ENGINEERING THERMODYNAMICS

II B. Tech III semester (Autonomous)(IARE R-18)

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BASIC CONCEPTS AND FIRST LAW OF THERMODYNAMICS

INTRODUCTION

- Thermodynamics deals with stability of systems. It tells us '*what should happen?*'. '*Will it actually happen(?)*' is not the domain of thermodynamics and falls under the realm of kinetics.
- At –5°C at 1 atm pressure, ice is more stable then water. Suppose we cool water to –5°C. "Will this water freeze?" (& "how long will it take for it to freeze?") is (are) not questions addressed by thermodynamics.

- One branch of knowledge that all engineers and scientists must have a grasp of *(to some extent or the other!)* is thermodynamics.
- Thermodynamics can be considered as a ‘system level’ science- i.e. it deals with descriptions of the whole system and not with interactions (say) at the level of individual particles. TD puts before us some fundamental laws which are universal in nature (and hence applicable to fields across disciplines).

- To understand the laws of thermodynamics and how they work, first we need to get the terminology right.
- System is region where we focus our attention *(Au block in figure).*
- Surrounding is the rest of the universe *(the water bath at constant 'temperature').*
- Universe = System + Surrounding (the part that is within the dotted line box in the figure below)

- More practically, we can consider the ‘Surrounding’ as the immediate neighbourhood of the system (the part of the universe at large, with which the system ‘effectively’ interacts).
- Things that matter for the surrounding: (i) T (ii) P (iii) ability to: do work, transfer heat, transfer matter, etc. Parameters for the system: (i) Internal energy, (ii) Enthapy, (iii) T, (iv) P, (v) mass,

- Matter is easy to understand and includes atoms, ions, electrons, etc.
- Energy may be transferred (‘added’) to the system as heat, electromagnetic radiation etc.
- In TD the two modes of transfer of energy to the system considered are Heat and Work.

  Heat and work are modes of transfer of energy and not ‘energy’ itself.

- It is clear that, *bodies contain internal energy and not heat (nor work).*

- Matter when added to a system brings along with it some energy.

- The ‘energy density’ (energy per unit mass or energy per unit volume) in the incoming matter may be higher or lower than the matter already present in the system.

Macroscopic and microscopic approaches

Behavior of matter can be studied by these two approaches.

- In macroscopic approach, certain quantity of matter is considered, without a concern on the events occurring at the molecular level.

- These effects can be perceived by human senses or measured by instruments.

  eg: pressure, temperature

In microscopic approach, the effect of molecular motion is considered.

Ex: At microscopic level the pressure of a gas is not constant, the temperature of a gas is a function of the velocity of molecules.

Property

- It is some characteristic of the system to which some physically meaningful numbers can be assigned without knowing the history behind it.
- These are macroscopic in nature.
- Invariably the properties must enable us to identify the system.

Categories of Properties

Extensive property:

- Whose value depends on the size or extent of the system.

  eg: Volume, Mass (V,M).

- If mass is increased, the value of extensive property also increases.

Intensive property*:*

Whose value is independent of the size or extent of the system.

eg: pressure, temperature (p, T).

Specific property

- It is the value of an extensive property per unit mass of system. (lower case letters as symbols) eg: specific volume, density (*v*, ρ).
- It is a special case of an intensive property.
- Most widely referred properties in thermodynamics: Pressure; Volume; Temperature*; Entropy; Enthalpy; Internal energy*

State

- It is the condition of a system as defined by the values of all its properties.

- It gives a complete description of the system.

- Any operation in which one or more properties of a system change is called a change of state.

Phase ,Path And Process

- It is a quantity of mass that is homogeneous throughout in chemical composition and physical structure.

  e.g. solid, liquid, vapour, gas.

- Phase consisting of more than one phase is known as heterogenous system .

- The succession of states passed through during a change of state is called the *path of the system*. A system is said to go through a process if it goes through a series of changes in state.

- A system may undergo changes in some or all of its properties.
- A process can be construed to be the locus of changes of state
- Processes in thermodynamics are like streets in a city

  eg: we have north to south; east to west; roundabouts; crescents

Quasi-static Processes

The processes can be restrained or unrestrained we need restrained processes in practice.

- A quasi-static process is one in which the deviation from thermodynamic equilibrium is infinitesimal.
- All states of the system passes through are equilibrium states
- No interactions between them occur. They are said to be in equilibrium.
- Thermodynamic equilibrium implies all those together.
- A system in thermodynamic equilibrium does not deliver anything.

Zeroth Law of Thermodynamics

- If two systems (say A and B) are in thermal equilibrium with a third system (say C) separately (that is A and C are in thermal equilibrium; B and C are in thermal equilibrium).

- Then they are in thermal equilibrium themselves (that is A and B will be in thermal equilibrium

Heat And Work

Thermodynamic definition of work:

Positive work is done by a system when the sole effect external to the system could be reduced to the rise of a weight.

Thermodynamic definition of heat:

It is the energy in transition between the system and the surroundings by virtue of the difference in temperature

- Work done BY the system is +ve Obviously work done ON the system is –ve.
- Heat given TO the system is +ve Obviously Heat rejected by the system is –ve

Types of Work Interaction

- Expansion and compression work (displacement work)
- Work of a reversible chemical cell
- Work in stretching of a liquid surface
- Work done on elastic solids

SECOND LAW OF THERMODYNAMICS

- There exists a law which determines the direction in which a spontaneous process proceeds.

- The law, known as the second law of thermodynamics, is a principle of wide generality and provides answer to the above questions.

- It is essential to understand the meaning of the following terms in order to discuss the second law of thermodynamics:

- Thermal reservoir is a large body from which a finite quantity of energy can be extracted or to which a finite quantity of energy can be added as heat without changing its temperature.

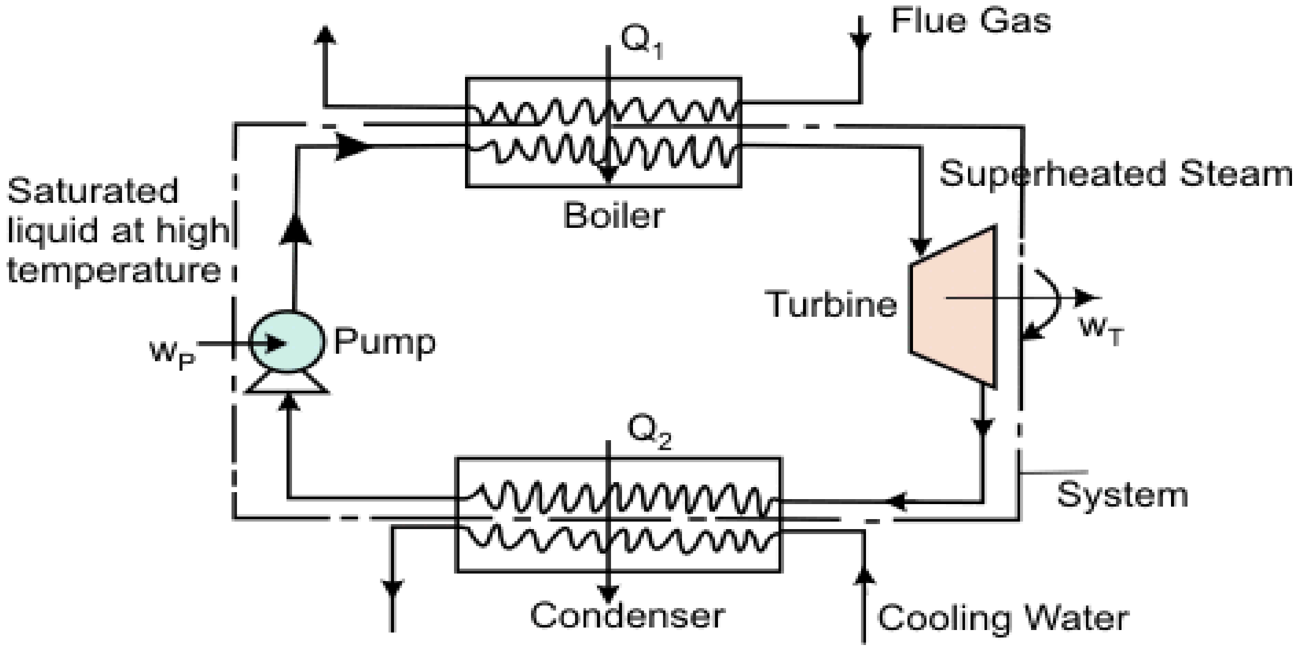
- A source is a thermal reservoir at high temperature from which a heat engine receives the energy as heat.

