 6.82.$$

Actual $COP = \eta_{rel} \times COP_{theoritical}$

$= 0.5 \times 6.82$

$= 3.41$

Heat extracted from 1kg of water at 20°C for the formation of 1kg of ice at 0°C

$= 1 \times 4.187 \times (20) + 335$

$= 418.74 \ kJ/kg$

$COP_{actual} = 3.41 = \frac{R_n \ actual}{W}$

$= \frac{m_{ice} \times 418.74}{m(h_3 - h_2)}$

$m_{ice} = \frac{6(133.2 - 123.8) \times 3.41}{418.74}$

$= 0.459 \ kg/min$

$= \frac{0.459 \times 60 \times 24}{1000}$

$= 0.661$ tonne

prob: 5.2.
Pg: 815. → (R. Put)

soln:

Given:

5 tonne plant.

(h1) Compressor enthalpy h_1 = 183.19. kJ/kg.

(h4) Condenser = 74.59 kJ/kg.

h_3 = 209.41 kJ/kg.

soln:

Total refrigeration effect produced = 5 TR.

= 5×14,000 = 70,000 kJ/h

i) The refrigerant flow rate, $\dot{m}$:

Net refrigerant effect = $h_2 - h_1$

= 183.19 - 74.59.

= 108.6 kJ/kg.

Refrigerant flow rate,

$$\dot{m} = \frac{19.44}{108.6} = 0.179\ kg/s.$$

ii) The Cop:

$$Cop = \frac{h_2 - h_1}{h_3 - h_2} = \frac{183.19 - 74.59}{209.41 - 183.19}$$

= 4.142.

iii) The Power required to drive the Compressor.

$P = \dot{m}(h_3 - h_2)$

= 0.179(209.41 - 183.19)

= 4.69 kW.

iv) The rate of heat rejection to the Condensor.

= $\dot{m}(h_3 - h_4)$

= 0.179(209.41 - 74.59)

= 24.13 kW.

5.3 Prob:
Pg: 823.

Given:

$h_2 = 615$ kJ/kg.

$h_3 = 664$ kJ/kg.

$h_4 = h_1 = 446$ kJ/kg.

$v_2 = 0.14\ m^3/kg$.

Soln:

i) Refrigerating effect Per kg.

$= h_2 - h_1 = 615 - 446 = 169$ kJ/kg.

ii) Mass of refrigerant to be Circulated Per min,

$$m = \frac{20 \times 14\,000}{169 \times 60} = 27.6\ kg/min.$$

iii) Theoritical piston displacement.

= Specific Volume at suction × Mass of refrigerant used/min

$= 0.14 \times 27.6 = 3.864\ m^3/min.$

iv) Theoritical Power:

$$m \times (h_3 - h_2) = \frac{27.6}{60}(664 - 615)$$

$= 22.54$ kJ/s.

v). $$Cop = \frac{h_2 - h_1}{h_3 - h_2} = \frac{615 - 446}{664 - 615} = 3.45.$$

vi) heat removed through the Condenser.

$= m(h_3 - h_4)$

$= 27.6(664 - 446)$

$= 6016.8$ kJ/min,

5.5 Air Conditioning:

It is the simultaneous Control of temperature, humidity, motion and Purity of atmosphere in Confined space.

Components:

- Fans
- Filters
- ducts
- Heating Chamber (or) Cooling unit.

operation:

The fan forces air into duct work which is Connected to the opening in the room.

The duct work directs the air to the room.

Air is Cleaned through the filters. it is either heated (or) Cooled depends upon the Condition in room. If Cool air is required. the air is Passed over the surface of a cooling Coil.

finally the air flows back to the fan and the cycle is Completed.

