A Laboratory Manual for

Applied Thermodynamics (3161910)

B.E. Semester 6 (Mechanical)

Directorate of Technical Education, Gandhinagar, Gujarat

LUKHDHIRJI ENGINEERING COLLEGE, MORBI

Vision of the Institute

To provide quality engineering education and transforming students into professionally competent and socially responsible human beings.

Mission of the Institute

- To provide a platform for basic and advanced engineering knowledge to meet global challenges
- To impart state-of-art know- how with managerial and technical skills
- To create a sustainable society through ethical and accountable engineering practices

MECHANICAL ENGINEERING DEPARTMENT

Vision of the Department

To deliver quality engineering education for Mechanical Engineers with Professional competency, Human values and Acceptability in the society.

Mission of the Department

- To nurture engineers with basic and advance mechanical engineering concepts
- To impart Techno-Managerial skill in students to meet global engineering challenges
- To create ethical engineers who can contribute for sustainable development of society

Program Educational Objectives (PEOs)

Program Educational Objectives of the Department are,

1. Apply their knowledge of basic science and engineering to analyze and solve problems related to mechanical engineering.
2. Able to design and develop the new system/process using advanced technologies and tools.
3. Enhance professional practice to meet global challenges with their ethical and social responsibility.

Program Specific Outcomes (PSOs)

1. Students will be able to apply the knowledge of computer aided tools for design and development of products based on engineering principles.
2. Students will be able to manage production of components/systems using conventional and advanced manufacturing methods.

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Certificate

This is to certify that Mr./Ms. ______________________________________ _________ Enrollment No. ________________ of B.E. Semester _____ Mechanical Engineering of this Institute (GTU Code: ____________) has satisfactorily completed the Practical / Tutorial work for the subject **Applied Thermodynamics (3161910)** for the academic year __________.

Place: ___________

Date: ___________

Name and Sign of Faculty member

Head of the Department

Preface

Main motto of any laboratory/practical/field work is for enhancing required skills as well as creating ability amongst students to solve real time problem by developing relevant competencies in psychomotor domain. By keeping in view, GTU has designed competency focused outcome-based curriculum for engineering degree programs where sufficient weightage is given to practical work. It shows importance of enhancement of skills amongst the students and it pays attention to utilize every second of time allotted for practical amongst students, instructors and faculty members to achieve relevant outcomes by performing the experiments rather than having merely study type experiments. It is must for effective implementation of competency focused outcome-based curriculum that every practical is keenly designed to serve as a tool to develop and enhance relevant competency required by the various industry among every student. These psychomotor skills are very difficult to develop through traditional chalk and board content delivery method in the classroom. Accordingly, this lab manual is designed to focus on the industry defined relevant outcomes, rather than old practice of conducting practical to prove concept and theory.

By using this lab manual students can go through the relevant theory and procedure in advance before the actual performance which creates an interest and students can have basic idea prior to performance. This in turn enhances pre-determined outcomes amongst students. Each experiment in this manual begins with competency, industry relevant skills, course outcomes as well as practical outcomes (objectives). The students will also achieve safety and necessary precautions to be taken while performing practical.

This manual also provides guidelines to faculty members to facilitate student centric lab activities through each experiment by arranging and managing necessary resources in order that the students follow the procedures with required safety and necessary precautions to achieve the outcomes. It also gives an idea that how students will be assessed by providing rubrics.

Applied thermodynamics is the course which provides an understanding of Refrigeration and Air-conditioning, Internal combustion engines and fluid power engineering fundamentals. The course consists of different internal combustion engines, fluid power engines and refrigeration cycles, types, components and understanding of its components. Further, the psychrometry for producing comfort air-conditioning and fundamentals of compressible fluid flow also addressed in this course.

Utmost care has been taken while preparing this lab manual however always there is chances of improvement. Therefore, we welcome constructive suggestions for improvement and removal of errors if any.

Applied Thermodynamics
(3161910)

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Practical – Course Outcome matrix

Sr. No.	Objective(s) of Experiment	CO1	CO2	CO3	CO4	CO5
1.	To understand different components of VCR system and to determine its COP.		√			
2.	To determine $(COP)_C$ and $(COP)_H$ of heat pump.		√			
3.	To study different psychrometric processes	√				
4.	To understand construction and working of window air-conditioner / split air-conditioner	√				
5.	To find COP of an Electrolux refrigerator (VARS)		√			
6.	To determine saturation efficiency of air cooler/air washer.	√				
7.	To study construction details of 4 stroke Petrol Engine			√		
8.	To carry out performance test of computerized four stroke single cylinder diesel engine test rig and draw heat balance sheet			√		
9.	Determination of friction power of multi cylinder petrol engine using Morse Test Method			√		
10.	To study the constructional details of various air compressors					√

Industry Relevant Skills

The following industry relevant competencies are expected to be developed in the student by undertaking the practical work of this laboratory.

1. Testing the performance of I.C. Engines, Compressors, Refrigeration and Air Conditioning devices.
2. Selecting the material for the required I.C. Engines, Compressors, RAC system and its layout.

Guidelines for Faculty members

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain basic concepts/theory related to the experiment to the students before starting of each practical
3. Involve all the students in performance of each experiment.
4. Teacher is expected to share the skills and competencies to be developed in the students and ensure that the respective skills and competencies are developed in the students after the completion of the experimentation.
5. Teachers should give opportunity to students for hands-on experience after the demonstration.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected from the students by concerned industry.
7. Give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions or not.
8. Teacher is expected to refer complete curriculum of the course and follow the guidelines for implementation.

Instructions for Students

1. Students are expected to carefully listen to all the theory classes delivered by the faculty members and understand the COs, content of the course, teaching and examination scheme, skill set to be developed etc.
2. Students shall organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and build confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. apart from those included in scope of manual.
6. Student shall refer technical magazines and ASHRAE design data books.
7. Student should develop a habit of submitting the experimentation work as per the schedule and should be well prepared for the same.

Common Safety Instructions

1. Students are expected to carefully wear goggles and gloves while charging refrigerants to the system.
2. Maintain laboratory clean and organized.
3. Switch off the main power supply to the experimental set up on completion of experiment.
4. Loose clothing and jewelry are prohibited.
5. Do not leave any running experimental set up unattended.

Index
(Progressive Assessment Sheet)

Sr. No.	Objective(s) of Experiment	Page No.	Date of performance	Date of submission	Assessment Marks	Sign. of Teacher with date	Remarks
1	To understand different components of VCR system and to derivation of its COP.						
2	To determine $(COP)_C$ and $(COP)_H$ of heat pump.						
3	To study different psychrometric processes						
4	To understand construction and working of window air-conditioner / split air-conditioner						
5	To find COP of an Electrolux refrigerator (VARS)						
6	To determine saturation efficiency of air washer.						
7	To study construction details of 4 stroke Petrol Engine						
8	To carry out performance test of computerized four stroke single cylinder diesel engine test rig and draw heat balance sheet						
9	Determination of friction power of multi cylinder petrol engine using Morse Test Method.						
10	To study the constructional details of various air compressors						
				Total			

Experiment No: 1

To understand different components of VCR system and derivation of its COP

Date:

Aim: To understand different components of VCR system and derivation of its COP.

Relevant CO: CO2

Objectives: (1) To study different components of VCR system. (2) To derive COP of VCR System.

Theory:

Refrigeration may be defined as an art of producing and maintaining a temperature in a space below the surrounding temperature. It also includes the process of removing heat from the substance under controlled conditions. It is used for the manufacturing of ice and similar products. This is widely used for cooling of storage chambers in which perishable foods, drinks and medicines are stored. The refrigeration has also wide application in submarine ships, aircrafts.

Vapour Compression Refrigeration (VCR) Cycle:

This cycle consists of following four processes:

(1) Reversible adiabatic compression from the saturated vapour to a superheated condition. (2) Reversible heat rejection at constant pressure (de-superheating and condensation of the refrigerant)

(3) Irreversible is enthalpy expansion from saturated liquid to a low-pressure vapour.

(4) Reversible heat addition at constant pressure.

System components and its function: -

(1) Compressor: Compressor is most important part of the system. The compressor raises the measure of incoming vapour from the evaporator to a high pressure.

Different types of compressors are:

1. Reciprocating compressor
2. Rotary compressor
3. Screw compressor
4. Centrifugal compressor

The selection of the above-mentioned compressor depends upon the usage. Usually, domestic refrigerator is installed with reciprocating compressor. A hermetic type compressor is one in which the compressor and motor integral on one shaft and they are both contained in a pressure shield housing. It is compact in size, quiet, low in cost and no problem of refrigerant gas leakage. The motor in a hermetic type compressor is cooled by refrigerant suction gas.

(2) Condenser: The function of a condenser is to remove heat from the superheated high pressure refrigerant vapour and to condense the vapour into a sub cooled high pressure liquid. This is accomplished a cooling medium either air or water. The air-cooled condenser may be of static cooled type where natural convective motion of air surrounding heat is enough to cool the condenser or they may be of fan cooled type. The static cooled condenser is used in domestic refrigerators. In commercial appliances and windows air-conditioners usually fan cooled condensers are used. The water condenser is normally used in large system firms 5 tons and above.

(3) Expansion Devices: As the high pressure sub-cooled refrigerant liquid from the condenser passes through the expansion device its pressure and temperature is reduced. And outlet refrigerant, mostly in liquid stage.

Expansion device is of many types and are selected as per the requirement. For example, for constant evaporator pressure requirement automatic expansion valve are used. If variation in cooling load is high the thermostatic valves are best suited. Hermetic compressor is almost invariably are used with capillary tube, through a few of them might also be used with thermostatic expansion valves.

(a) Thermostatic expansion valve: Thermostatic expansion valve controls the mass flow rate of refrigerant by sensing evaporator outlet temperature. Thus, the valve is sensitive to the cooling load. If the load is more, the degree of super hit of refrigerant coming out of the evaporator increases. To maintain the degree of super heat to preset level, more liquid is fed to evaporator. When the load is low, valve closes and less liquid quantity is fed. Selection of thermostatic expansion is done based on refrigerant used in capacity.

(b) Capillary tube: It is the simplest and cheapest form of expansion device. It does not include any moving parts hence no maintenance is required. Capillary tube is supposed to be a single point operation device in the sense that the best control is achieved only at a given set of operating parameters. Under varying loads, the capillary tube does not function satisfactorily. For example, at lower loads than designed value capillary tube may overfeed the evaporator causing liquid to return to compressor. Under higher loads than designed the capillary tube starves the evaporator, causing excessive return gas superheat. Hence for variation in cooling loads, it is not suitable.

(4) Evaporator: The function of evaporator is to remove heat from the product or the area to be cooled and maintain it at any desired temperature. The liquid refrigerant inside the evaporator evaporates by absorbing heat and converts into vapour refrigerant and then it returns into the compressor. Various types of constructions of the evaporator used in refrigerant system are,

1. Finned tube evaporator coil
2. Bare tube soldered/clamped to the tank
3. Bare tube dipped in the liquid to be cooled
4. Shell & coil type evaporator

The choice of construction depends on the type of appliance. However, in every case the heat capacity depends on these factors viz. temperature difference between the load and the refrigerant, heat transfer co-efficient and areas of the heat transfer.

(5) Drier: If by chance refrigerant is containing any water particle then in low temperature region (i.e. at and after the expansion valve) it forms ice and chokes the valve or bends thereby preventing the smooth passage of refrigerant through it. To prevent this drier is used to remove any water particles carried into the refrigerant. It is used in between the evaporator and compressor.

(6) Accumulator: It is fitted in between the evaporator and compressor. It prevents the liquid refrigerant from entering the compressor.

The processes of VCR cycle are:

Process 1-2: vapor refrigerant is compressed to a relatively high temperature and pressure requiring work input.

Process 2-3: vapor refrigerant condenses to liquid through heat transfer to the cooler surroundings.

Process 3-4: liquid refrigerant expands to the evaporator pressure.

Process 4-1: two-phase liquid-vapor mixture of refrigerant is evaporated through heat transfer from the refrigerated space.

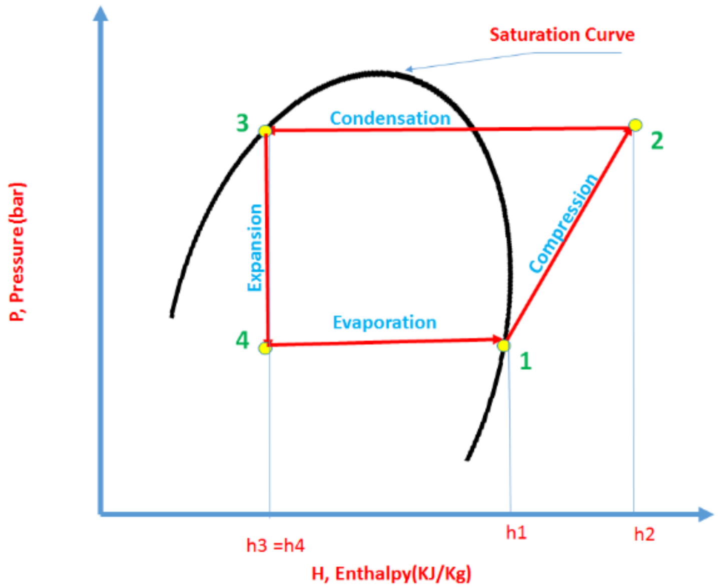


Fig. 1 VCR cycle on p – h diagram.

Applying mass and energy rate balances

Evaporator

$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_4$$

The term is referred to as the refrigeration capacity, expressed in kW in the SI unit system.

Compressor (assuming adiabatic compression)

$$\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1$$

Condenser

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3$$

Expansion valve (Assuming a throttling process)

$$h_4 = h_3$$

Coefficient of Performance (COP) = $\frac{Refrigeration\ Effect}{Compressor\ work} = \frac{\left[\frac{\dot{Q}_{in}}{\dot{m}}\right]}{\left[\frac{\dot{W}_c}{\dot{m}}\right]} = \frac{h_1 - h_4}{h_2 - h_1}$

Theoretical COP= $\frac{\mathbf{h_{eo} - h_{ei}}}{\mathbf{h_{co} - h_{ci}}} = \frac{\mathbf{h_1 - h_4}}{\mathbf{h_2 - h_1}}$

Carnot COP= $\frac{\mathbf{T_L}}{\mathbf{T_H - T_L}}$

Where, T_H = saturation temperature corresponding to condenser pressure and T_L = saturation temperature corresponding to evaporator pressure

Quiz: (attach separate sheets)

1. Why in practice a throttle valve is used in vapour compression refrigerator rather than an expansion cylinder to reduce pressure between the condenser and the evaporator?
2. Explain construction and working of simple vapour compression refrigeration system. With p–V, T–s and p–h diagram.

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.
(2) Engineering Thermodynamics by P.K. Nag, McGraw-Hill Education

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 2
To determine $(COP)_C$ and $(COP)_H$ of heat pump.

Date:

Competency and Practical Skills: Fundamentals and second law of thermodynamics.

Relevant CO: CO2

Objectives: To determine heating and cooling COP of a Heat pump.

Equipment/Instruments: Heat pump test rig.