- A sink is a low temperature thermal reservoir to which a heat engine rejects energy as heat.

Heat Engine

- A heat engine is a device which converts the energy it receives at heat, into work. It is a cyclically operating device.
- It receives energy as heat form a high temperature body, converts part of it into work and rejects the rest to a low temperature body.
- A thermal power plant is an example of a heat engine.

Basic arrangement of thermal power plant



- In the boiler, the working fluid receives a certain amount of heat from the hot combustion products.
- The superheated steam enters a turbine where it undergoes expansion performing the shaft work .
- The low pressure steam enters a condenser where it exchange energy as heat at constant pressure with the cooling water and emerges as the condensate. The condensate rejects a certain amount of heat to the cooling water.
- The low pressure condensate from the condenser enters the pump. Work is done on the pump to elevate the condensate to the boiler pressure and return it to the boiler.

Finally, the thermal efficiency of a heat engine can be expressed as

$$\eta = \frac{(\text{Energy absorbed as heat} - \text{Energy rejected as heat})}{\text{Energy absorbed as heat}}$$

$$= \frac{\text{Net work done}}{\text{Energy absorbed as heat}}$$

$$= \frac{W_T - W_P}{Q_1}$$

Heat Pump

- Heat Pump is cyclically operating device which absorbs energy form a low temperature reservoir and reject energy as heat to a high temperature reservoir when work is performed on the device.

- Its objective is to reject energy as heat to a high temperature body (space heating in winter). The atmosphere acts as the low temperature reservoir.

Kelvin Plank Statement

It is impossible to construct a cyclically operating device such that it produces no other effect than the absorption of energy as heat from a single thermal reservoir and performs an equivalent amount of work.

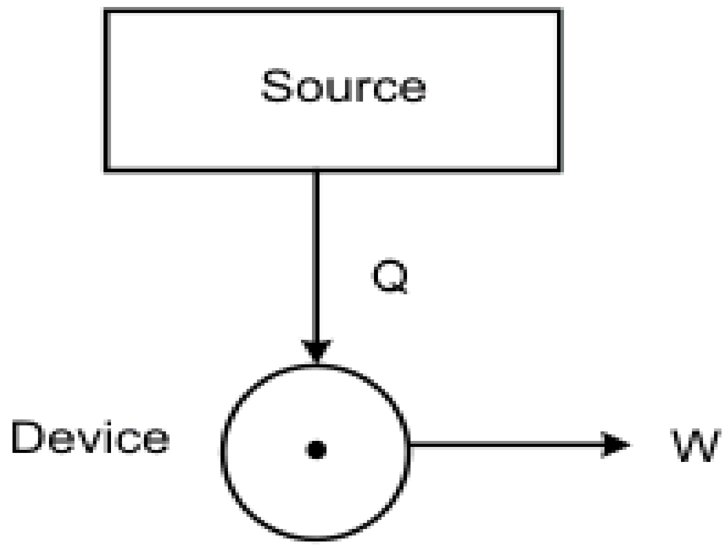
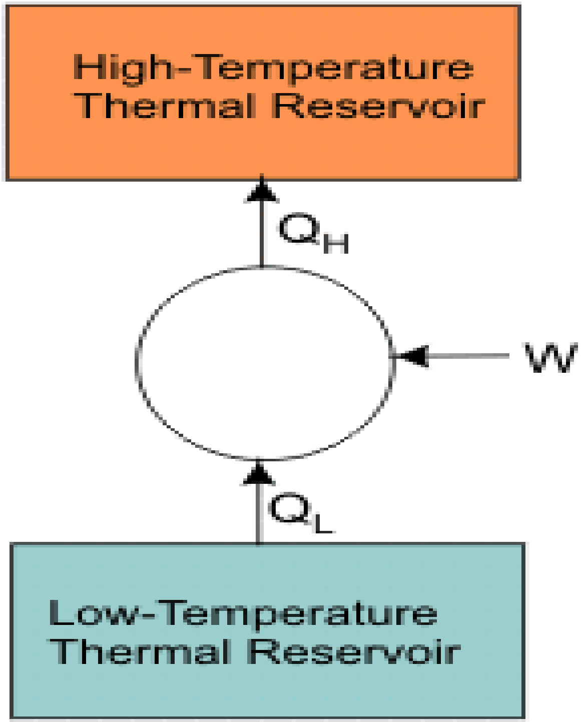


Figure 2.1 Kelvin Plank

Clausius Statement of the Second Law

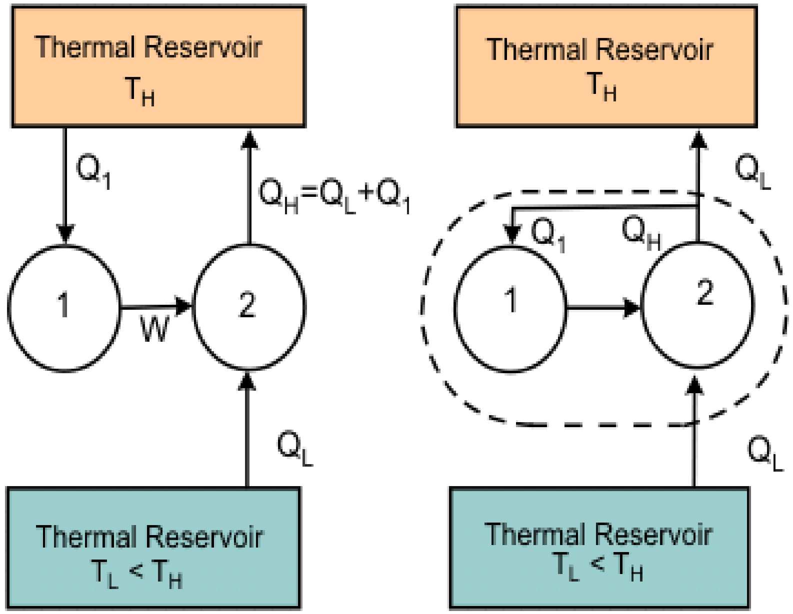
- Heat always flows from a body at higher temperature to a body at a lower temperature. The reverse process never occurs spontaneously.
- Clausius statement of the second law gives: It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a low-temperature body to a high temperature body.