Types & Working:

Central System:

In this system the equipments such as fans, Coil are assembled in the field. A central system serves different rooms, requires individual Control of each room. The Condensed air is Carried to Varies rooms through ducts and return back to the Control plants through return duct.

oned System:

In Zoned Systems the building is divided into Zones Such that as nearly possible Conditions may be expected. Variation in requirements of this kind are the most Common Case with which air-Conditioning has to deal. The return air from the room passes through grills into the Corridor which acts as the returning air Collecting duct. The Cooling (or) heating booster Coils Could be served from Circulating water mains.

unitary System:

* They are assembled and fitted near to the Zone.

unitary is prefered for 15 tonnes Capacity (or) above $200 m^3/min$

Components are Attic; Remote units; self Contained units; Room air Conditioners; unit air Coolers.

5.6 Cooling Load Calculation:

The Cooling load is influenced by:

1. Location of the place geographically ie the lattitude, elevation above mean sea level and the normal

2. orientation, wheather it is north (or) South (or) East (or) west facing.

3. The building Construction features, regarding walls, window etc.

4. The load to the system Contributed by the number of People, appliences, lightning etc.

The heat Gain is divided into

i) Sensible heat

ii) latent heat.

Sensible heat gain:

It is the direct addition of heat in a given space. It may be due to Conduction through walls, Convection & radiation

laten heat gain:

It is due to the addition of moisture Coolent in the space If the humidity ratio is to be maintained (change of phase).

Room Sensible Heat factor:

Sensible heat factor is the ratio of sensible to total heat. The total heat is made up of the sensible heat and latent heat.

The room sensible heat factor is the ratio of room sensible to room total heat. The supply air must be able to remove both the room sensible heat & room latent heat.

Room Sensible heat factor RSHF $= \frac{RSH}{RTH} = \frac{RSH}{RSH + RLH}$

$$= \frac{\text{Room Sensible heat}}{\text{Room Total heat}}$$

$$RSHF = \frac{\text{Room Sensible Heat}}{\text{Room Sensible heat} + \text{Room latent Heat}}.$$

Grand Sensible Heat factor:

It is defined as the ratio of total sensible heat to the grand total heat load.

$$GSHF = \frac{TSH}{GTH} = \frac{TSH}{GSH + GLH}.$$

$$= \frac{\text{Total Sensible Heat}}{\text{Total sensible Heat} + \text{Total latent heat}}.$$

Effective Sensible Heat

It is the ratio of effective room Sensible heat to the sum of effective room Sensible heat and latent heat. Thus

$$ESHF = \frac{ERSH}{ERSH + ERLH} = \frac{ERSH}{ERTH}$$

$$= \frac{RSH + BF \times (OSH)}{[RSH + (BF \times OSH) + RLH + (BF \times OLH)]}$$

OSH → outside sensible heat

OLH → outside latent heat

Prob: 5.7
Pg: 8.52
(Ramoorthy).

Given:

Outdoor air

30° DB and 75% RH

No of People 50

Air / Person / min = 0.4 m³.

Room Air 20° DBT and 60% RH

Process: Sensible Cooling.
Dehumidification
Heating.

$T_c = 25°c$.

Soln:

(i) Estimate mass of air/s.

Volume of air $= \frac{.4 \times 50}{60} = 0.33\ m^3/s$

(ii) Cooling Coil Capacity = Mass of air × Drop in enthalphy.

$= .3766\ (81.5 - 34)\ kJ/s.$

$= 17.88\ kJ/s.$

$= 1073\ kJ/m.$

$= \frac{1073}{211}$ Tons of Ref $= 5.09.$

5.09 Tonnes of Refrigeration.

iii) Capacity of heating Coil $= mC_p\ (T_R - T_{dp})$

$= .3766 \times 1.005\ [20 - 12)$

$= 3.03\ kw.$

iv). Water removed /Hr $= (W_1 - W_2) \times .3766 \times 3600$

$= (20 - 8.75) \times .3766 \times \frac{3600}{1000}$

$= 15.25\ kg/Hr.$

Ans:

Cooling Coil Capacity = 4.23 Tons of Ref.

Heating Coil " = 3.03 kw.

Water removal/hr = 15.25 kg/hr.