Theory:

Now-a-days, energy conservation is becoming very important. Hence engineers have started using heat pump systems for commercial and industrial buildings to save energy. The heat pump is a machine that absorbs heat at one location and transfers it to another location at a different temperature. Heat pump is the modern expression for a refrigeration system in which heat discharged at the condenser is of prime importance. Thus, heat pump is device which collects heat from one source and delivers it to another source using refrigeration cycle. The medium being, cooled serves as heat source. Heat is picked up by the refrigerant, which is pumped to another higher level by the compressor and given to the medium cooling condenser so that it can be used practically. The heat pumps can be operated on low temperature heat energy using winter air, a body of water or the ground as a reservoir and rejecting heat at a higher temperature, not enough to energize heating systems. Thus, the basic heat sources that are normally used are air, water and earth. When heat pumps are installed frequently provision is made for both heating and cooling services to be supplied simultaneously to the separate zones of buildings.

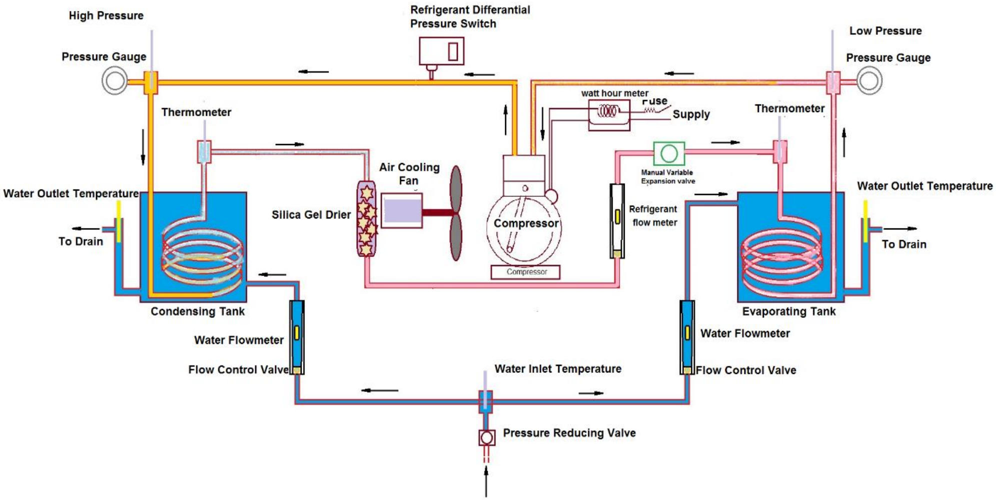


Fig. 1 Layout of heat pump system

Description:

The apparatus consists of refrigeration system with water-cooled shell coil type evaporator and condenser. A hermetically sealed compressor using R-134a refrigerant, Compresses the refrigerant and send to the condenser. Liquid refrigerant from the condenser passes through flow meter and drier/filter to capillary tube, where it is throttled to low pressure and temperature. The low temperature refrigerant passes to evaporator, boils in evaporator while absorbing heat from the water surrounding the coil and this low pressure superheated refrigerant returns to compressor. The condenser and evaporator are shell and coil type with continuous water flow. Flow rates of condenser and evaporator can be changed to obtain different working temperature for condenser and evaporator. Heat collected in evaporator, Heat rejected to condenser and input to the system can be measured and performance of the system can be evaluated as refrigeration cycle or as a heat pump.

Specification:

(1) Compressor – Hermetically sealed using R-134a refrigerant
(2) Condenser – Shell and coil type condenser
(3) Evaporator- Shell and coil type Evaporator
(4) Expansion device- capillary tube
(5) Measurements –
  a) Pressure gauge for condensing and evaporating pressure-2-No.
  b) Wattmeter for compressor input measurement
(6) Control
  a) Overload protector for compressor
  b) Necessary switches and fuse

Experimental Procedure: Heat Pump Test Rig

1) Connect and start the water supply to the unit.
2) Record initial temperature of water in both the tanks.
3) Switch "ON" the main supply. Switch "ON" the compressor. The temperature on the hot side will start steadily increase and that from the cold side shall be reducing. Note down all the readings when steady state condition is reached and complete the observation table.
4) May you need conduct another set of readings, drain the water completely with help of drain valves provided at the bottom and relief the tanks with fresh water and repeat the procedure.
5) Water inlet temperature should be taken before switching on compressor.

Observations:

(1) Mass flow rate of water in condenser m_1= __________ kg/sec
(2) Inlet temperature of water in condenser T_1 = _________K
(3) Outlet temperature of water in condenser T_2= __________ K
(4) Mass flow rate of water in evaporator m_2 = __________ kg/sec
(5) Inlet temperature of water in evaporator T_3 = __________ K
(6) Outlet temperature of water in evaporator T_4 = ___________ K
(7) Energy meter reading
  (i) Initial = ___________ kWh
  (ii) Final = ____________ kWh
(8) Time duration between two readings t = _________ sec
(9) Energy Meter constant = _____________ rev/kWh

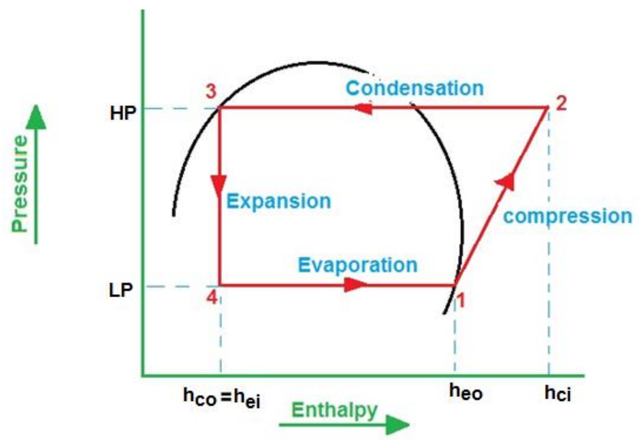


Fig. 2 Plot the operating cycle on p-h chart

Calculations: (attach separate sheets)

(1) From the refrigerant temperatures, plot the cycle on p-h chart of R-134a and find out following enthalpies

a. h_{ci} =   kJ/kg
b. h_{co} =   kJ/kg
c. h_{ei} =   kJ/kg
d. h_{eo} =   kJ/kg

Where above enthalpies are corresponding to condenser inlet, condenser outlet, evaporator inlet and evaporator outlet respectively.

(2) Refrigerating effect, RE = $h_{ei} – h_{eo}$ =
Compressor work Wc = h_{ci} - h_{eo} =
Hence, COP of cooling cycle
COP = RE / Wc

(3) Carnot COP= Te/(Tc – Te)

Where, Te and Tc are evaporator and condenser temperatures respectively

Evaporator side

(4) Cooling effect obtained in evaporator $Q_e = m_e \times c_{pw} \times \Delta Te$
Where, m_e = mass flow rate of water in evaporator, ΔTe = temperature drop of water in evaporator

(5) Actual coefficient of performance of cooling system $COP_{act} = Q_e/Wca$
Where, Wca = (10 × 3600) / (t × EMC), Energy meter constant EMC =3200 pulses/kWh

Condenser side

(6) Heat rejected by the condenser $Q_c = m_c \times c_{pw} \times \Delta Tc$
Where, m_c = mass of water in condenser

(7) Heat rejected by refrigerant in condenser HRc = $m_r (h_{ci} – h_{co})$

(8) Heating COP = HRc /Wca

Conclusions:

Quiz: (attach separate sheets)

1. Define COP.
2. Differentiate heat engine, heat pump and refrigerator

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.
(2) Engineering Thermodynamics by P.K. Nag, McGraw-Hill Education

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 3
To study different psychrometric processes

Date:

Relevant CO: CO1

Objectives: To study different psychrometric processes.

Psychrometer:

The word 'psychrometry' means study of properties of atmospheric moist air. The device which measures the dry bulb temperature and wet bulb temperature of moist air is known as psychrometer.

1. Sling psychrometer:

It is used to measure the thermodynamic dry bulb and wet bulb temperatures of the air. Thermodynamic wet bulb temperature is the temperature at which water by evaporating into air, may bring the air to saturation adiabatically at the same temperature. In construction, a wet bulb thermometer is attached at two points along length of the wooden sick & the thermometer whirl around it. When the thermodynamic temperature is to be measured, (a) wet the wick (b) whirl the thermometer around the wooden stick for some time and (c) then immediately measure the temperature

2. Wall psychrometer:

It is mounted on a wooden piece. They are used to measure the wet bulb and dry bulb temperature respectively. In case of wet bulb thermometer, the bulb of the thermometer is always covered with a wet wick. But in case of dry bulb thermometer, bulb of the thermometer is not covered with wet wick; rather it is always kept dry.

3. Hair hygrometer:

It directly measures the relative humidity of the air in terms of percentage. Relative humidity is defined as ratio of mass of water vapor in given volume of air at a temperature to the mass of water vapor in a saturated air at same temperature. Volume of the horse hair and biological matter changes with humidity. This is the working principle of hair hygrometer. The scale also gives the idea of weather viz. dry, normal or humid.

4. Barometer:

It measures the pressure of the moist air. There are two scales provided on it. The outer scale gives the pressure of the air in terms of inches of mercury whereas the inner scale gives the pressure of air in terms of milli-bars.

Psychrometric charts:

Psychrometric chart (Fig. 1) gives the graphical representation of different important properties of moist air. These charts are readily available for different mixture pressure.

Abscissa (x-axis) of chart gives the dry bulb temperature (ºC) and the ordinate (y-axis) has humidity ratio (ω) in kg or gram of water vapour per kg of dry air.

Since humidity ratio can be directly related to partial pressure of water vapor (p_v), it can also be shown on ordinate. Constant relative humidity (φ) curves are also shown on psychrometric chart for different φ values such as φ = 10%, ..., 60%, ..., 100%. Mixture enthalpy per unit mass of dry air (kJ/kg of dry air) is also available on psychrometric chart. Dew point temperature for the moist air can be known by following the line of constant ω (or constant p_v) up to saturation line, φ = 100% as the dew point refers to the state where mixture becomes saturated when cooled at constant vapour pressure. Constant wet bulb temperature lines run from upper left to the lower right of chart. These constant wet bulb temperature lines approximate to the lines of constant mixture enthalpy per unit mass of dry air. Psychrometric chart also has lines representing volume per unit mass of dry air (m^3/kg of d.a.). These specific volume lines can be approximated as state giving volume of dry air or water vapour per unit mass of dry air since each component of mixture i.e. air and water vapour occupy the same volume.

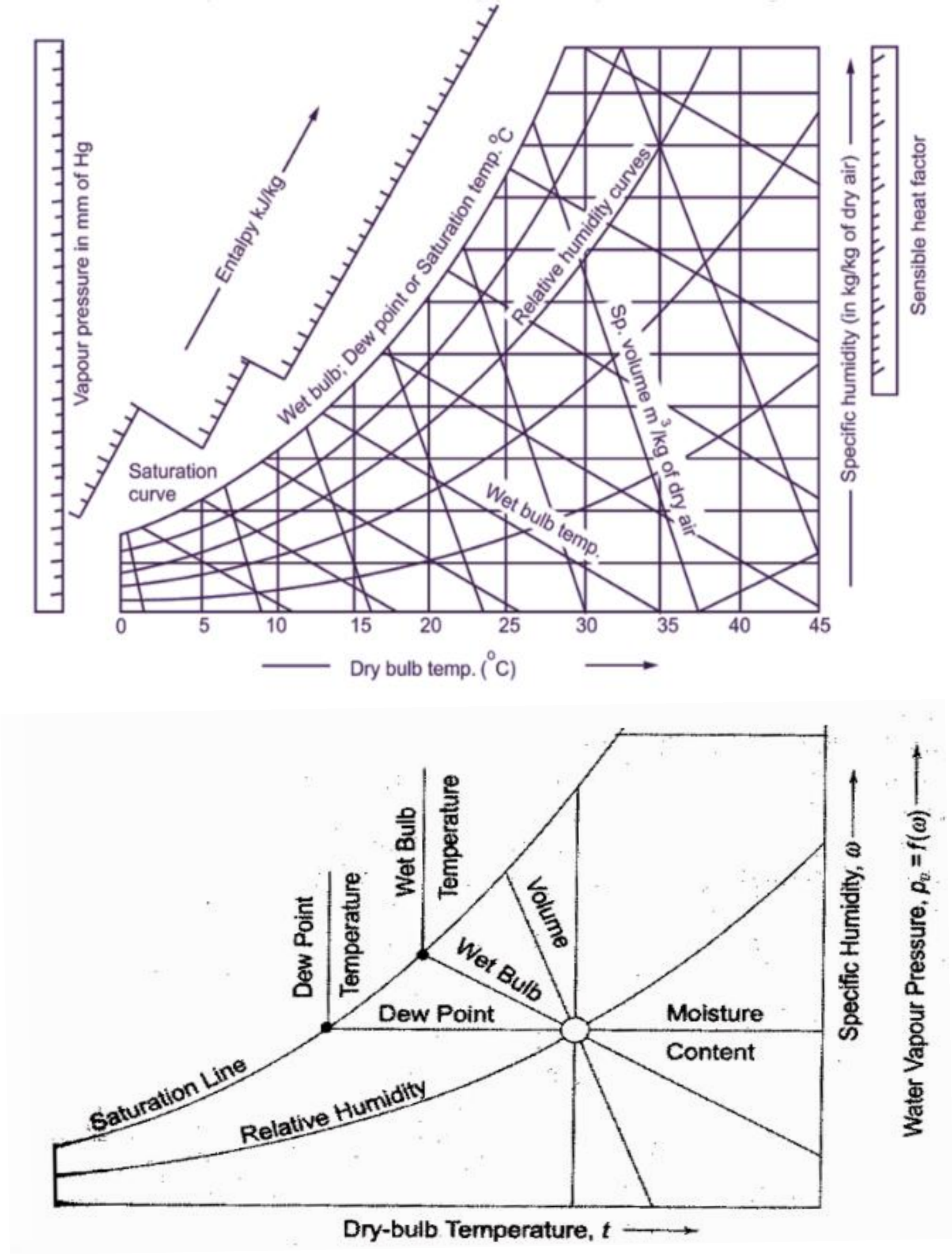


Fig. 1 Psychrometric charts

Psychrometric processes:

The basic psychometric processes that are carried out in air conditioning practice are illustrated below Fig. 2.

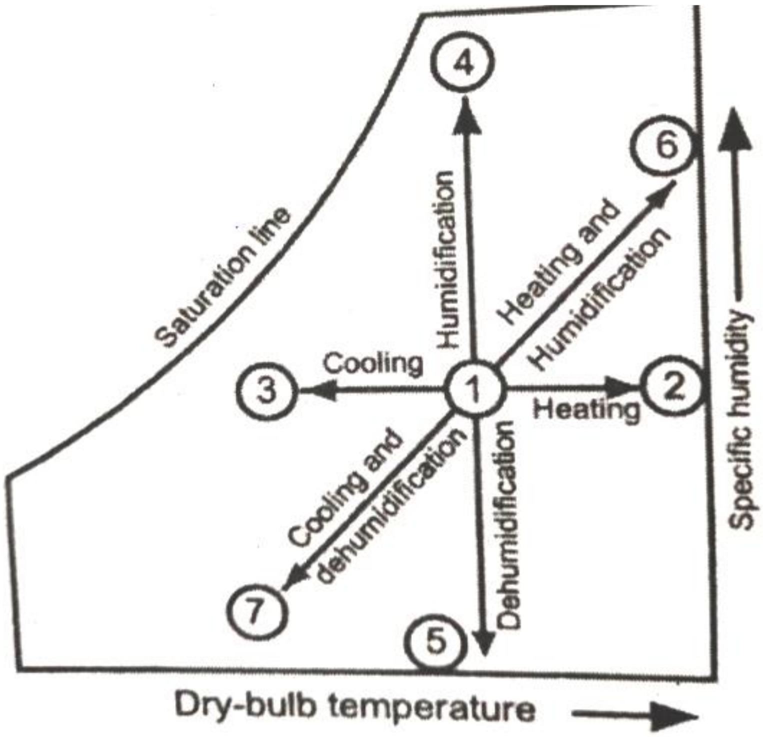


Fig. 2 Important Psychrometric processes.