Clausius Statement of the Second Law



Thermal reservoir

Clausius Statement of the Second Law



Clausius statement

$$W = Q_1,$$

$$Q_H = Q_L + W = Q_L + Q_1$$

Carnot Engine

Let us consider the operation of a hypothetical engine which employs the Carnot cycle. The Carnot engine consists of a **cylinder-piston assembly** in which a certain amount of gas(working fluid) is enclosed.

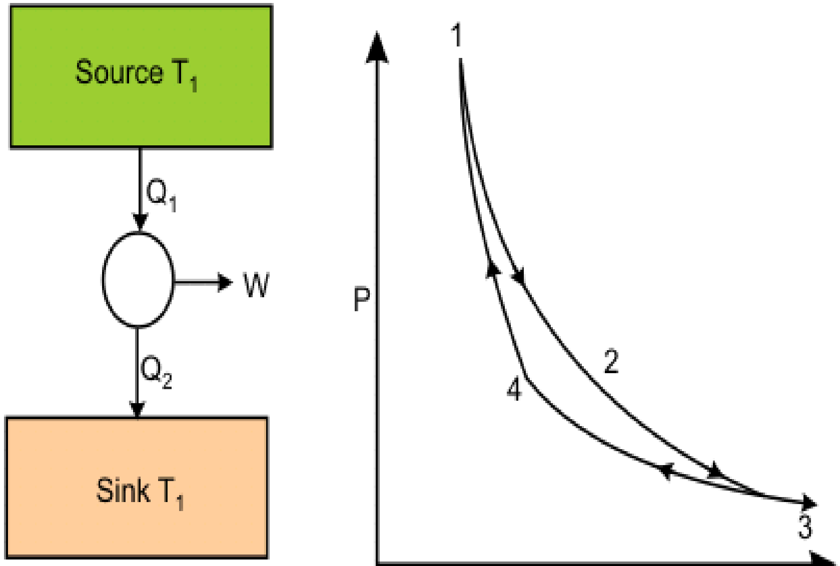


Fig 2.2 Carnot Cycle

The thermal efficiency,

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

Efficiency of Carnot Engine Using Ideal Gas

$$\eta = 1 + \frac{RT_2 \ \text{In}(v_4 / v_3)}{RT_1 \ \text{In}(v_2 / v_1)}$$

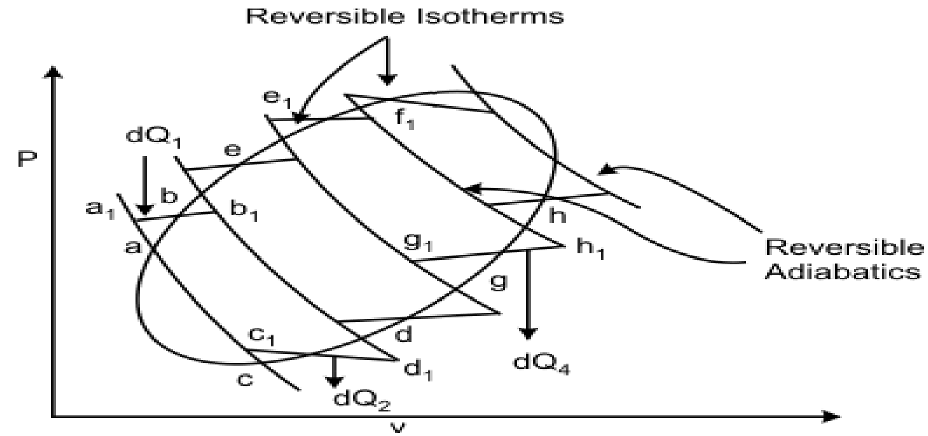
$$\eta = 1 - \frac{T_2 \ In(v_2 / v_1)}{T_1 \ In(v_2 / v_1)} = 1 - \frac{T_2}{T_1}$$

Thermodynamic Temperature Scale

A temperature scale, which does not depend on the thermodynamic property of the substance can be established by making use of the fact that the efficiency of a reversible heat engine does not depend on the nature of the nature of the working fluid but depends only upon the temperature of the reservoirs between which it operates.

Clausius Inequality

Consider a system undergoing a reversible cycle. The given cycle may be sub-divided by drawing a family of reversible adiabatic lines. Every two adjacent adiabatic lines may be joined by two reversible isotherms



$$\oint \frac{dQ}{T} \leq 0$$

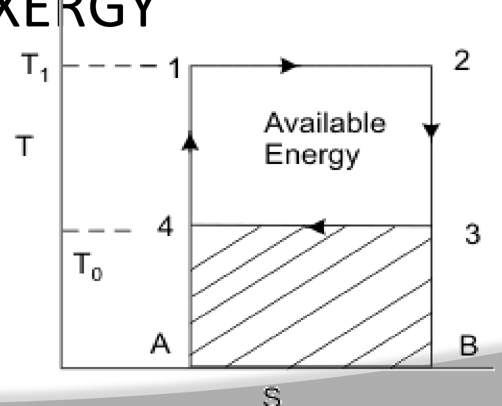
- The equality holds good for a and the inequality holds good for an irreversible cycles.
- The complete expression ireversible cycle s known as Clausius Inequality.

Entropy

- Clausius inequality can be used to analyze the cyclic process in a quantitative manner.
- The second law became a law of wider applicability when Clausius introduced the property called entropy.
- By evaluating the entropy change, one can explain as to why spontaneous processes occur only in one direction.

Available energy

- In order to determine that part of the energy which can be converted into work by an engine.
- We require consider a thermal reservoir at constant temperature T from which a quantity of energy Q is being absorbed as heat.
- The portion of energy is not available for conversion into work is called unavailable energy. Therefore, the available energy represents the portion of the energy supplied as heat which can be converted into work by means of a reversible engine. It is also known as EXERGY



PURE SUBSTANCES AND MIXTURES OF PERFECT GASES

PURE SUBSTANCE

A substance that has a fixed chemical composition throughout is called a pure substance such as water, air, and nitrogen. A pure substance does not have to be of a single element or compound.

A mixture of two or more phases of a pure substance is still a pure substance as long as the chemical composition of all phases is the same.

PHASES OF A PURE SUBSTANCE

A pure substance may exist in different phases. There are three principal phases solid, liquid, and gas. A phase: is defined as having a distinct molecular arrangement that is homogenous throughout and separated from others (if any) by easily identifiable boundary surfaces. A substance may have several phases within a principal phase, each with a different molecular structure. For example, carbon may exist as graphite or diamond in the solid phase, and ice may exist in seven different phases at high pressure. Molecular bonds are the strongest in solids and the weakest in gases.

T-S AND H-S DIAGRAMS

A T-s diagram is the type of diagram most frequently used to analyze energy transfer system cycles. ... By the definition of entropy, the heat transferred to or from a system equals the area under the T-s curve of the process.