(a) Sensible Cooling:

During this process, the moisture content of air remains constant but its temperature decreases as it flows over a cooling coil. For moisture content to remain constant the surface of the cooling coil should be dry and its surface temperature should be greater than the dew-point temperature of air. If the cooling coil is 100% effective, then the exit temperature of air will be equal to the coil temperature. However, in practice, the exit air temperature will be higher than the cooling coil temperature. Fig. 3 shows the sensible cooling process 1-2 on a psychometric chart. The heat transfer rate during this process is given by:

$$Q_c = m_a(h_1 - h_2) = m_a c_p(T_1 - T_2)$$

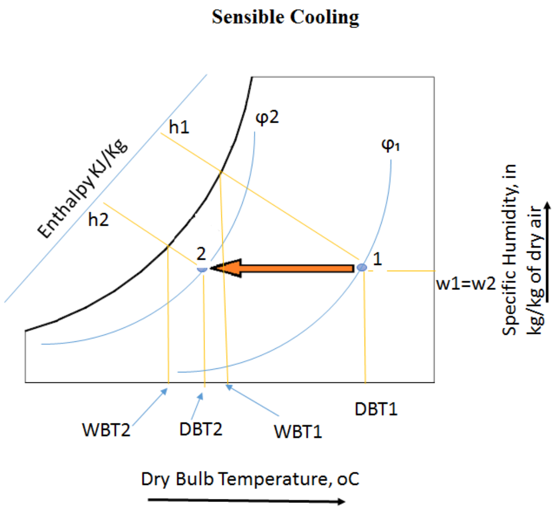


Fig. 3 Sensible cooling process on psychrometric chart

Where c_p is the humid specific heat (≈1.0216 kJ/kg d.a.) and m_a is the mass flow rate of dry air (kg/s).

(b) Sensible Heating :

Fig. 4 shows the sensible heating process on a psychometric chart. During this process, the moisture content of air remains constant and its temperature increases as it flows over a heating coil. The heat transfer rate during this process is given by:

$$Q_h = m_a(h_2 - h_1) = m_a c_p (T_2 - T_1)$$

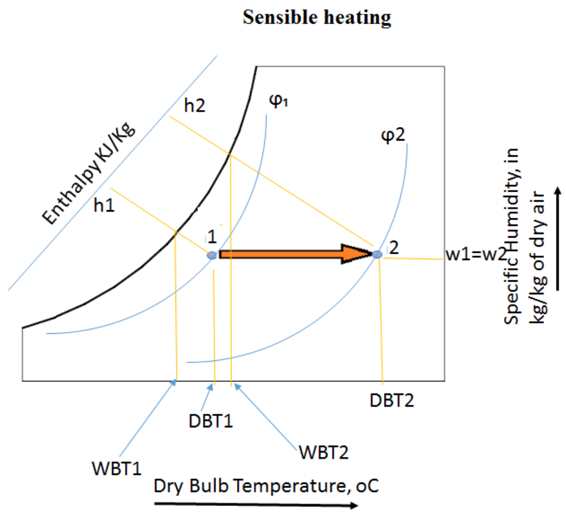


Fig. 4 Sensible heating process on psychometric chart

(c) Cooling and Dehumidification:

When moist air is cooled below its dew point by bringing it in contact with a cold surface as shown in Fig. 5, some of the water vapor in the air condenses and leaves the air stream as liquid, as a result both the temperature and humidity ratio of air decreases as shown. This is the process air undergoes in a typical air conditioning system. Although the actual process path will vary depending upon the type of cold surface, the surface temperature, and flow conditions, for simplicity the process line is assumed to be a straight line. The heat and mass transfer rates can be expressed in terms of the initial and final conditions by applying the conservation of mass and conservation of energy equations as given below:

By applying mass balance for the water:

$$m_a.w_1 = m_a.w_2 + m_w$$

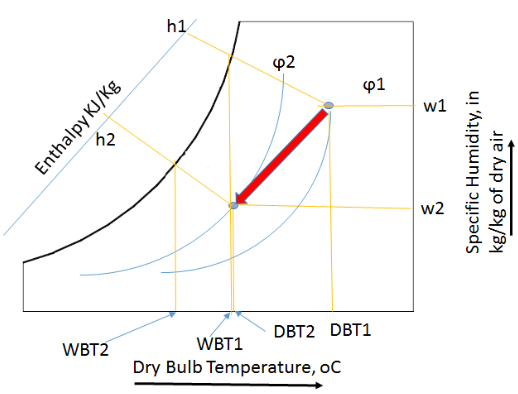


Fig. 5 Cooling and dehumidification process

By applying energy balance:

$$m_a.h_1 = Q_T + m_w.h_w + m_a h_2$$

From the above two equations, the load on the cooling coil, Qt is given by:

$$Q_T = m_a(h_1 - h_2) - m_a(w_1 - w_2).h_w$$

The 2nd term on the RHS of the above equation is normally small compared to the other terms, so it can be neglected. Hence,

$$Q_T = m_a(h_1 - h_2)$$

It can be observed that the cooling and de-humidification process involves both latent and sensible heat transfer processes, hence, the total, latent and sensible heat transfer rates (Q_t, Q_L and Q_S) can be written as:

$$Q_T = Q_L + Q_s$$

where,

$$Q_L = m_a(h_1 - h_w) = m_a h_{fg\ at\ 0°C}(w_1 - w_2)$$

$$Q_S = m_a(h_w - h_2) = m_a c_p(T_1 - T_2)$$

By separating the total heat transfer rate from the cooling coil into sensible and latent heat transfer rates, a useful parameter called Sensible Heat Factor (SHF) is defined. SHF is defined as the ratio of sensible to total heat transfer rate, i.e.

$$SHF = \frac{Q_s}{Q_T} = \frac{Q_s}{Q_s + Q_L}$$

From the above equation, one can deduce that a SHF of 1.0 corresponds to no latent heat transfer and a SHF of 0 corresponds to no sensible heat transfer. A SHF of 0.75 to 0.80 is quite common in air conditioning systems in a normal dry-climate. A lower value of SHF, say 0.6, implies a high latent heat load such as that occurs in a humid climate.

In Fig. 5, the temperature T_s is the effective surface temperature of the cooling coil, and is known as apparatus dew-point (ADP) temperature. In an ideal situation, when all the air comes in perfect contact with the cooling coil surface, then the exit temperature of air will be same as ADP of the coil. However, in actual case the exit temperature of air will always be greater than the apparatus dew-point temperature due to boundary layer development as air flows over the cooling coil surface and also due to temperature variation along the fins etc. Hence, we can define a by-pass factor (BPF) as:

$$BPF = \frac{T_2 - T_s}{T_1 - T_s}$$

It can be easily seen that, higher the by-pass factor larger will be the difference between air outlet temperature and the cooling coil temperature. When BPF is1.0, all the air by-passes the coil and there will not be any cooling or de-humidification. In practice, the by-pass factor can be increased by increasing the number of rows in a cooling coil or by decreasing the air velocity or by reducing the fin pitch.

Alternatively, a contact factor (CF) can be defined which is given by: CF =1 – BPF

(d) Heating and Humidification :

During winter it is essential to heat and humidify the room air for comfort. As shown in Fig. 6, this is normally done by first sensibly heating the air and then adding water vapour to the air stream through steam nozzles as shown in the figure.

Mass balance of water vapor for the control volume yields the rate at which steam must be added, i.e., m_w:

$$m_w = m_a(w_2 - w_1)$$

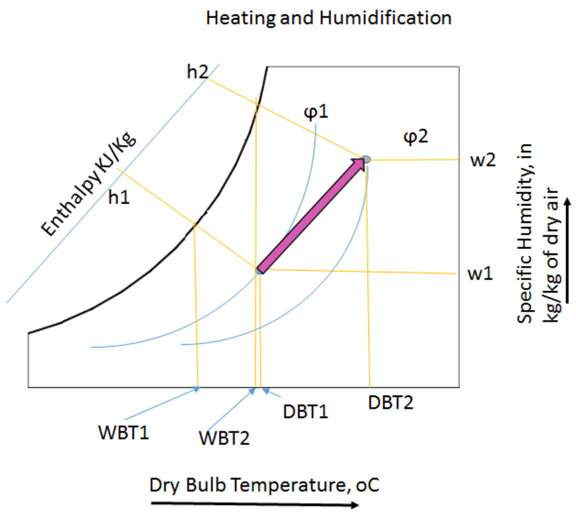


Fig. 6 Heating and Humidification process

From energy balance:

$$Q_h = m_a(h_2 - h_1) - m_w h_w$$

Where Q_h is the heat supplied through the heating coil and h_w is the enthalpy of steam.
Since this process also involve simultaneous heat and mass transfer, we can define a sensible heat factor for the process in a way similar to that of a cooling and dehumidification process.

(e) Cooling & humidification:

As the name implies, during this process, the air temperature drops and its humidity increases. As shown in the Fig. 7, this can be achieved by spraying cool water in the air stream. The temperature of water should be lower than the dry-bulb temperature of air but higher than its dew-point temperature to avoid condensation ($T_{DPT} < T_w < T_2$).

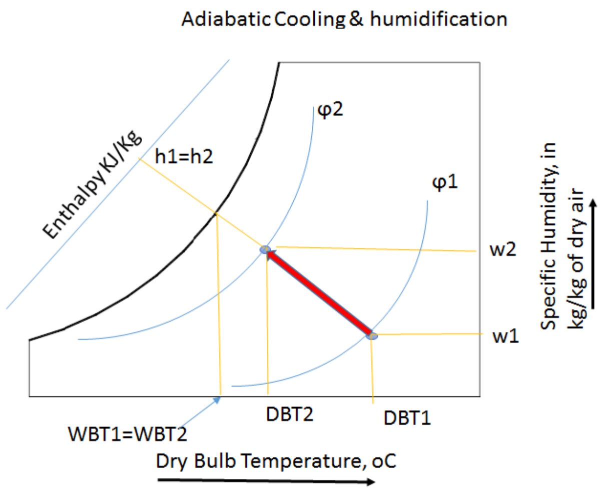


Fig. 7 Cooling and humidification process

It can be seen that during this process there is sensible heat transfer from air to water and latent heat transfer from water to air. Hence, the total heat transfer depends upon the water temperature. If the temperature of the water sprayed is equal to the wet- bulb temperature of air, then the net transfer rate will be zero as the sensible heat transfer from air to water will be equal to latent heat transfer from water to air. If the water temperature is greater than WBT, then there will be a net heat transfer from water to air. If the water temperature is less than WBT, then the net heat transfer will be from air to water. Under a special case when the spray water is entirely recirculated and is neither heated nor cooled, the system is perfectly insulated and the make-up water is supplied at WBT, then at steady-state, the air undergoes an adiabatic saturation process, during which its WBT remains constant. This is the process of adiabatic saturation. The process of cooling and humidification is encountered in a wide variety of device such as evaporative coolers, cooling towers etc.

(f) Heating and Dehumidification (Adiabatic Dehumidification):

This process can be achieved by using a hygroscopic material, which absorbs or adsorbs the water vapour from the moisture. If this process is thermally isolated, then the enthalpy of air remains constant, as a result the temperature of air increases as its moisture content decreases as shown in Fig. 8. This hygroscopic material can be a solid or a liquid. In general, the absorption of water by the hygroscopic material is an exothermic reaction, as a result heat is released during this process, which is transferred to air and the enthalpy of air increases.

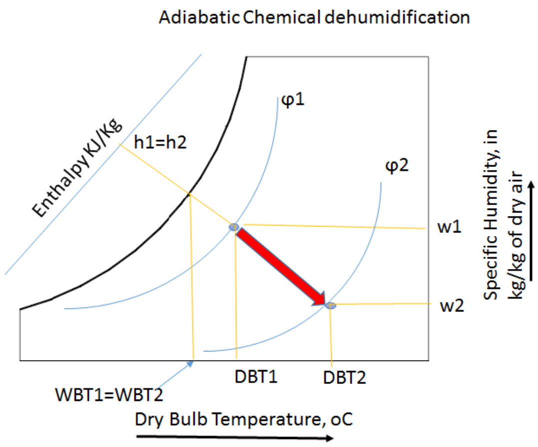


Fig. 8 Heating and dehumidification process

Quiz: (attach additional sheets)

1. Define following terms: (a) saturated air (b) specific humidity (c) relative humidity (d) absolute humidity (e) dry bulb temperature (f) dew point temperature (g) wet bulb depression.
2. Describe construction and working of sling psychrometer with neat sketch.

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 4
To understand construction and working of window air-conditioner / split air-conditioner

Date:

Competency and Practical Skills: Maintenance and working of window/split air conditioner

Relevant CO: CO2

Objectives: To study construction and working of window/split air conditioner.

Equipment/Instruments: Prototype/test rig of window/split air conditioner.

Theory: The windows air conditioner mainly used for conditioning of air in the room. Commonly it is mounted in a window, hence it is known as window air conditioner. The basic function of room air conditioner is to provide comfort cooling, dehumidification, filtering and circulation of the air.

Components of Air Conditioning System: An air conditioning system is defined as an assembly of different parts of the system used to produce a specified condition of air within an enclosed space.

The basic elements of air conditioning system are:

1. **Fan:** Its function is to circulate the air inside the room.
2. **Filters:** Its function is to remove dust, dirt and other harmful bacteria from the air.
3. **Refrigeration plant:** It provides the refrigerating effect for cooling. It consists of compressor, condenser, expansion device (or capillary tube) and evaporator.
4. **Heating coil:** It consists of electric heater and is used to heat the air.
5. **Control knob:** It consists of thermostat for temperature control and humidistat for moisture control.
6. **Grills:** It adjusts the direction of conditioned air to the room.
7. **Drain line:** It collects the condensate and drains it outside the room.

Window Room Air- Conditioner: It is known as window room air conditioner as it is fitted in a window. Its function is to provide comfortable temperature, dehumidify the air, filter and circulate the air into the room. It also provides ventilation by introducing outside air into the room and exhausts some amount of room air into the atmosphere.

Construction: It mainly consists of hermetically sealed compressor, condenser, capillary tube, evaporator and works on vapor compression cycle. Other components are air filter, control panel, double shaft motor that drives a fan on condenser side and blower on the evaporator side as shown in Fig. 1. The evaporator and capillary tube are located at the room side (indoor) while compressor and condenser are located on outer side. The room side and outdoor side of the unit are separated by a partition wall. The control panel is fitted on room side. A tray is provided below the evaporator to collect the water removed from the air by dehumidifying it. Tray is connected by pipeline and fed outside for draining the water. An air filter is provided at bottom for cleaning the air while grills are provided above it as shown in the figure.

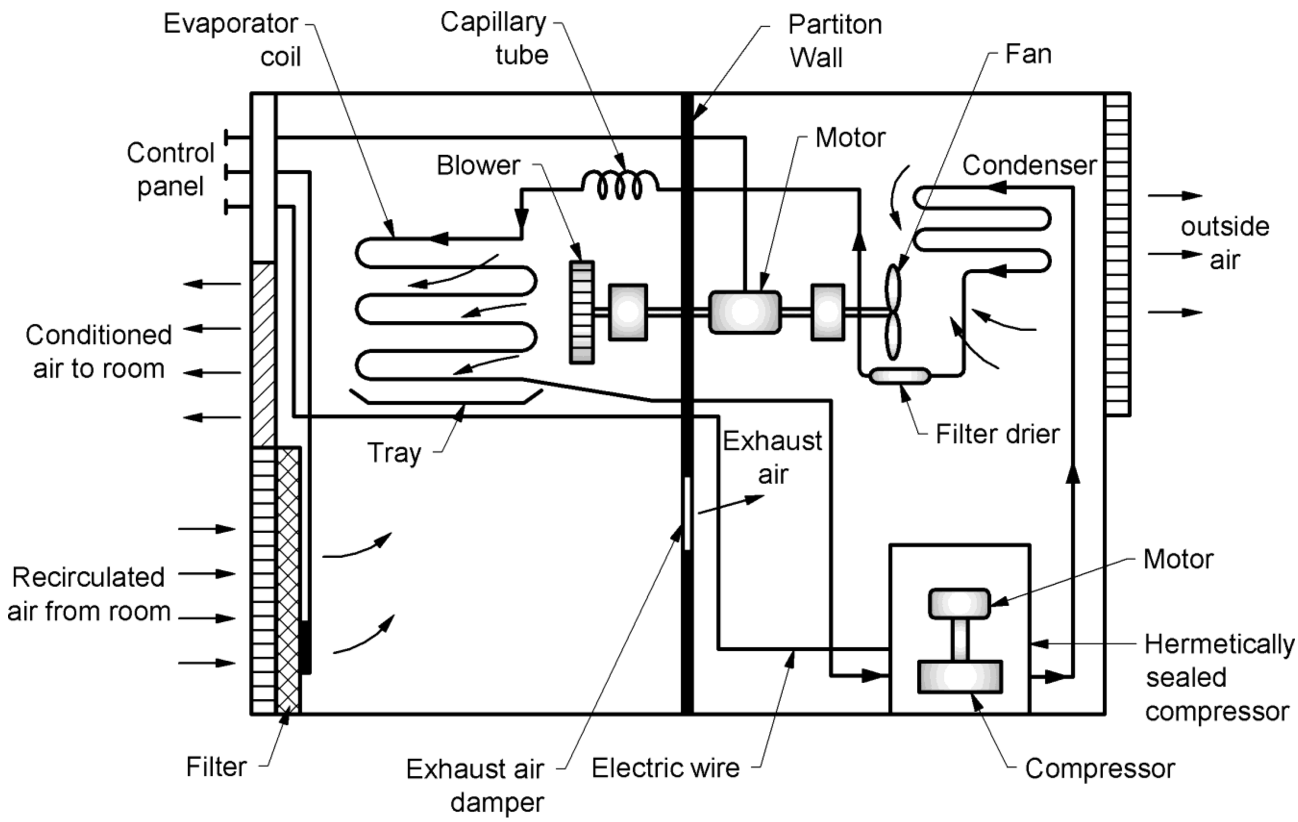


Fig. 1 Layout of window air conditioner.

Working: Low pressure and low temperature refrigerant vapor are drawn from the evaporator to the compressor and is compressed to high pressure and high temperature. This high pressure, high temperature vapor is passed through the condenser coils. The fan located at the outdoor side draws atmospheric air and blows over the condenser coils. The heat contained in the refrigerant is dissipated to the atmosphere and as a result, vapor refrigerant condenses to liquid state and passes through a filter drier. It filters the refrigerant and absorbs the moisture if it is present in the refrigerant. The liquid refrigerant at high pressure is passed through the capillary tube where it is expanded to low pressure and low temperature. The refrigerant then enters the evaporator coils. The blower draws the warm air from the room through the air filter. The low pressure and low temperature liquid refrigerant flowing through the evaporator coils absorbs the heat from the warm air and undergoes a change of phase from liquid to vapor. The air loses its heat and water removed from the air dips into the tray located at the bottom of the evaporator and is led to the atmosphere through the drain pipe. The cooled and dehumidified air and small amount of outside air through the dampers is delivered to the room by the blower through the grills which direct the flow of air. After the desired room temperature is achieved, thermostat in the air conditioner unit cuts the power supply to turn the compressor off. As the room warms up, thermostat initiates the power supply and cycle repeats till the desired temperature in the room is achieved.

Disadvantages of window room air conditioner

- Since compressor is kept in the cabinet which is placed near the room, it creates noise at working place.
- It requires appropriate size of window in the wall to fit the air conditioner.
- It requires outside air for condenser cooling hence it cannot be installed in interior rooms.

Split Air Conditioner:

Construction: A split air conditioner is similar in operation to a window room air conditioner except the components are split into two separate units instead of being entirely enclosed in a single unit as in window room air conditioner as shown in Fig. 2. In indoor unit (inside the room) consists of evaporator, blower driven by electric motor and capillary tube while the outdoor unit consist of compressor, condenser, fan driven by electric motor. The indoor unit may be mounted on the wall at suitable height or on the false ceiling. The two units are connected by set of electric wires and copper tubing. The distance between indoor and outdoor units must be maximum 10 to 12 m and elevation difference between them should be maximum 5 m as it causes pressure loss of the refrigerant. These units are available in capacity ranges from 1 to 3 TR.

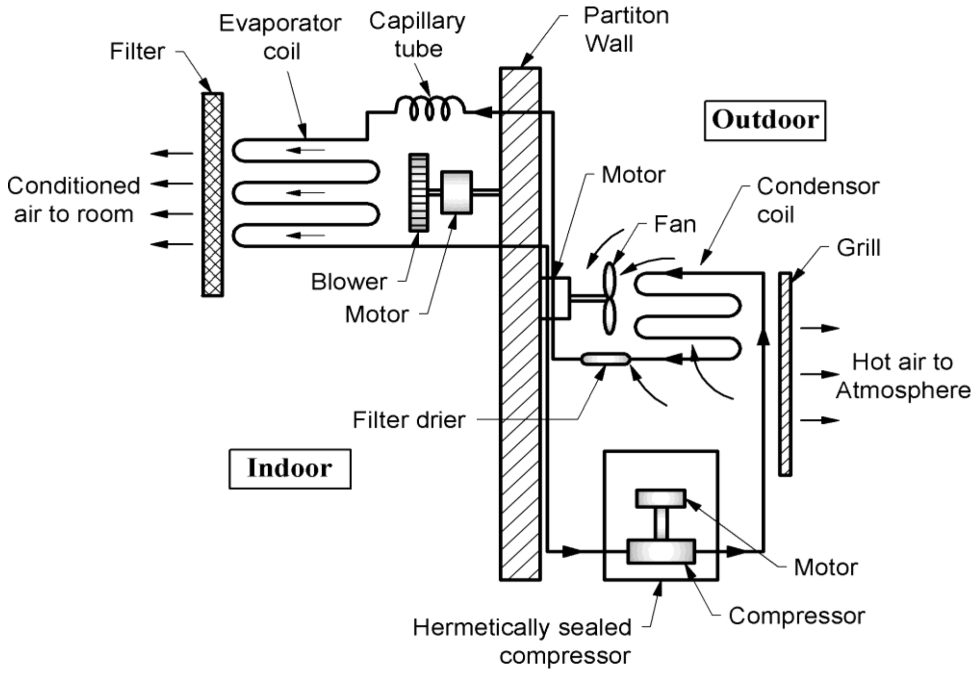


Fig. 2 Layout of split air conditioner

Working: Low pressure and low temperature refrigerant vapor is drawn from the evaporator to the compressor and is compressed to high pressure and high temperature. This high pressure and high temperature vapor is passed through the condenser coils. The fan located at the outdoor side draws atmospheric air and blows over the condenser coils. The heat contained in the refrigerant is dissipated to the atmosphere and as a result, vapor refrigerant condenses to liquid state and passes through a filter drier. It filters the refrigerant and absorbs the moisture if it is present in the refrigerant. The liquid refrigerant at high pressure is passed through the capillary tube where it is expanded to low pressure and low temperature. The refrigerant then enters the evaporator coils. The blower draws the warm air from the room through the air filter. The low pressure and low temperature liquid refrigerant flowing through the evaporator coils absorbs the heat from the warm air and undergoes a change of phase from liquid to vapor. The air loses its heat and water removed from the air is led to the atmosphere through the drain pipe. The cooled and dehumidified air is delivered to the room by the blower through the grills which direct the flow of air. After the desired room temperature is achieved, thermostat in the air conditioner unit cuts the power supply to turn the compressor off. As the room warms up, thermostat initiates the power supply and cycle repeats till the desired temperature in the room is achieved.

Advantages of spilt air conditioner: There is negligible noise inside the room due to absence of compressor in the indoor unit. It can be installed in interior room unlike in window room air conditioner which requires outside air for condenser cooling. No window opening is required for fixing it. Only small hole is required to connect the indoor and outdoor unit.

Disadvantages: Power consumption is higher as two separate motors are required, one each for operating blower in indoor unit and fan in outdoor unit. Also, power consumption increases due to longer length of copper tubes. Suction line requires better insulation. It has no provision for ventilation.

Quiz: (attach separate sheets)

1. Discuss comparison between window and split air conditioner.
2. Mention specifications of a split air conditioner available in market.

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.

References used by the students:

Rubric wise marks obtained:

Rubrics	**1**	**2**	**3**	**Total**
Marks				

Signature of faculty member

Experiment No: 5
To find COP of an Electrolux refrigerator (VARS)

Date:

Competency and Practical Skills: Construction and working of vapor compression cycle.

Relevant CO: CO1

Objectives: To determine C.O.P. of Electrolux refrigerator.

Introduction:
"Vapour Absorption Refrigerator" earlier known as "Electrolux" refrigerator is a self-contained refrigerator working on absorption technology. In the absence of a compressor or pump, the circulation takes place by density difference. The system is pre-changed with three fluids namely water, ammonia, and hydrogen. Hydrogen is used as an "inter gas" and does not undergo any phase change and heat transfer processes. Its purpose is to keep the pressure of the system constant. It uses an electrically operated generator, where the ammonia vapours dissolved in water are separated and pure ammonia vapours dissolved in water are separated and pure ammonia vapours enter the condenser. In the condenser, the high-pressure vapours reject its latent heat to the surroundings and get liquefied. The liquid ammonia expands through expansion device where its pressure and temperature are reduced and cold low-pressure vapour enters the evaporator where it absorbs heat from the space to be cooled and then vaporized ammonia absorbs in water. This strong solution then enters the generator and the cycle repeats.

Theory:
Electrolux principle works on 3-fluid system. There is solution circulation pump, Total pressure is the same throughout the system. The third fluid remains mainly in the evaporator thus reducing partial pressure of refrigerant to enable it to evaporate at low pressure and hence low temperature. The schematic diagram of the Electrolux refrigerator working on NH_3-H_2O system with H_2 as the third fluid is shown in figure. Liquid NH3 evaporates in the evaporator in the pressure of H_2. Hydrogen is chosen as it is non-corrosive and insoluble in water.

A thermosyphon bubble pump is used to lift the weak aqua from the generator to the separator. The discharge tube from the evaporator the generator to the separator, the discharge tube from the evaporator the generator is extended down below the liquid level in the generator. The bubble rise and carry slugs of weak NH_3-H_2O solution in the separator. Two U-bends are provided as vapour-locks to prevent H_2 from getting into the high side or solution circuit. Partial pressure of H_2 provides the pressure difference of NH_3 between the condenser and evaporator. Accordingly, we have:
In condenser pure NH_3 vapour pressure = Total pressure
In evaporator NH_3 vapour pressure = Total pressure – partial pressure H_2

Technical Specifications:
(Given specification of an equipment for sample calculation only. Use specification as per the equipment available in laboratory for the calculation.)

- Gross Volume : 40 Liters
- Refrigerant : Water, Ammonia, Hydrogen
- Generator : Electrically Heated
- Condenser : Natural Convection Type
- Evaporator : Natural Convection Type
- Material of Construction : M.S.
- Supply : 230 Volts, 50Hz, 1 ph
- Energy Consumption : 1.07 kWh

Experimental Procedure:

(1) Keep the machine on level ground.
(2) Connect the machine electrically with a stabilized power supply of 230 volts, 50Hz, 1PH.
(3) Put on the power supply.
(4) Wait till the cabinet temperature (channel no-5) reaches 15 to 18°C
Important: The time to reach the specific temperature may vary depending upon the ambient conditions. The approximate time is 1.5 to 2 hrs.
(5) Now put the load ON.
(6) Adjust the dimmer such that cabinet temperature remains constant.
(7) Record the reading as per the observation table.
(8) Calculate the results.

Observation Table:

Sr. No.	Time	Load (output)		Generator (ref. Input)		Temperature in °C				
	Hrs.	Volts	Mill Amps.	Volts	Mill Amps.	Generator T1	Condenser T2	Evaporator T3	Absorber T4	Cabinet T5
01										
02										
03										
04										
05										
06										
07										
08										
09										
10										

Refrigeration effect = load (output)

n =

System input (generator) = V × I

q = …………….

Actual COP = n/q

Result:

C.O.P. of System =

Theoretical COP of the System:

Let Q1 = Heat absorbed in the evaporator at T1

Q2 = Heat discharged in the condenser and absorber at T2

Q3 = Heat given in the generator at T3

Assuming there is no heat transfer except these points, according to law of conservation of energy,

$$Q1 + Q2 = Q3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Considering ideal reversible process,

Initial entropy = Final entropy

$$(Q1/T1) + (Q3/T3) = (Q2/T2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

There are two heat sources and one heat sink

C.O.P. = (Refrigeration effect / heat input)

$$= (Q1/Q3) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

From equations (1), (2), (3)

And eliminating Q2; we have

C.O.P. = (T1/T2-T1) x (T3-T2/T3), where, T3>T2>T1

OR

$$C.O.P. = (T1/T2) \times ((T3-T2)/(T2-T1))$$

Precautions:

- Ensure refrigerator is level.
- The pipe work at the back gets hot in use.
- The refrigerator has no ‘Motor’ and is therefore virtually silent.
- Allow at least 3 hours for sign of cooling.
- It is important that the appliance is not directly exposed to radiated heat (sunlight, radiator, near an oven, etc.)

Maintenance:

Frost will gradually form on the cooling surface and it must not be allowed to become too thick since it restricts the cooling.

This frost formation is kept back by the FUZZY LOGIC system built into the appliance by switching off the unit for two hours in every 24 hours. The frost will melt and the defrost water will run through the drain tube from the drip channel into an evaporating vessel located at the bottom rear of the refrigerator. The defrost water will evaporate automatically into circulating air and the vessel swill not need emptying.

To switch off the unit, turn the thermos knob to “0” disconnect the refrigerator from the electricity supply and leave the cabinet door open. After defrosting the cabinet interior should be wiped out with a clean, damp cloth.