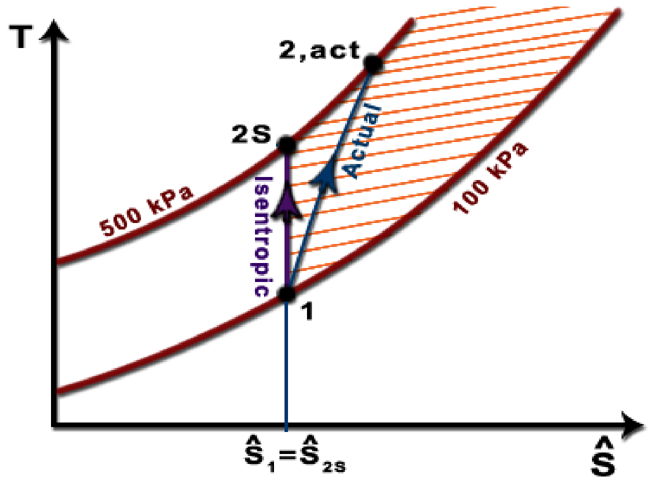


Fig.3.1Mollier (t-s) diagram

- The Mollier diagram is used only when quality is greater than 50% and for superheated steam.
- For any state, at least two properties should be known to determine the other unknown properties of steam at that state.

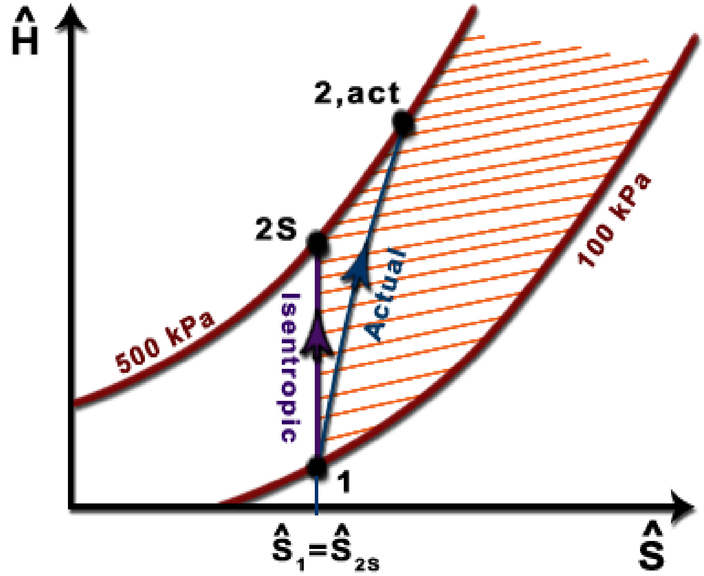
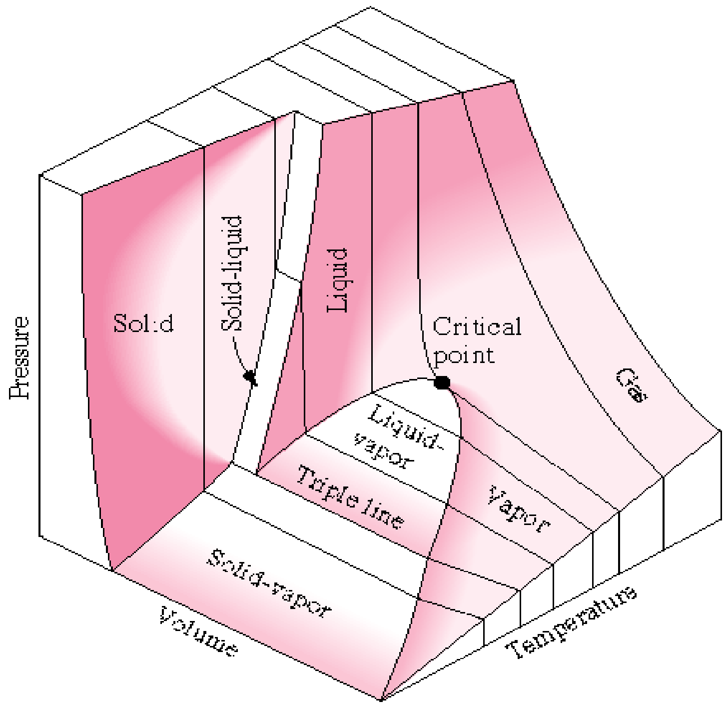


Fig.3.2 Mollier or Enthalpy-Entropy (h-s) diagram

P-V-T SURFACES

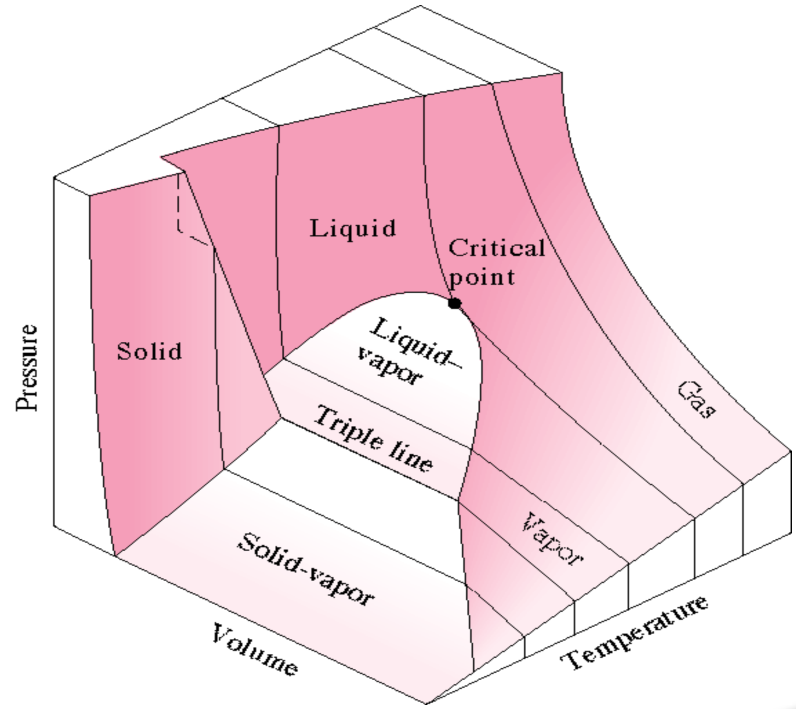
As we know very well that equation of state for an ideal gas deals with the relationship between pressure, volume and temperature. If we will plot above mentioned variables along x, y and z axis then we will have one surface which will indicate the equation of state i.e. PV=RT. And this surface will be termed as P-V-T surface in thermodynamics. Following figure displayed here indicates the P-V-T surface for an ideal gas.