Troubleshooting:

- Changing the light bulb

If the light bulb needs changing, pull out the plug and proceed as follows:

Press the metal reflector to one side and draw the lamp covering backwards.
Replace the bulb and push the covering back into place.
A new 10-watt bulb can be obtained at any service shop

- Reversing the door hang

Lay the appliance on its back. Remove the 8 screws. Remove the door, together with the two hinges from housing. Remove the two cover caps from the housing and place them in the open hinge holes in the housing. Place the bottom right-hand hinge in the top left of the door and the top right-hand hinge in the bottom left of the door and hang the door on its hinges in the open cover cap holes in the housing. Secure the hinges and caps with 8 screws.

- Replacing the decorative door panel

Remove the two screws from the upper hinge of the door. Pull the door together with the hinge away from the housing and up off the lower hinge bolt. Remove screws and pull off the frame edge. Slide the decorative panel out of the doorframe and insert the new panel so that the upper edge of panel.

Conclusions:

Quiz: (attach separate sheets)

1. Draw neat sketch of Electrolux refrigeration system.
2. What is the function of liquid seal?
3. What is the driving potential for hydrogen?
4. What are the differences between two fluids and three fluids systems?

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 6
To determine saturation efficiency of air washer

Date:

Competency and Practical Skills: Construction and working of air cooler/air washer.

Relevant CO: CO-1

Objectives: To understand construction and working of air washer and to determine its saturation efficiency.

Equipment/Instruments: Air-washer unit, sling psychrometer

Theory:
An air washer is used for heating, cooling, humidifying and dehumidifying of the air. In the winter season warm water is sprayed to increase the moisture content of the dry air whereas in summer cold water is sprayed to decrease its moisture content. Air washer as shown in Fig. 1 is also used for cleaning of the air. The air flows through to the water sprays the removes the remaining impurities by washing. The air washer is an adiabatic air saturator in which the air follows a constant wet bulb process. Knowing the dry bulb temperature of air at the inlet and outlet of the air washer, wet bulb temperature, the efficiency of air washer can be calculated as the follows.

Calculations:

$$\eta = \frac{t_1 - t_2}{t_1 - t_s} \times 100$$

Where,
t_1 = Dry bulb temperature of air at inlet
t_2 =Dry bulb temperature of air at outlet
t_s = Wet bulb temperature of air at outlet

An air washer is a device for conditioning air. As shown in Fig. 1, in an air washer air comes in direct contact with a spray of water and there will be an exchange of heat and mass (water vapor) between air and water. The outlet condition of air depends upon the temperature of water sprayed in the air washer. Hence, by controlling the water temperature externally, it is possible to control the outlet conditions of air, which then can be used for air conditioning purposes.

Concept:
- An air washer is a hybrid appliance, a combination of an air purifier and a humidifier.
- Like conventional humidifiers, air washers add therapeutic moisture to the air.
- And, like a conventional air purifier, an air washer removes symptom-triggering allergens from the air.
- Essentially this type of humidifier consists of a chamber containing a spray nozzle system, a reciprocating water pump, and a collection tank.

- As the air passes through the chamber, it comes into contact with the water spray from the nozzles, resulting in heat transfer between the air and water.
- This, in turn, results in either humidification (adding moisture) or dehumidification (removing moisture) depending on the relative temperatures of the sprayed water and the air passing through the chamber.
- Dehumidification occurs when the temperature of the water is lower than the dew point of the air; humidification occurs when it is higher.

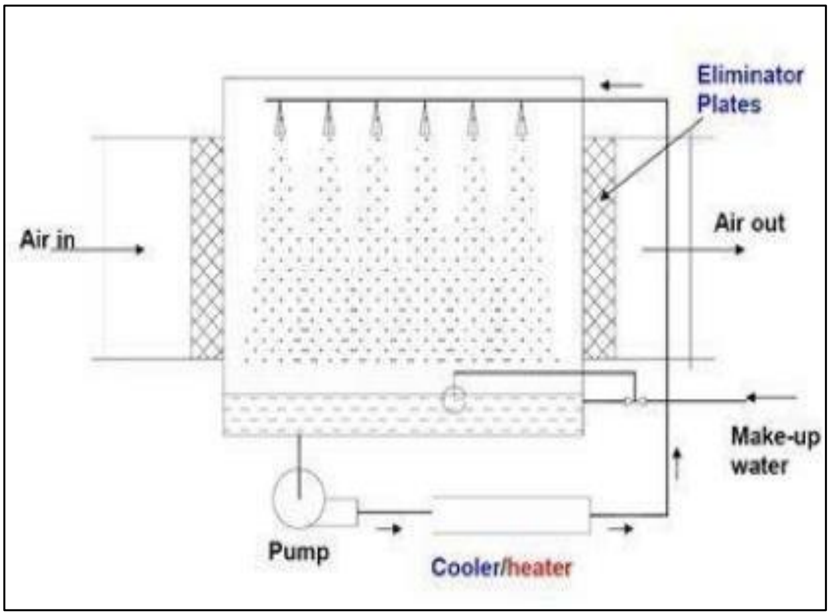


Fig. 1 Working of air washer

Introduction:

The air conditioning field is one of the increasingly important for both human comfort and industrial applications. Controlled humidity and temperature requirements are of vital one in industries such as textile industry, printing industry etc. The use of air washer fulfils the humidity and temperature needs for the process industries. The air washer cleans, humidify or dehumidify the air depending upon the requirements. The cleaning of air includes the removal of air borne impurities such as dust, Smoke and fumes. Humidifying means the increase of water vapour in the air whereas dehumidifying means removal of water vapour from the air.

Air washer construction:

The main components of air washer are an insulated water tank, pump, pipes and fitting, main chamber, blower casing, water spray nozzles, filter and blower motor. The insulated water tank is located at the bottom of the air washer. The blower is used to draw the atmospheric air into the air washer main chamber. Proper pipeline arrangements ensure to deliver the water from the water tank to the spray nozzles attached at the pipe header. The pump supplies water from the tank to the spray nozzles at the required pressure.

Air washer working:

The line diagram of air washer is shown in Fig. 6.1. A constant level of water is maintained in the water tank located in the bottom of the air washer by providing make-up water provision. The pump pumps the water in a required pressure passes through cooler cum heater arrangement and finally to the spray nozzles fitted in the header pipe. The blower which is run by an electric motor sucks the ambient air and admitted into the main chamber through a filter. The filtered air mixes with the spray water in the main chamber where heat exchange and mass exchange takes place. Also, some mass of water vapor added to the air. Then the conditioned air leaves out the air washer through an eliminators and sent to the space where the conditioned air is needed

Air washer working as humidifier:

Humidification is the psychrometric process of addition of water vapour to the air. The air washer can be used as humidifier if the DBT and WBT of the incoming air should be equal to the spray water temperature. At this condition no dehumidification takes place because the spray water temperature is above the DPT of entering air into the air washer main chamber.

Air washer working as dehumidifier:

Dehumidification is psychrometric process of removal of water vapour from the air. The dehumidification is achieved in the air washer by maintaining the spray water temperature well below the DPT of entering air into the main chamber. During this process in addition to dehumidification cooling also done on the air. Sometimes if the temperature of leaving air is below the required space temperature, then the air can be heated using a heating coil at the out let of the air washer to bring the air temperature to the required space temperature.

Psychrometric processes in air washer:

The following psychrometric processes can be achieved using air washer

- Heating and humidification
- Humidification
- Cooling and humidification
- Adiabatic saturation
- Cooling
- Cooling and dehumidification

Applications of air washer:

- Comfort air conditioning requirement for hotels, malls, industrial units etc.,
- Industrial process application in textile, printing, packing industries etc.
- Compressor and gas turbine pre-cooling applications
- Applications where 100% fresh air requirements
- Application in areas where dust free needs

Conclusions:

Quiz: (attach separate sheets)

(1) Enlist different applications of an air washer.
(2) Explain how dehumidification can be accomplished with the help of air washer.
(3) What is the difference between wet bulb temperature and thermodynamic wet bulb temperature?
(4) Write brief note about bypass factor.

Suggested Reference:

(1) Refrigeration and Air Conditioning by C P Arora, McGraw-Hill India Publishing Ltd.

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 7
To study construction details of 4 stroke Petrol Engine

Date:

Relevant CO: CO-3

Objectives: To understand construction and working of 4 stroke petrol engine.

Introduction:
The four stroke-cycles refers to its use in petrol engines, gas engines, light, oil engine and heavy oil engines in which the mixture of air fuel are drawn in the engine cylinder. Since ignition in these engines is due to a spark, therefore they are also called spark ignition engines.

Working of 4 stroke petrol engines:

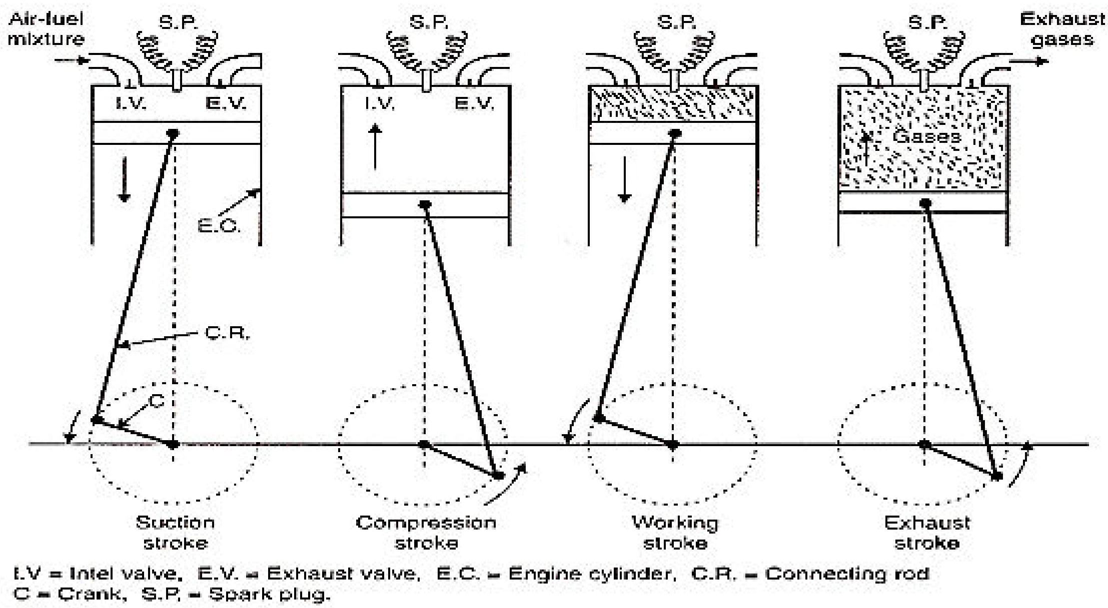
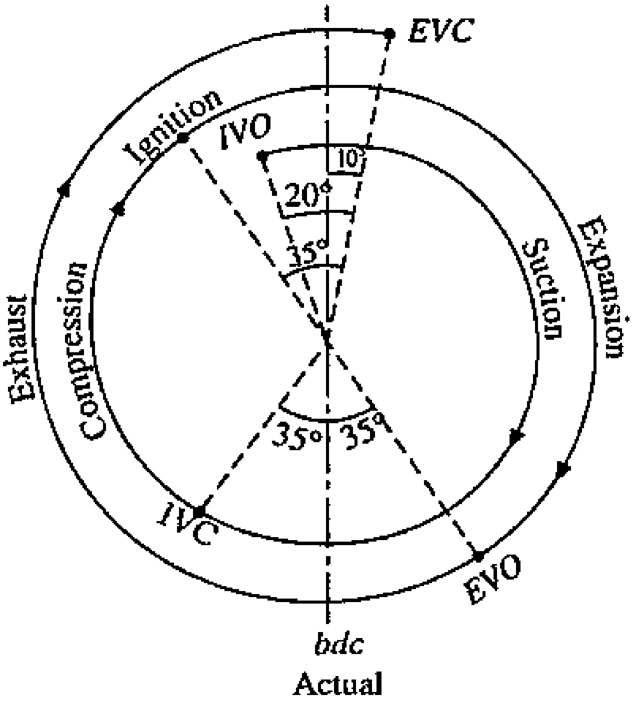


Fig. 1 Working of 4 stroke petrol engines

Suction Stroke: In this Stroke the inlet valve opens and proportionate fuel-air mixture is sucked in the engine cylinder. Thus, the piston moves from top dead centre (T.D.C.) to bottom dead centre (B.D.C.). The exhaust valve remains closed throughout the stroke.
Compression Stroke: In this stroke both the inlet and exhaust valves remain closed during the stroke. The piston moves towards (T.D.C.) and compresses the enclosed fuel-air mixture drawn. Just before the end of this stroke the operating plug initiates a spark which ignites the mixture and combustion takes place at constant pressure.
Power Stroke or Expansion Stroke: In this stroke both the valves remain closed during the start of this stroke but when the piston just reaches the B.D.C. the exhaust valve opens. When the mixture is ignited by the spark plug the hot gases are produced which drive or throw the piston from T.D.C. to B.D.C. and thus the work is obtained in this stroke.
Exhaust Stroke: This is the last stroke of the cycle. Here the gases from which the work has been collected become useless after the completion of the expansion stroke and are made to escape through exhaust valve to the atmosphere. This removal of gas is accomplished during this stroke.

The piston moves from B.D.C. to T.D.C. and the exhaust gases are driven out of the engine cylinder; this is also called Scavenging.

Valve timing diagram of 4 stroke petrol engine



I.V.O-Inlet Valve Open 10°-20° before the piston reaches TDC

I.V.C-Inlet Valve Close 30°-40° after the piston reaches BDC

E.V.O-Exhaust Valve Open 30°-50° before the piston reaches BDC

E.V.C-Exhaust Valve Close 10°-15° after the piston reaches TDC

Fig. 2 Valve timing of 4 stroke petrol engine

Quiz: (attach separate sheets)

1. Enlist factors affecting engine performance.
2. Discuss phenomenon of engine detonation.
3. Differentiate between indicated power and brake power.
4. Explain stoichiometric air fuel ratio.
5. Compare petrol engine and diesel engine.

Suggested Reference:

(1) Internal Combustion Engines by V. Ganeshan, McGraw Hill Publication

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 8

To carry out performance test of computerized four stroke single cylinder diesel engine test rig and draw heat balance sheet

Date:

Relevant CO: CO-3

Objectives: To evaluate performance of 4 stroke diesel engine.

Equipment/Instruments: Single cylinder 4 stroke diesel engine test rig, stop watch, Digital tachometer.

Introduction: To conduct performance test on given single cylinder diesel engine in order to determine heat balance sheet of the engine.

Standard accessories:

- Fuel Measurement consumption by volumetric method and also provide fuel measurement by load cell on fuel tank.
- Air intake measurement by using orifice plate U tube manometer of proper height & Air box with size of 300 × 300 × 500 mm.
- Digital RPM meter (Except Mechanical loading)
- Digital Electronic torque controller for Eddy current dynamometer
- Digital temperature gauges (Air IN, Exhaust OUT, Cooling Water IN and OUT)
- fuel tank 10 lit capacity
- Water flow Measurement through Rota-meter with 2400 LPH capacity
- Clean and soft water supply tank of capacity 300 lit with ISI certified motor pump set.
- Combustion pressure sensor, crank angle sensor,
- Exhaust gas calorimeter,
- Engine interfaces, computer system with i3 processor or equivalent AMD processor, window 8 OS and MS office 2014, 1 PCI slot and PC card, data logger with suitable software & LED colour monitor.

Test rig is capable of find out different parameters like:

1. Brake Power
2. Fuel Consumption
3. Brake Thermal Efficiency
4. BMEP
5. Volumetric Efficiency
6. Air-fuel ratio
7. Indicated Power
8. Friction Power
9. IMEP
10. Indicated thermal efficiency
11. Mech. Efficiency

12. Indicated Torque
13. Diagrams of Combustion pressure versus crank angle, Combustion pressure versus volume, Heat Release Curve.

Safety Precautions:

1. Use this test rig with permission of lab in charge/ subject teacher/ competent authority only.
2. Testing and performance on this test rig must be done under able supervision only.
3. Before starting engine start cooling water circulation pump without fail. Never run the test rig without cooling water supply, this may damage pressure measuring sensors.
4. Immediately turn OFF the engine if water supply is interrupted, or temperature sensor is showing higher temperature then permissible value.
5. Make sure for proper quantity of fuel and cooling water supply is available in respective tanks for the duration of performance.
6. After starting engine wait of steady state before taking results for batter accuracy of reading.
7. In the computer, save all reading and performance report in a proper directory with proper name to have hassled-free reporting and filing.
8. Do not use USB drive to take the data / report etc. from computer, concern lab in-charge shall provide that.
9. After copulation of performance / testing shut off all equipment and peripherals properly.
10. Without fail make an entry of using this test rig in UTILIZATION REGISTER of test rig

Operating Procedure (S.O.P.):

1. Select start – all programs – engine_9ch_new, the main window computerized test bench tester opens.
2. Before starting test set all the engine parameters and initial values through initial settings which are necessary for calculating various engine parameters.
3. To open initial setting window, select file DUT info - initial settings.
4. All the channels must be calibrated before starting the test for the first time.
5. “Load & Heat balance test” window displays load applied on the engine along with torque and speed.
6. Following 4-tab windows: a) observation data, b) load and efficiency, c) heat balance, d) heat balance credit and debit will appear enter data recorded.
7. File path shows where the data are stored when SAVE button is pressed.
8. Time taken for fuel consumption for last test will show in sec taken for the engine to consume the quantity of fuel between high sense and low sense sensors for the last set of readings taken.
9. Clicking on start test button “Datalog10CH” window will appear.
10. Data logger will test the engine automatically and “PV-Pθ Diagram” window will appear.

Schematic Layout:

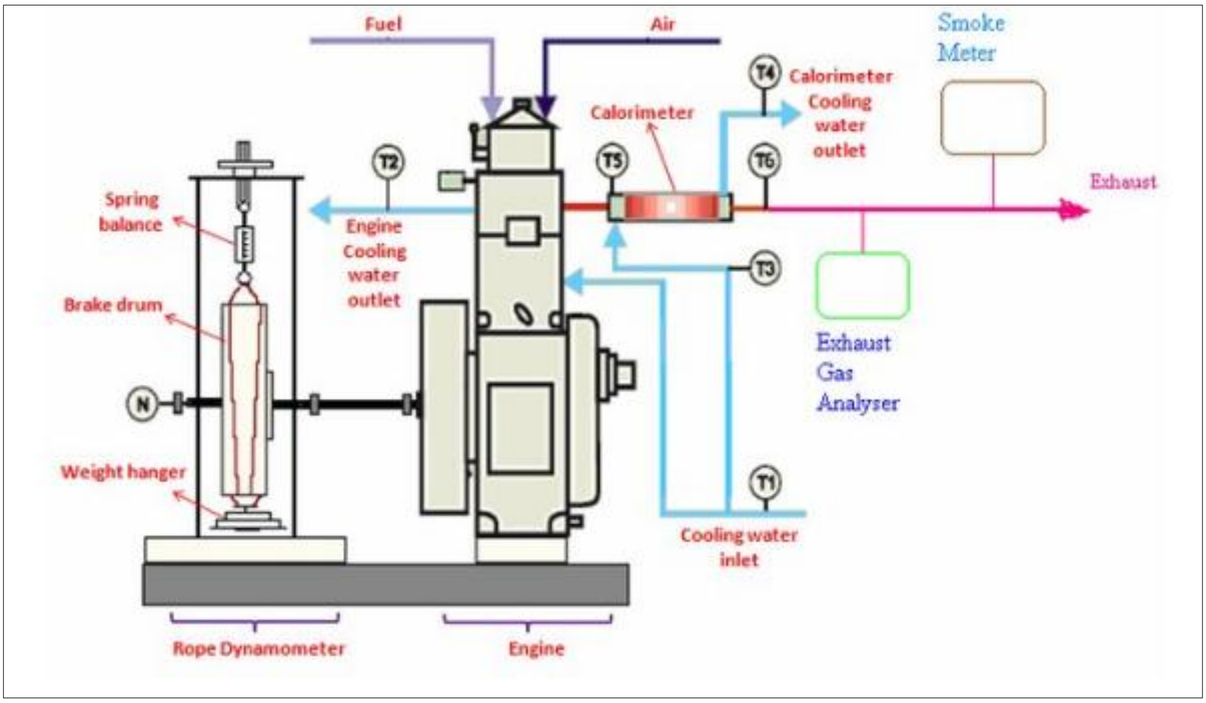


Fig. 1 Schematic layout of diesel engine test rig

Observations and Calculations:

Testing Parameters of Engine:

- Note it down from the test data sheet developed from test rig software

Sr. No.	**Particulars**	**Value as available**	**Value** with Unit conversion (if Required)
1	Engine Type as per classification:		
2	Bore Diameter:		
3	Stroke Length:		
4	Engine speed(Rated):		
5	Fuel used:		
6	C. V. of Fuel used:		

Observations for efficiency calculations:

- Note it down from the test data sheet developed from test rig Software

Sr. No	**Particulars**	**Test 1**
1	Pressure indicated:	
2	Engine Speed:	
3	Rate of Fuel supply:	
4	Load on Dynamometer	
5	Load Arm Length:	
6	Break Power:	
7	Indicated Power:	
8	Mechanical Efficiency:	

9	Break Thermal Efficiency:	
10	Indicated Thermal Efficiency:	
11	Specific Fuel Consumption:	

Calculations: (attach separate sheets)

(1) Indicated Power:

$$IP = \frac{P_m\ LAN}{60 \times 10^3}\ \ kW$$

Here *N* = the number of working stroke per minutes = *Engine Speed/2* for four stroke engine

(2) Break Power:

$$\mathrm{B}P = \frac{2\pi NT}{60 \times 10^3} kW$$

(3) Mechanical Efficiency:

$$\eta_{\mathrm{m}} = \frac{\mathrm{BP}}{\mathrm{IP}} \times 100\ \%$$

(4) Indicated Thermal Efficiency:

$$\eta_{\mathrm{ith}} = \frac{\text{Indicated power}}{\text{Fuel Supplied}\left(\frac{\mathrm{kg}}{\mathrm{sec}}\right) \times \text{Calorific valve of Fuel}\left(\frac{\mathrm{kJ}}{\mathrm{kg}}\right)} = \frac{\mathrm{IP}}{\mathrm{m_f} \times \mathrm{CV}} \times 100\%$$

(5) Break Thermal Efficiency:

$$\eta_{\mathrm{bth}} = \frac{\text{Break power}}{\text{Fuel Supplied}\left(\frac{\mathrm{kg}}{\mathrm{sec}}\right) \times \text{Calorific valve of Fuel}\left(\frac{\mathrm{kJ}}{\mathrm{kg}}\right)} = \frac{\mathrm{BP}}{\mathrm{m_f} \times \mathrm{CV}} \times 100$$

Calculations for heat balance sheet:

(1) Total Heat Supplied:

$$Q_S = m_f \times C.V.\quad kJ$$

(2) Break Power: (as calculated in (2) above)

(3) Heat carried away by Exhaust Gasses:

$$Q_{Exhust\ Gasses} = m_a \times C_{pair} \times (T_{Exhaust\ gasses} - T_{air\ in})\ kJ$$

(4) Heat carried away by Cooling water:

$$Q_{cooling\ water} = m_w \times C_{pwater} \times (T_{water\ out} - T_{water\ in})\ kJ$$

(5) Unaccounted Heat:

$$Q_{mis} = Q_s - B.P. - Q_{Exhust\ Gasses} - Q_{Cooling\ Water}$$

Heat Balance Sheet based on Heat and Percentage of Heat:

Heat Supplied:			**Heat Utilized:**			
	kJ	**%**			**kJ**	**%**
			1	Break Power		
			2	Heat Carried away by Exhaust gas		
			3	Heat Carried Away by Cooling water		
			4	Unaccented Heat		

Conclusions:

Quiz: (attach separate sheets)

1. What is purpose of decompression lever.
2. Discuss phenomenon of engine knocking.
3. How the engine speed is maintained constant at all loads.
4. Explain function of fuel injector in diesel engine.
5. Explain pollution from diesel engine.

Suggested Reference:

(1) Internal Combustion Engines by V. Ganeshan, McGraw Hill Publication

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 9
Determination of friction power of multi cylinder petrol engine using Morse Test Method

Date:

Relevant CO: CO-3

Objectives: To determine the friction power and mechanical efficiency of multi-cylinder petrol engine using Morse Test

Theory: Morse test is applicable to multi cylinder engines only and it is used to find indicated power, break power, frictional power and mechanical efficiency of the petrol engine as well as diesel engine for set positions of throttle, choke and for a selected speed by cutting each cylinder in succession. If the engine consists of 'k' cylinders then the break power of the engine should be measured k-times, cutting each cylinder one by one. The cylinder of petrol engine is made inoperative by cut-off the spark plug. If all the "k" cylinders of the engine are in working, then

$$IP1 + IP2 + IP3 + ... + IPk = \sum_1^k BP + FP$$

Where IP, BP and FP are indicated, brake and frictional power respectively and suffix stands for the cylinder number. This test carried out on multi cylinder I.C. engine. In this test, first engine is allowed to run at constant speed and brake power of engine is measured when all cylinders are working and developing indicated power.

Considering four-cylinder engine

$$I_1 + I_2 + I_3 + I_4 = BP + (F_1 + F_2 + F_3 + F_4)$$

Where, I_1, I_2, I_3 and I_4 are Indicated power of four cylinders

BP = brake power of engine when all cylinders are working

F_1, F_2, F_3, F_4 are frictional power of all four cylinders

Then, the first cylinder is cut off by short circuiting spark plug in case S.I. engine (or cutting fuel supply in case C.I. engine). This causes the speed to drop due to non firing of first cylinder. It should be noted that although first cylinder is not producing power still it is reciprocating so its frictional power is to be considered. This speed is once again maintained to its original value by reducing load on the engine

$$I_2 + I_3 + I_4 = (BP)_{2,3,4} + (F_1 + F_2 + F_3 + F_4)$$

where $(BP)_{2,3,4}$ is brake power of 2, 3 and 4 cylinders only

Repeat the above procedure for remaining cylinders and calculate IP of the engine.

Cylinder 2 is cut off: $I_1 + I_3 + I_4 = (BP)_{1,3,4} + (F_1 + F_2 + F_3 + F_4)$

Cylinder 3 is cut off: $I_1 + I_2 + I_4 = (BP)_{1,2,4} + (F_1 + F_2 + F_3 + F_4)$

Cylinder 4 is cut off: $I_1 + I_2 + I_3 = (BP)_{1,2,3} + (F_1 + F_2 + F_3 + F_4)$

IP of cylinder 1 is calculated as, $I_1 = BP - (BP)_{2,3,4}$

Similarly, I_2, I_3 and I_4 is calculated as follows

$I_2 = BP - (BP)_{1,3,4}$

$I_3 = BP - (BP)_{1,2,4}$

$I_4 = BP - (BP)_{1,2,3}$

Total Indicated power of engine (IP) = $I_1 + I_2 + I_3 + I_4$

Frictional power of engine (FP) = IP – BP

Mechanical efficiency η_m = BP / IP

Schematic Layout:

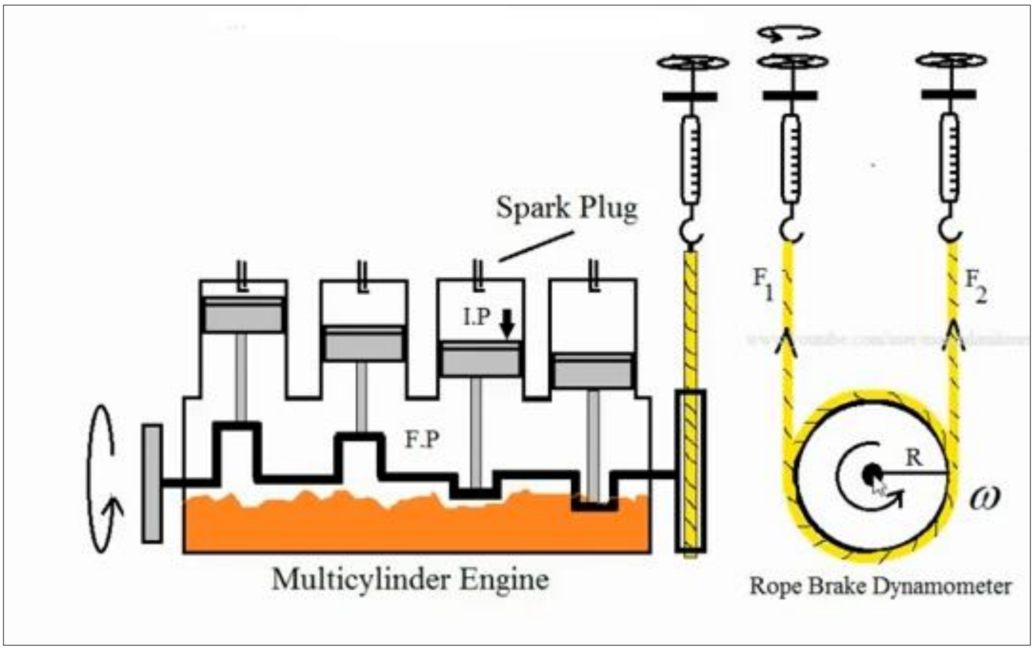


Fig. 1 Schematic layout of multi cylinder petrol engine test rig

Conclusion:

Quiz: (Attach separate sheets)

(1) Compare single cylinder and multi cylinder engines.
(2) What is function of hydraulic dynamometer?
(3) What is need of measurement of speed of an I.C. Engine?
(4) Explain function of flywheel in an engine.
(5) Discuss about catalytic converter.

Suggested Reference:

(1) Internal Combustion Engines by V. Ganeshan, McGraw Hill Publication

References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member

Experiment No: 10
To study the constructional details of various air compressors

Date:

Relevant CO: CO-5

Reciprocating Compressors:
In a reciprocating compressor, a volume of gas is drawn into a cylinder; it is trapped, and compressed by piston and then discharged into the discharge line. The cylinder valves control the flow of gas through the cylinder; these valves act as check valves. It is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure. The intake gas enters the suction manifold, and then flows into the compression cylinder. It gets compressed by a piston driven in a reciprocating motion via a crankshaft, discharged at higher pressure.
Reciprocating compressors can be Single acting or double acting.