P-V-T Surface for a Substance that contracts upon freezing



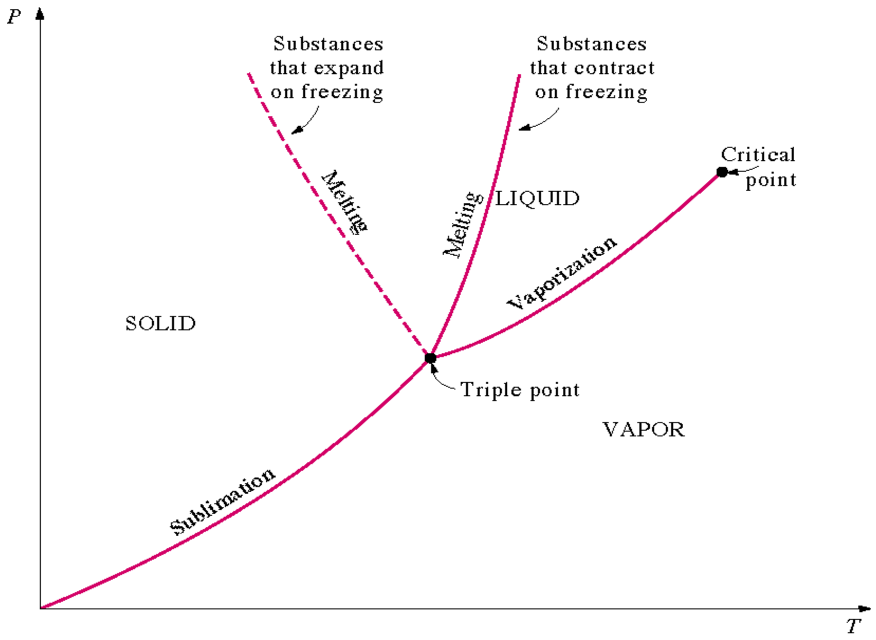
Temperature volume diagram

P-V-T Surface for a Substance that expands upon freezing



Temperature volume diagram

The *P-T* diagram, often called the phase diagram, for pure substances that contract and expand upon freezing



The triple point of water is 0.01°C, 0.6117 kPa.
The critical point of water is 373.95°C, 22.064 Mpa.

Property Tables

In addition to the temperature, pressure, and volume data, tables contain the data for the specific internal energy *u* the specific enthalpy *h* and the specific entropy *s*. The enthalpy is a convenient grouping of the internal energy, pressure, and volume and is given by

$$H = U + PV$$

The enthalpy per unit mass is

$$h = u + pv$$

Saturation pressure is the pressure at which the liquid and vapor phases are in equilibrium at a given temperature.

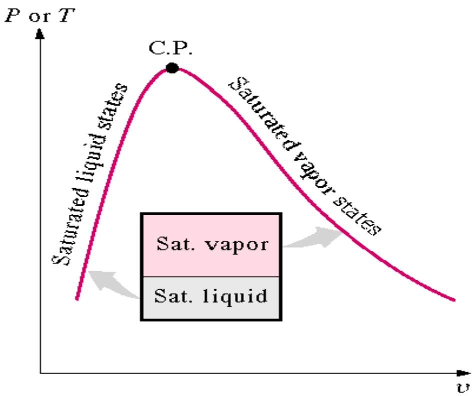
Saturation temperature is the temperature at which the liquid and vapor phases are in equilibrium at a given pressure.

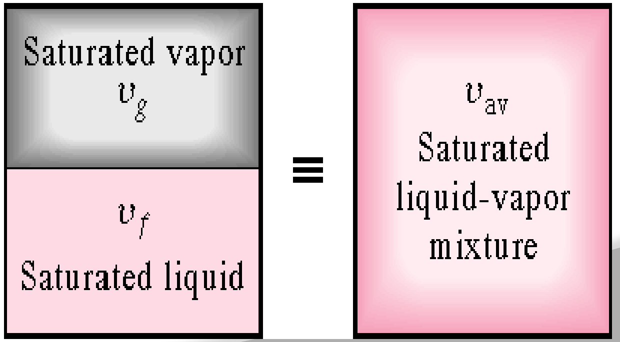
Quality and Saturated Liquid-Vapor Mixture

Now, let's review the constant pressure heat addition process for water shown in Figure. Since state 3 is a mixture of saturated liquid and saturated vapor, how do we locate it on the T-v diagram? To establish the location of state 3 a new parameter called the quality x is defined as

$$x = \frac{mass_{saturated\ vapor}}{mass_{total}} = \frac{m_g}{m_f + m_g}$$

The quality is zero for the saturated liquid and one for the saturated vapor (0 ≤ x ≤ 1). The average specific volume at any state 3 is given in terms of the quality as follows. Consider a mixture of saturated liquid and saturated vapor. The liquid has a mass *mf* and occupies a volume V_f. The vapor has a mass *mg* and occupies a volume V_g.





We note

$$V = V_f + V_g$$

$$m = m_f + m_g$$

$$V = mv, \quad V_f = m_f v_f, \quad V_g = m_g v_g$$

$$mv = m_f v_f + m_g v_g$$

$$v = \frac{m_f v_f}{m} + \frac{m_g v_g}{m}$$

Recall the definition of quality *x*

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g}$$

$$\frac{m_f}{m} = \frac{m - m_g}{m} = 1 - x$$

Compressed Liquid Water Table

A substance is said to be a **compressed liquid** when the pressure is greater than the saturation pressure for the temperature.

Saturated Ice-Water Vapor Table

- When the temperature of a substance is below the triple point temperature, the saturated solid and liquid phases exist in equilibrium.
- Here we define the quality as the ratio of the mass that is vapor to the total mass of solid and vapor in the saturated solid-vapor mixture.
- The process of changing directly from the solid phase to the vapor phase is called sublimation.

Although thermodynamics applies to all forms of matter it is easiest to consider a gas or vapor. The equation of state is of the form f(P,V,T)=0.

The mechanical variables (P,V) occur as “canonically conjugate pairs”, the extensive variable V and the intensive variable P.

NOTE: The term “canonically conjugate” comes from Lagrangian mechanics. The close association of these variables will become clear as we develop the formalism.

TRIPLE POINT AT CRITICAL STATE PROPERTIES DURING CHANGE OF PHASE

- For simplicity and clarity, the generic notion of critical point is best introduced by discussing a specific example, the liquid-vapor critical point. This was the first critical point to be discovered, and it is still the best known and most studied one.
- The figure to the right shows the schematic PT diagram of a pure substance (as opposed to mixtures, which have additional state variables and richer phase diagrams, discussed below).
- The commonly known phases solid, liquid and vapor are separated by phase boundaries. At the triple point, all three phases can coexist. However, the liquid-vapor boundary terminates in an endpoint at some critical temperature Tc and critical pressure pc. This is the critical point.

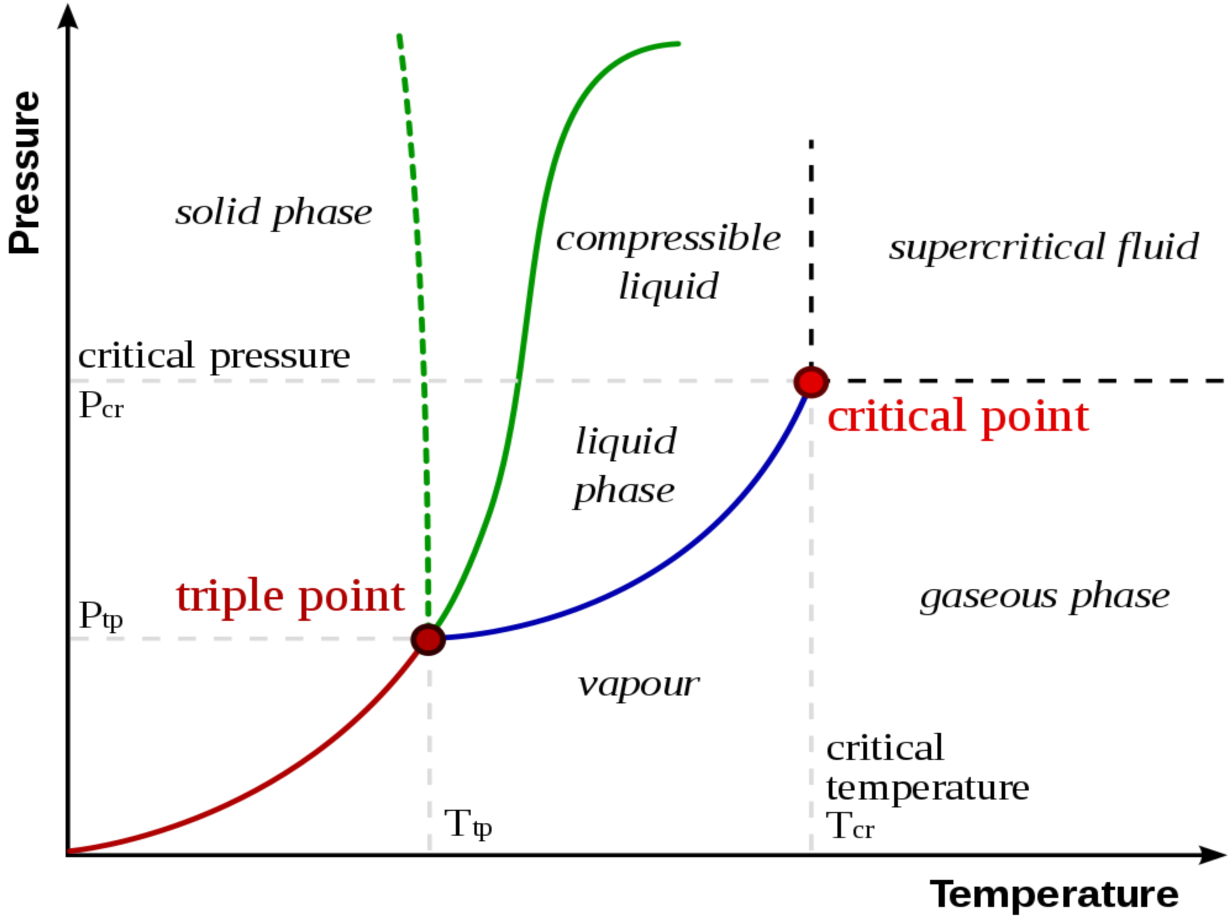


Fig 3.4 triple point at critical state properties during change of phase

- In water, the critical point occurs at around 647 K(374°C or 705°F) and 22.064 MP(3200 psia or 218 atm).
- In the *vicinity* of the critical point, the physical properties of the liquid and the vapor change dramatically, with both phases becoming ever more similar. For instance, liquid water under normal conditions is nearly incompressible, has a low thermal expansion coefficient, has a high dielectric constant, and is an excellent solvent for electrolytes. Near the critical point, all these properties change into the exact opposite: water becomes compressible, expandable, a poor dielectric, a bad solvent for electrolytes, and prefers to mix with nonpolar gases and organic molecules.
- *At* the critical point, only one phase exists. The heat of vaporization is zero. There is a stationary inflection point in the constant-temperature line (*critical isotherm*) on a PV diagram. This means that at the critical point:

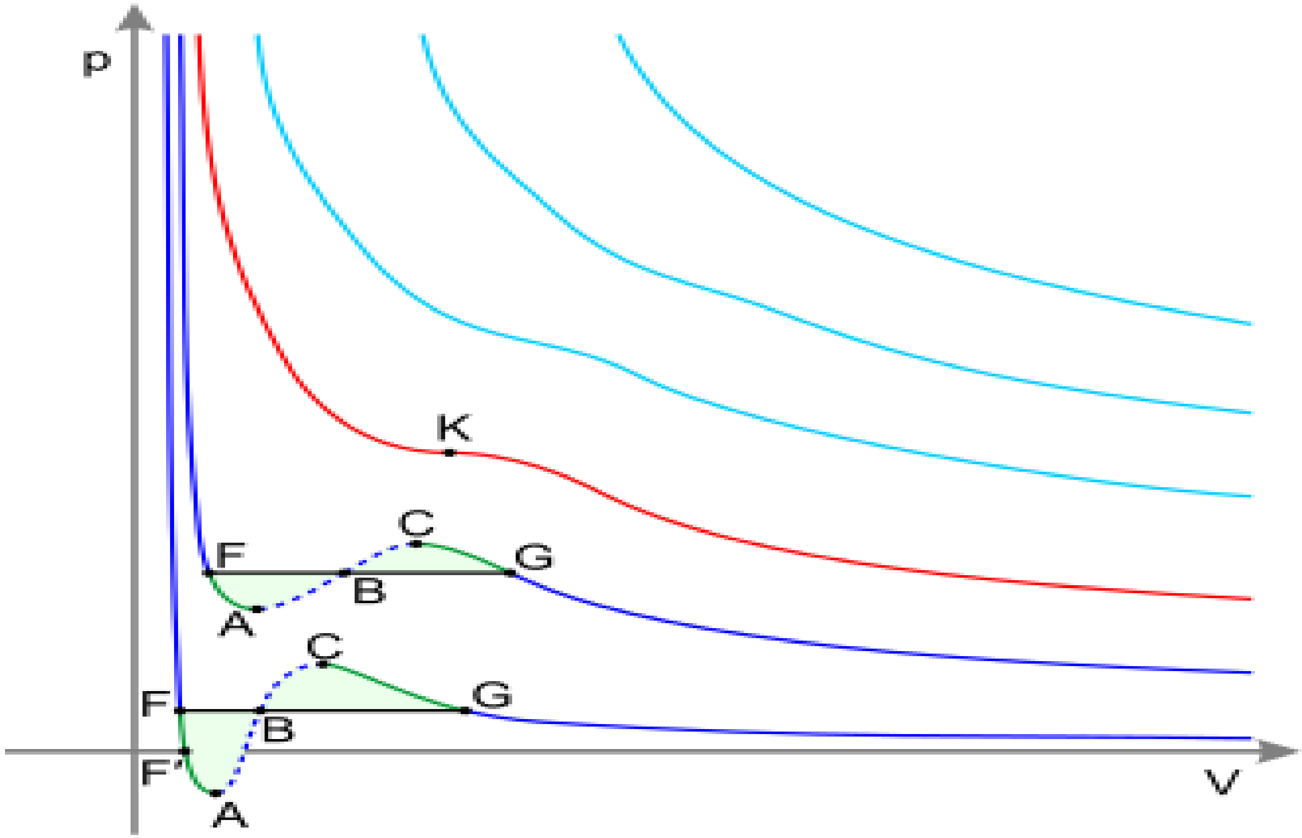


Fig 3.5 The *critical isotherm* with the critical point K

- Above the critical point there exists a state of matter that is continuously connected with (can be transformed without phase transition into) both the liquid and the gaseous state. It is called supercritical fluid. The common textbook knowledge that all distinction between liquid and vapor disappears beyond the critical point has been challenged by Fisher and Widom who identified a p,T-line that separates states with different asymptotic statistical properties (Fisher-Widom line).