Single–Stage Reciprocating Compressor: Compression is done in single stage or by single cylinder only and it is used for generation of low-pressure air.
Double–stage Reciprocating Compressor: It is a compressor that produces highly pressurized air and mostly it is used nowadays in heavy duty mechanical devices.

Construction of reciprocating Compressor: The major components of a reciprocating compressor and their functions give the machine its level of functionality. This positive displacement machine's parts include: Frame, Cylinders, Piston, Piston rings, Cross Head, Crankshaft, Connecting Rod, Valve, and Bearings.
Frame: The first thing you will notice in a compressor is its heavy and rugged frame which encloses all the rotating components such as the cylinder and crosshead guide. The frame is also called a crankcase and it has a square or rectangle shape. Its role is to offer support to the crankshaft. Notwithstanding, you can find Separable compressors or Integral compressors and in the case of the latter, the compressor and engine-power cylinders are fitted to the same frame and driven by the same crankshaft.

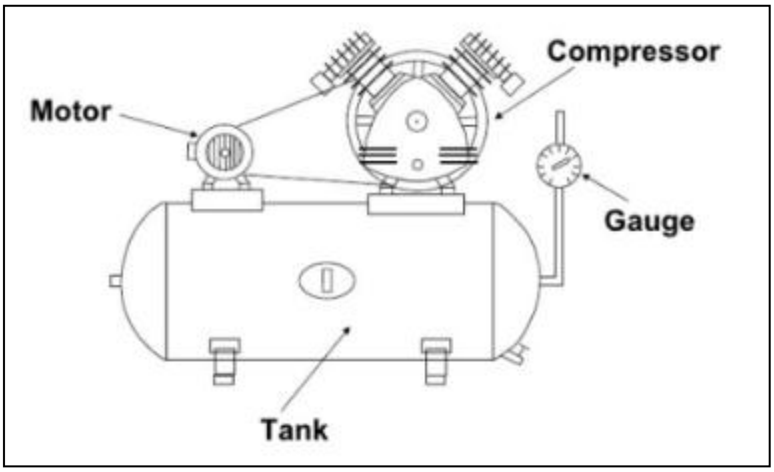


Fig. 1. Layout of reciprocating air compressor test rig

Cylinders: Cylinders are pressure vessels that contain the gas (air) that is to be compressed, and as such, they are one of the most important components of a reciprocating compressor. In large low-pressure cylinders, these parts are made up of cast iron and are removable from the major frame. Alternatively, small high-pressure cylinder compressors made of steel are directly fixed to the main body of the compressor. Cylinders support the discharge valve plates and suction and sometimes feature replaceable liners or sleeves which give the cylinder's wearing portion a renewable surface. The liners do not slip from the surface. Therefore, they ensure that if the cylinder is worn or damaged, it can easily be replaced instead of buying a new system entirely which is more expensive.

Piston: The mode of operation of the compressor greatly relies on the piston. This is because the piston is the component that compresses air. The piston must have weight, strength, and be compatible with the gas to be compressed. It also moves the energy from the crankcase to the gas contained in the cylinder in a bid to prevent the refrigerant from leaking through the gap. In between the piston and cylinder walls, this component is usually covered with piston rings. Furthermore, a piston in a reciprocating compressor can either be made of aluminium or cast iron and it moves upwards and downwards in the cylinder.

Piston Rings: The piston rings are wound on the piston and as the piston moves up and down the cylinder, the piston rings come in contact with the walls of the cylinder. Due to the amount of friction created during this reciprocating motion, rings must be replaced frequently to maintain the seamless operation of the compressor. In some cases, a wear band or rider ring is used as an additional piston ring. The function of rider ring in the reciprocating compressor is to reduce the probability of wear and tear occurring between the cylinder and piston. While rings must be softer than the liner wall and cylinder, different types of rings can be used for the piston and these are metallic rings and non-metallic rings.

Cross Head: A crosshead enables the piston to be inserted in the cylinder bore. The use of a crosshead enables a compressor to use a narrow piston and it enables longer strokes and higher efficiency.

Crankshaft: The crankshaft is the major shaft in a compressor, the other being a motor shaft. The shaft revolves around the frame axis and it drives the piston, piston rod, and connecting rod. This component is built as a forged steel crankshaft. It is in large compressors that operate above 150 kW (200 hp).For machines that work with less than or equal 150kW machines, a ductile iron crankshaft is used. Over and above that, a crankshaft in a reciprocating compressor is either connected to the electric motor directly or indirectly with the use of a belt and pulley system. As the motor shaft rotates, the crankshaft also performs a rotary motion which gives the piston the ability to carry out its reciprocating motion inside the cylinder. But first, a rod must be connected to the crankshaft and rod to enable the piston to perform an upward and downward movement.

Connecting Rod: When it comes to the crankshaft and piston, a connecting rod is linked between either. Depending on the power which the machine operates, a forged steel connecting rod or ductile iron material can be used. The former is in compressors that operate above 150 kW (200 hp) while the latter finds use in compressors that work around 150kW or less. The physical connection has one side of the rod linked to the piston using a piston pin. Alternately, the other side of the rod is connected to the crankshaft using a connecting cap rod. While the connection may sound simple, it is what is required to give the crankshaft its rotary motion which also helps the piston to translate within the cylinder. Therefore, the connecting rod changes the rotary motion to reciprocating motion.

Valve: A compressor valve's function is to allow gas to flow in the right direction while blocking those that may tend to flow in an undesired direction. Accordingly, these valves are placed in each operating end of a cylinder. One end will have a set of inlet valves to allow gas into the cylinder while another end features two discharge valves. The valves in a reciprocating compressor are also of various configurations. These include: Ring valve, Poppet valve, and Plate valve.

Bearings: Bearings are not the least component given that they can be found throughout the compressor's frame. They ensure other components in the compressor are properly positioned radially and axially. An instance is that of the main bearings which are fixed in the frame to ensure that the crankshaft is well fitted. There is also a crank pin bearing that is positioned between the connecting rod and crankshaft. Other bearings that can be found are the crosshead bearings and wrist pin bearings.

Working Principle:

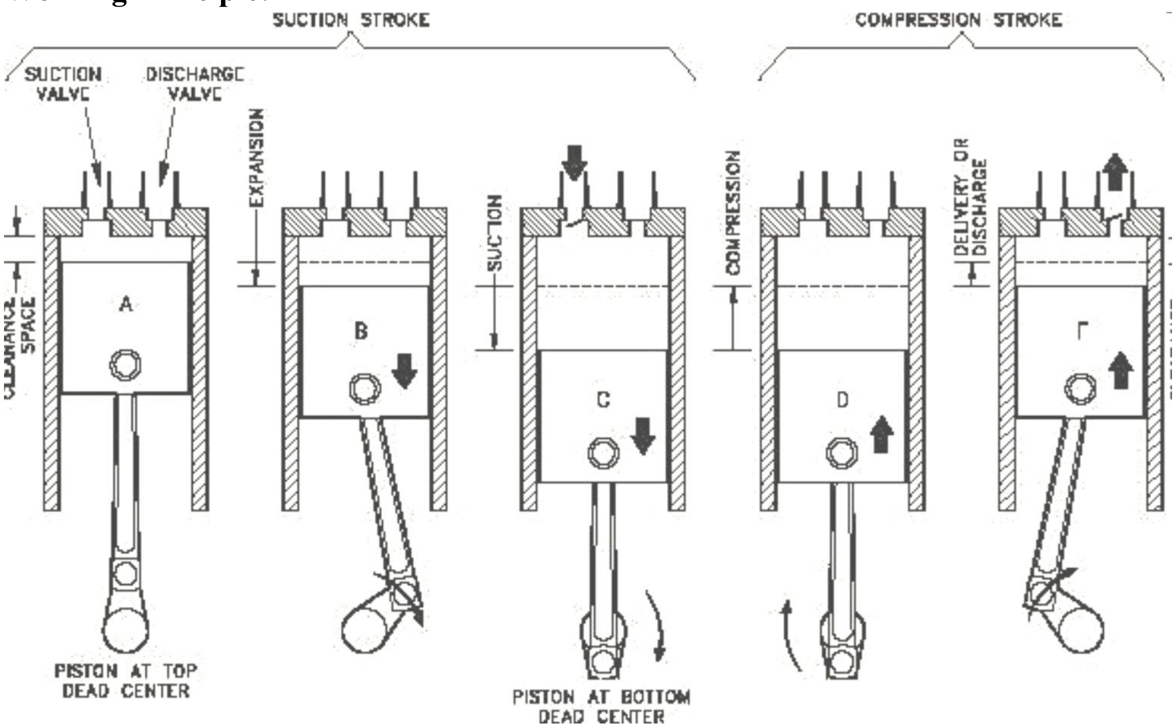


Fig. 2 Operation of Reciprocating Compressor

Fig. 2 shows single-acting piston actions in the cylinder of a reciprocating compressor. The piston is driven by a crank shaft via a connecting rod. At the top of the cylinder are a suction valve and a discharge valve. A reciprocating compressor usually has two, three, four, or six cylinders in it. As the piston travels toward the bottom dead center, the volume of the cylinder increases and due to the pressure difference, the suction valve is opened. The pressure inside the cylinder is slightly less than suction line pressure. So, the volume of the gas starts increasing as the piston moves towards BDC. So, the piston continues its motion towards BDC till the area above piston in the cylinder become full of fluid (gas) & then the suction valve gets closed. Now when the crankshaft moves further and completes its revolution the piston also moves in opposite direction this time towards TDC. Now, again due to the Pressure difference between the delivery line and inside of the cylinder the delivery valves open in the delivery stroke.

Operations:

4 – 1: Volume V1 of air aspirated into Compressor, at P_1 and T_1.

1 – 2: Air compressed according to PV_n = Const. from P_1 to P_2 Temp increase from T_1 to T_2

2 – 3: Compressed air at P_2 and V_2 with temperature T_2 is delivered.

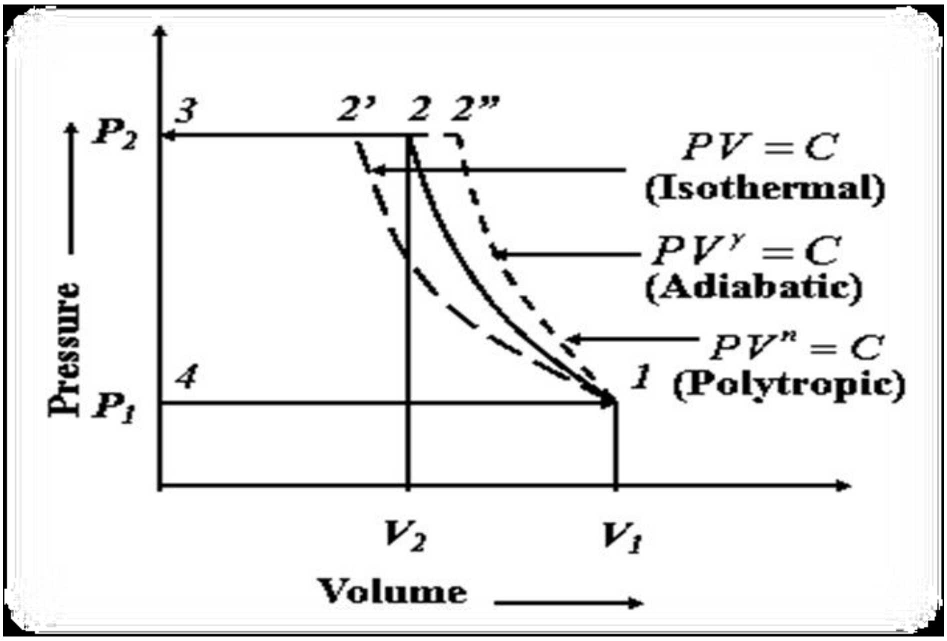


Fig.3 p-V Diagram of Reciprocating compressor

Axial flow Compressor

The compressors in most gas turbine applications, especially units over 5MW, use axial flow compressors. An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. The fluid is accelerated by a row of rotating airfoils (blades) called the rotor as shown in Fig. 4 (a), and then diffused in a row of stationary blades (the stator). The diffusion in the stator as shown in Fig. 4 (b) converts the velocity increase gained in the rotor to a pressure increase.

(a) (b)

Fig. 4 Axial flow compressor (a) rotor (b) stator.

A compressor consists of several stages: 1) A combination of a rotor followed by a stator make-up a stage in a compressor; 2) An additional row of stationary blades are frequently used at the compressor inlet and are known as Inlet Guide Vanes (IGV) to ensure that air enters the first-stage rotors at the desired flow angle, these vanes are also pitch variable thus can be adjusted to the varying flow requirements of the engine; and 3) In addition to the stators, another diffuser at the exit of the compressor consisting of another set of vanes further diffuses the fluid and controls its velocity entering the combustors and is often known as the Exit Guide Vanes (EGV). In an axial flow compressor, air passes from one stage to the next, each stage raising the pressure slightly. By producing low pressure increases on the order of 1.1:1 to 1.4:1, so very high efficiencies can be obtained. The use of multiple stages permits overall pressure increases of up to 40:1 in some aerospace applications and a pressure ratio of 30:1 in some Industrial applications.

Construction and Working of Axial Flow Compressor:

A typical Axial Flow Compressor consists of the following components.

1. Rotor
2. Rotor Blades
3. Casing
4. Stator Blades

Rotor: Axial-Flow Compressor has a rotating part called the rotor. It consists of a rotor drum. The rotor drum is connected to the shaft. The shaft is the actual rotating element. It transfers the rotary motion to the drum. The mounting for the rotor blades is on the rotor drum.

Rotor Blades: Rotor Blades are placed on the rotor drum. The rotor blades rotate and are hence responsible for increasing the kinetic energy of gases.

Materials for the construction of Rotor Blades are as follows.

- Composites
- Titanium
- Steel
- Nickel alloy

Casing : The casing forms an outer protective membrane for the axial flow compressor. It also performs several other functions. The stator blades are mounted on the casing. They are the fixed blades in an axial flow compressor. The casing of an axial flow compressor is made from one of the following components.

- Iron or high-quality steel
- Aluminium
- Magnesium
- Titanium

Stator: Unlike the rotor blades, which rotate along with the rotor drum, the stator blades remain stationary throughout the compression process. The stator blades reside in the casing of an axial flow compressor. The stator blades are from the following materials:-

- Composites
- Steel
- Titanium
- Nickel alloy

The functions of Stator Blades include the following:

- They act as guide vanes.
- They guide the gases to flow in a particular direction inside the compressor. It allows the gases to hit on the rotor blades with a proper angle of contact.
- They are also responsible for increasing the pressure of the gases.

The basic working principle behind an axial flow compressor is that the rotor imparts kinetic energy to the gas as shown in Fig. 10.5. This kinetic energy is later converted to static pressure when it is diffused through passages or when it strikes on the rotor. For an axial flow compressor, the flow of gases is along the axis. At the start, inlet guide vanes or stator blades are present. It is to ensure that the gases strike on the rotor with the proper angle of attack. And the rotor is placed next to the stator blade. The aero foil shape of the blade is a crucial feature for this action. Axial Flow Compressor works in many stages. A rotor and a stator together constitute one. Generally, there can be five to fifteen stages in an axial flow compressor. The number of stages is determined by the pressure ratio that needs to attain as well as the amount of gas. The stator and rotor blades are alternately packed. Gases first collide on the stator or the first guide vane. It guides the gases to the rotating rotor blade that follows next. The rotor blades then increase the kinetic energy of the gases and supply it to the adjacent stator blade. The gases then fall on the stator blades. When it hits on the stator, its pressure energy increases, but at the cost of its kinetic energy. The gases with a decreased velocity will now move to the next rotor. The rotor will now increase the kinetic energy of the gases. But the kinetic energy will be far less than the kinetic energy supplied by the rotor before. These processes repeat until the gases reach the exit. At the exit of the compressor, the gases have very high pressure.