DRYNESS FRACTION

- This handout assumes the student is familiar with Steam Tables and the terms found therein. If required, please review Steam Tables before continuing.
- The heavy solid line in the above chart represents the transformation of 1 kg of water at 0˚C and atmospheric pressure into steam, with the addition of heat. From 0˚C to 100˚C, energy is added to the water in the form of sensible heat.
- This causes an increase in temperature while its state remains the same. This energy is referred to in steam tables as "hf". The change from 1 kg of water at 0˚C into 1 kg of water at 100˚C requires the addition of 419.04 kJ of energy.

DRYNESS FRACTION

- Therefore, at atmospheric pressure: hf = 419.04 kJ/kg Thesaturation temperature of water at atmospheric pressure is 100˚C. The addition of more heat will not cause a temperature change but will, instead, cause a change of state.
- In this case, evaporation into steam at 100˚C. The change from 1 kg of water at 100˚C into dry saturated steam at 100˚C requires the addition of 2257.0 kJ of energy. Therefore, at atmospheric pressure: hfg = 2257.0 kJ/kg.

- Referring to the diagram, you will notice that hg = hf + hfg If not all of hfg is added to the water, then not all of the water can change into steam.
- If, say, 50% of hfg is added then only 50% of the water will be changed into steam and the steam will be referred to as 50% dry. This is known as the "dryness fraction" of the steam.
- Expanding on this, then, it can be seen that the total enthalpy content of steam of a certain dryness fraction, and made from water at 0˚C, can be found out by totalling hf and that portion of hfg which has been added (hfg multi plied by the dryness fracti on).

- If the steam is 100% dry, then the entire amount of hfg has been added and the dryness fraction of the steam would be 100% or 1.
- Putting this into a formula we get: total enthalpy = hf + (dryness fracti on) x (hfg).
- Using this formula and the information found in Steam Tables, one can determine the dryness fraction of steam at any pressure or temperature.

MOLLIER CHARTS

- Mollier diagram is named after Richard Mollier (1863-1935), a German professor who pioneered experimental research on thermodynamics associated with water, steam and water-vapor mixture.
- Mollier diagram is a graphical representation of a functional relationship between enthalpy, entropy, temperature, pressure and quality of steam. Mollier is often referred to as Enthalpy – Entropy Diagram or Enthalpy – Entropy Chart. The enthalpyentropy charts in Appendix B are Mollier Diagrams.
- They used commonly in the design and analysis associated with power plants, steam turbines, compressors, and refrigeration systems. Mollier diagram is available in two basic versions: The SI/Metric Unit version and the US/Imperial Unit version.

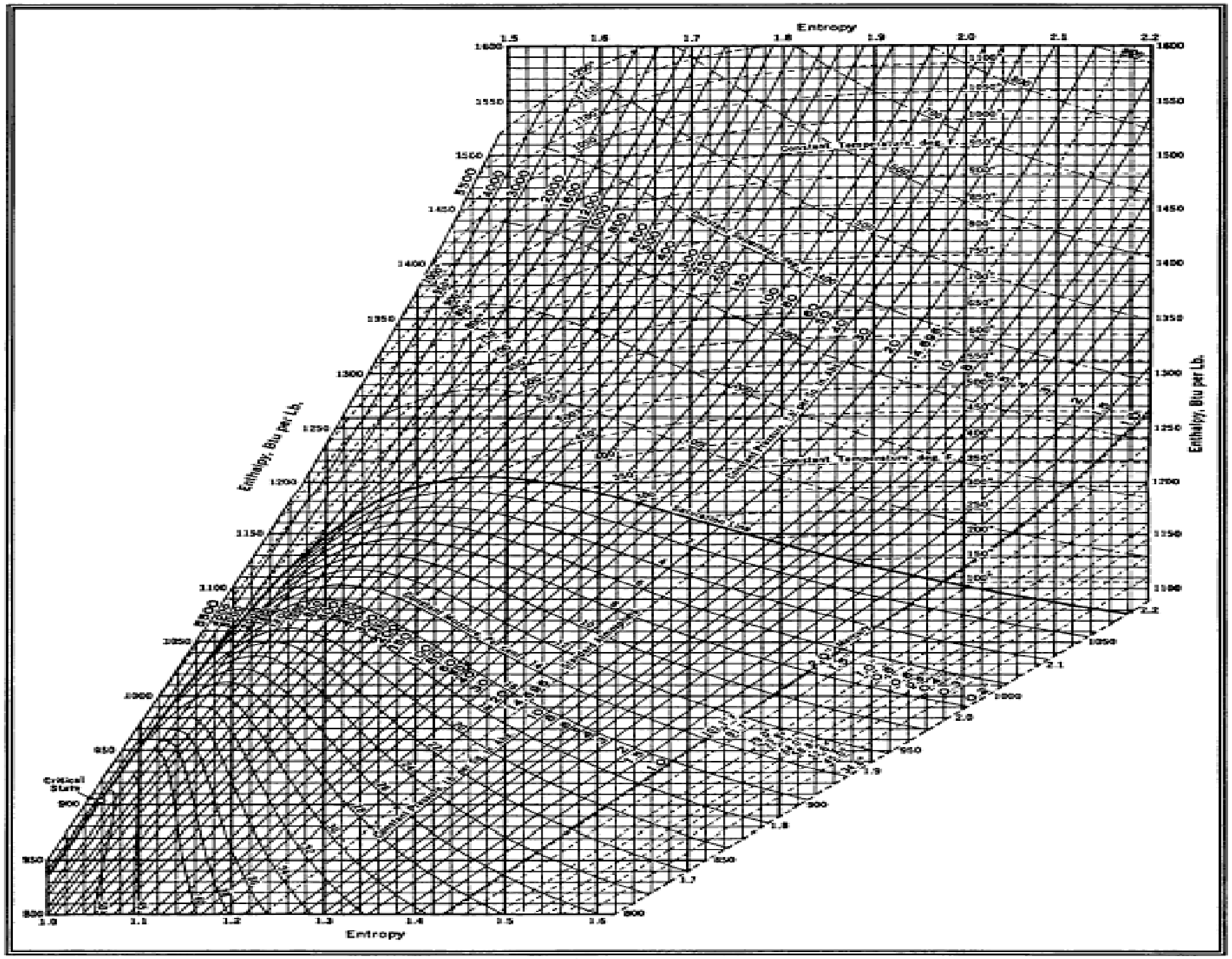


Figure A-1

Figure 3.6 – Mollier Diagram, SI/Metric Units

PSYCHOMETRIC PROPERTIES

- Here is a differentiation of reliability and validity as applied to the preparation of research instruments.

- One of the most difficult parts in research writing is when the instrument's psychometric properties are scrutinized or questioned by your panel of examiners.

- Psychometric properties may sound new to you, but they are not actually new.

- In simple words, psychometric properties refer to the reliability and validity of the instrument. So, what is the difference between the two?

- Reliability refers to the consistency while validity refers to the test results' accuracy. An instrument should accurately and dependably measure what it ought to measure. Its reliability can help you have a valid assessment; its validity can make you confident in making a prediction.

INSTRUMENT'S RELIABILITY

- How can you say that your instrument is reliable? Although there are many types of reliability tests, what is more usually looked at is the internal consistency of the test.