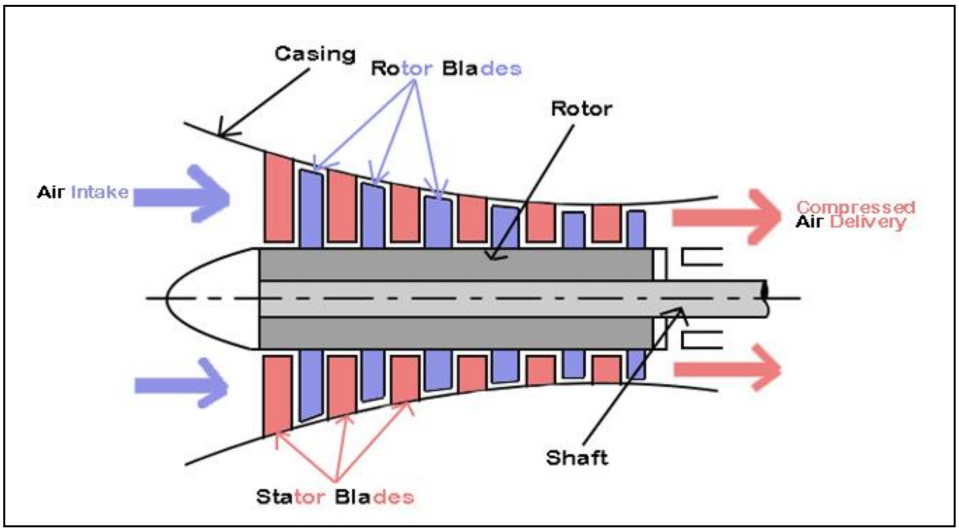


Fig. 5 Schematic layout of axial flow compressors

Characteristics Curve:

The characteristics curve of an axial flow compressor shown in Fig. 6. It is seen that the volume of air stream remains constant for given speed, an increase in pressure causes a little reduction in volume flow. But near design point i.e. the point of maximum efficiency, the change in volume is not appreciable with an increase in pressure. Further with decrease with pressure ratio and volume flow, efficiency also falls. So, it can be concluded that axial flow compressors are useful for high speeds and for high flow rate.

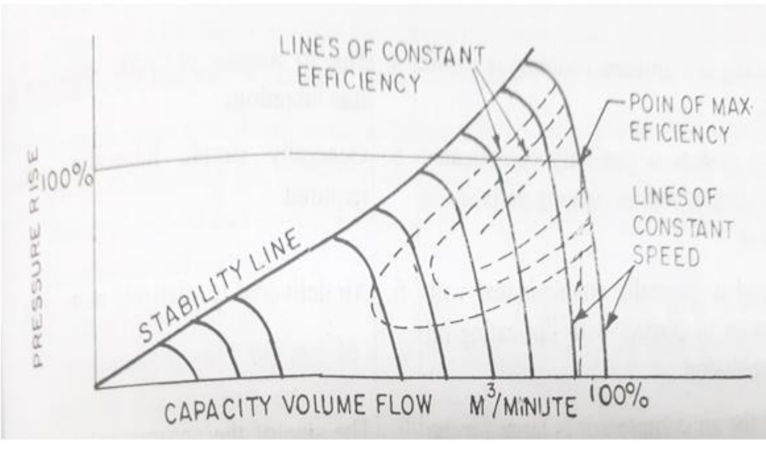


Fig. 6 Axial flow compressor characteristic curve

Centrifugal Compressor
Centrifugal flow compressors, sometimes referred to as radial compressors, are a special class of radial-flow work-absorbing turbo-machinery that include pumps, fans, blowers and compressors. The earliest forms of these dynamic-turbo machines were pumps, fans and blowers. What differentiates these early turbo machines from compressors is that the working fluid can be considered incompressible, thus permitting accurate analysis through Bernoulli's equation. In contrast, modern centrifugal compressors are higher in speed and analysis must deal with compressible flow. In an idealized sense, the dynamic compressor achieves a pressure rise by adding kinetic-energy/velocity to a continuous flow of fluid through the rotor or impeller as shown in Fig. 7. This kinetic energy is then converted to an increase in static pressure by slowing the flow through a diffuser. Centrifugal compressors are used in applications requiring pressurized air at high flow rates. Some of the applications are cooling systems, burner air supply for furnace application etc.

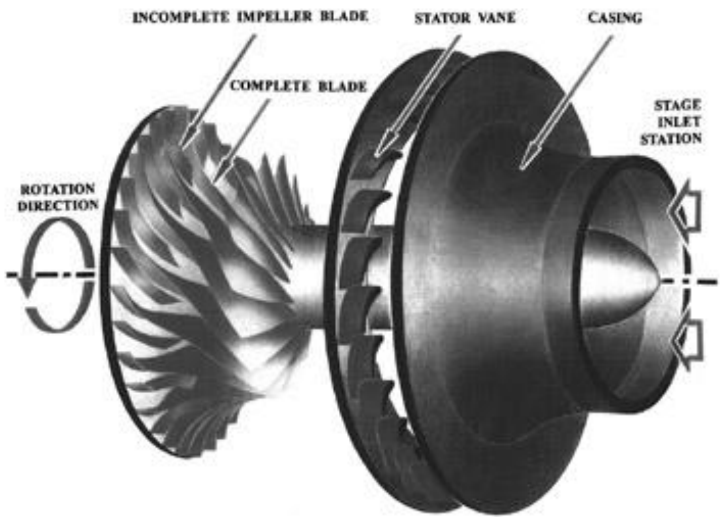


Fig. 7 Constructional details about centrifugal air compressor

Construction:
Inlet: The inlet to a centrifugal compressor is typically a simple pipe. It may include features such as a valve, stationary vanes/aerofoils (used to help swirl the flow) and both pressure and temperature instrumentation. All these additional devices have important uses in the control of the centrifugal compressor. Centrifugal Impeller: The key component that makes a compressor centrifugal is the centrifugal impeller. It is the impeller's rotating set of vanes (or blades) that gradually raises the energy of the working gas. This is identical to an axial compressor with the exception that the gases can reach higher velocities and energy levels through the impeller's increasing radius. Euler’s pump and turbine equation plays an important role in understanding impeller performance.
Diffuser: The next key component to the simple centrifugal compressor is the diffuser. Downstream of the impeller in the flow path, it is the diffuser's responsibility to convert the kinetic energy (high velocity) of the gas into pressure by gradually slowing (diffusing) the gas velocity. Diffusers can be vane less, vanned or an alternating combination. High efficiency vanned diffusers are also designed over a wide range of solidities from less than 1 to over 4. Hybrid versions of vanned diffusers include: wedge, channel, and pipe diffusers. There are turbocharger applications that benefit by incorporating no diffuser.

Collector: The collector of a centrifugal compressor can take many shapes and forms. When the diffuser discharges into a large empty chamber, the collector may be termed a Plenum. When the diffuser discharges into a device that looks somewhat like a snail shell, bull's horn or a French horn, the collector is likely to be termed a volute or scroll. As the name implies, a collector's purpose is to gather the flow from the diffuser discharge annulus and deliver this flow to a downstream pipe. Either the collector or the pipe may also contain valves and instrumentation to control the compressor.

Working Principle:
Centrifugal compressor working on Bernoulli's fluid dynamic principle. Bernoulli's principle derived from conservation of energy. In a centrifugal compressor, an additional kinetic energy imparted to the fluid by rotating impeller. Then this kinetic energy gets converted into pressure energy at diffuser. In a centrifugal compressor, the impeller is connected to a shaft driven by any mechanism. The rotating impeller draws air through the inlet at the center of the impeller and guides the air towards the periphery. During this movement, impeller increases the kinetic energy of air. At the periphery, the air is guided through a stationary passage known as diffuser where its velocity kinetic energy decreases. According to Bernoulli's law reduction in a velocity cause increase in pressure of the fluid, that is kinetic energy is converted into pressure energy.

Performance Curves of Centrifugal Flow Compressor:

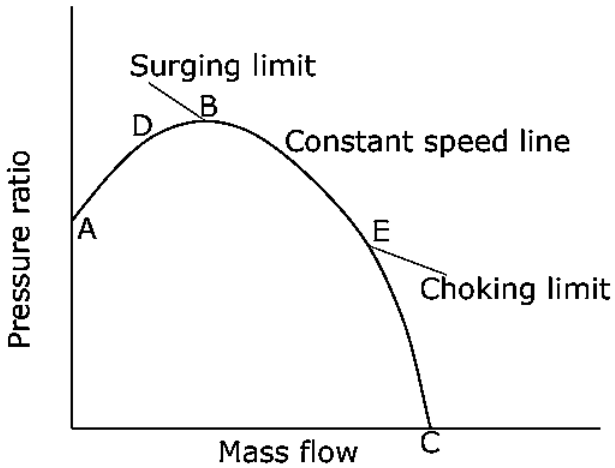


Fig. 8 Performance curve of centrifugal compressor

The centrifugal compressor performance characteristics can be derived in the same way as an axial compressor. Performance is evaluated based on the dependence of pressure ratio and efficiency on the mass flow at different operating speeds. Centrifugal compressors also suffer from instability problems like surge and rotating stall.

There are two limits to the operation of the compressor. Operation between A and B are limited due to occurrence of surge. Surging is sudden drop in delivery pressure and violent aerodynamic pulsations. Operation on the positive slope of the performance characteristics is unstable surging usually starts to occur in the diffuser passages.
Rotating stall might also affect the compressor performance. In this case a stall cell (that might cover one or more adjacent blades) rotates within the annulus. Full annulus rotating stall may eventually lead to surge. Rotating stall may also lead to aerodynamically induced vibrations and fatigue failure of the compressor components.

The other limiting aspect of centrifugal compressors is choking. As the mass flow increases, the pressure decreases, density reduces. After a certain point, no further increase in mass flow will be possible. The compressor is then said to have choked. The right-hand side of the constant speed lines together form the choking line.

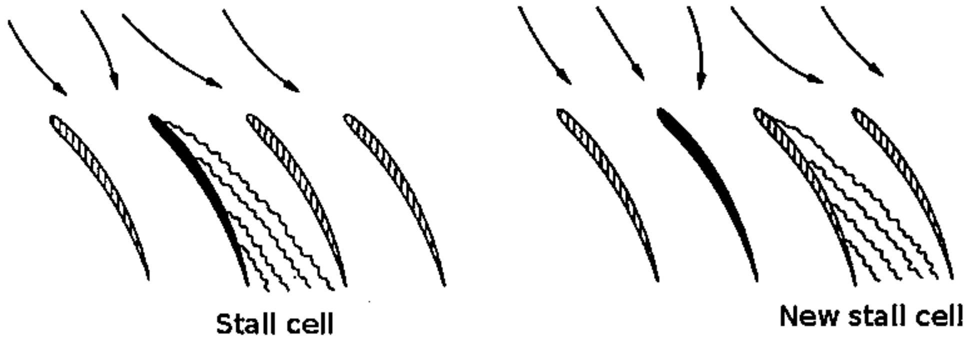


Fig. 9 Propagation of rotating stall

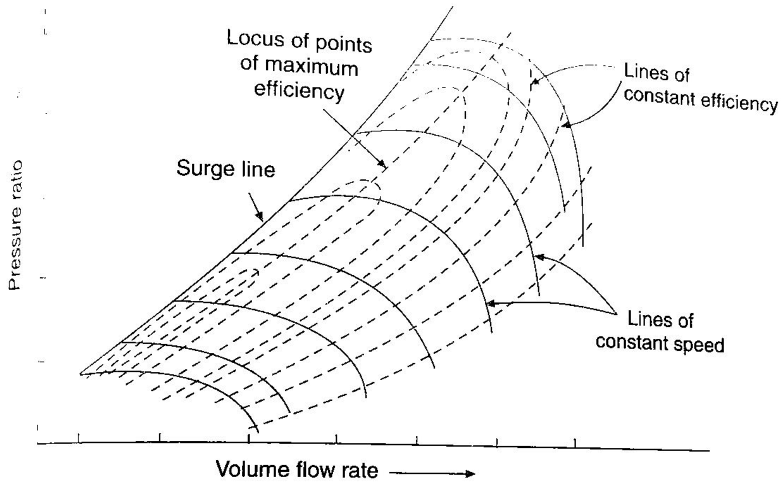


Fig. 10 Performance curves for centrifugal compressor

As shown in Fig. 10, we can notice that at low rotational speeds, the curves are flat and are limited by surging. As well as at high speeds, the range is very much limited because surging occurs at one end and chocking on the other. Also, it is seen that for a given speed, the mass flow rate decreases as the pressure ratio increases. For a given pressure ratio, the mass flow rate increases with increase in speed which leads to fall in efficiency.

Advantages:

1. Low weight, easy to design and manufacture.
2. Suitable for continuous compressed air supply, such as cooling unit.
3. The oil free in nature and have fewer rubbing parts.
4. High-flow rate than the positive displacement compressor.
5. Relatively energy efficient and wide range of rotational speed.
6. Centrifugal compressors are reliable, low maintenance.
7. Generating a higher-pressure ratio per stage as compared to axial flow compressor.
8. It does not require special foundation.

Disadvantages:

1. Large frontal area for a given air flow rate compared to the axial flow compressor.

2. Unsuitable for very high compression, limited pressure.
3. They are sensitive to changes in gas composition.
4. They work at high speed, sophisticated vibration mounting needed.
5. Problem of surging, stalling, and choking.

Application:
1. Food and beverage industry - centrifugal compressor provides oil frees compressed air
2. for some sensitive application such as food processing.
3. Centrifugal compressor meets high demand of compressed air.
4. Gas turbines, in automobile turbochargers and supercharger.
5. Oil refineries, natural-gas processing.
6. Refrigeration and air-conditioning

Quiz: (Attach separate sheets)
Reciprocating Compressor
1. Define: (a) Free air delivered (b) Compressor capacity (c) Swept volume (d) Pressure ratio
2. Classify air compressors.
3. Differentiate between reciprocating and rotary compressors.
4. Enlist different uses of compressed air.
5. Why majority of air compressors available in the market are multi staged? Explain

Axial Flow compressor
1. State different applications of axial flow compressors.
2. Give merits and limitations for axial flow compressors.
3. Differentiate between centrifugal and axial flow compressors.
4. Discuss about the stalling in axial flow compressors.
5. Define and explain degree of reaction for axial flow compressors.

Centrifugal Flow compressor
1. Define Slip Factor, Work input factor and Pressure co-efficient.
2. What is different between fan, blower and compressor?
3. State applications and advantages of centrifugal flow air compressors.
4. Explain significance of Pre-whirl.
5. Explain surging and chocking.

Suggested Reference:
(1) Turbines, Compressors and Fans by S.M. Yahya., TMH Publishers
References used by the students:

Rubric wise marks obtained:

Rubrics	1	2	3	Total
Marks				

Signature of faculty member