- When presenting the results of your research, your panel of examiners might look for the results of the Cronbach's alpha or the Kuder-Richardson Formula 20 computations.

- If you cannot do the analysis by yourself, you may ask a statistician to help you process and analyze data using a reliable statistical software application.

INSTRUMENT'S RELIABILITY

- But if your intention is to determine the inter-correlations of the items in the instrument and if these items measure the same ***construct***, Cronbach's alpha is suggested.

- According to David Kingsbury, a construct is the behavior or outcome a researcher seeks to measure in the study.

- This is often revealed by the independent variable.

INSTRUMENT'S VALIDITY

- There are many types of validity measures. One of the most commonly used is the construct validity. Thus, the *construct* or the independent variable must be accurately defined.
- To illustrate, if the independent variable is the school principals' leadership style, the sub-scales of that construct are the types of leadership style such as authoritative, delegate and participative.
- The construct validity would determine if the items being used in the instrument have good validity measures using factor analysis and each sub-scale has a good inter-item correlation using Bivariate Correlation. The items are considered good if the p-value is less than 0.05.

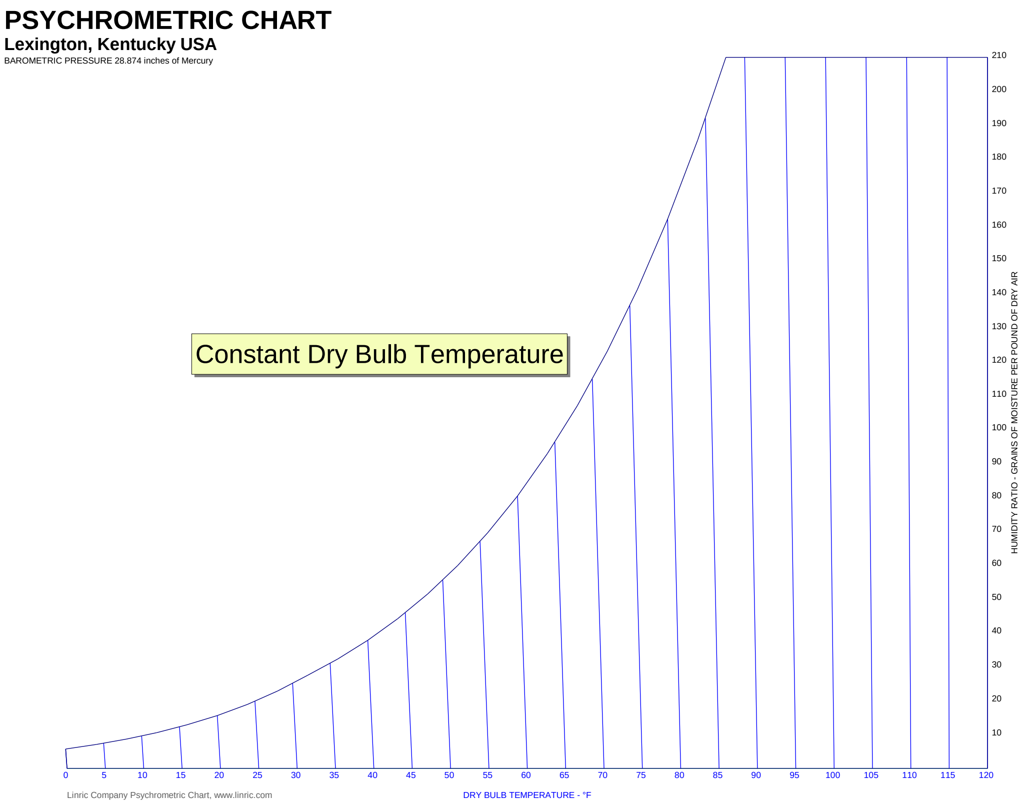
THERMODYNAMIC METHOD OF MEASURING HUMID

- It is the only method used in mines. The instruments used are called hygrometers or psychrometers.
- These instruments have a pair of thermometers, one of them having its bulb covered with wet muslin cloth.
- The thermometer with wet bulb muslin cloth on its bulb records wet-bulb temperature and the other one records dry-bulb temperature.
- These two temperatures along with barometric pressure is used in calculating humidity. Let us understand the three terms separately.

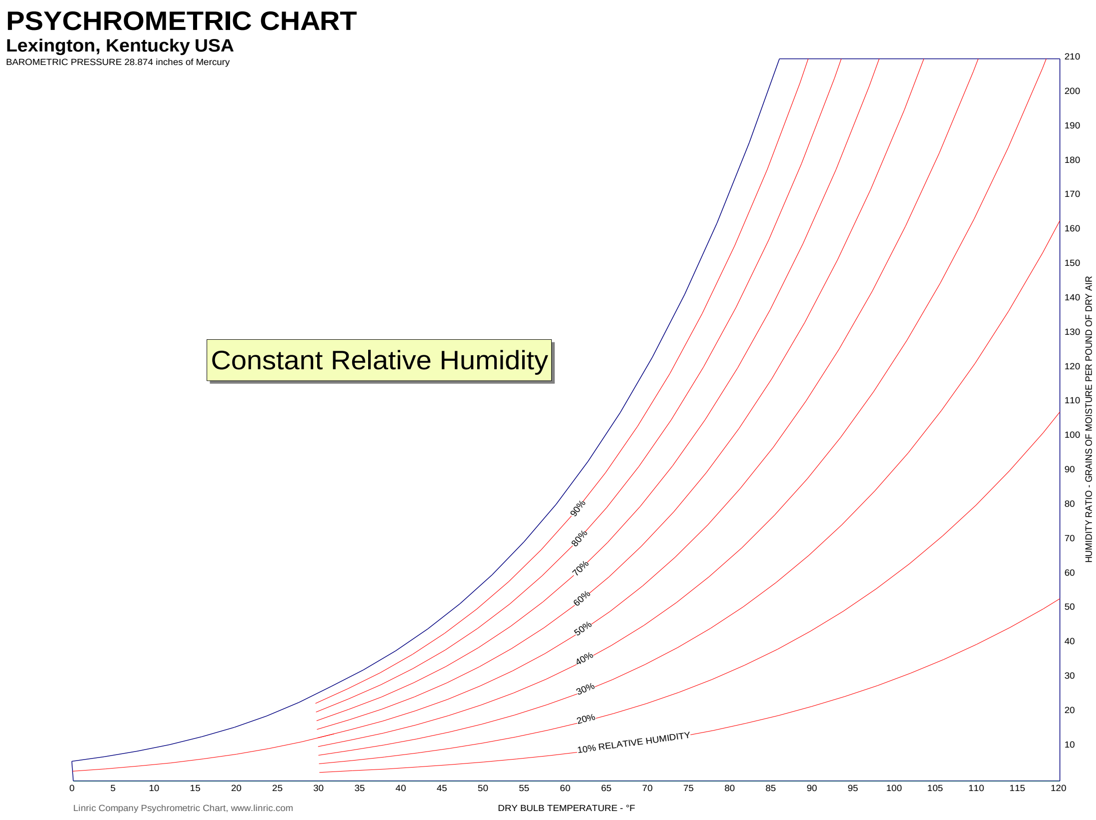
DRY-BULB TEMPERATURE

- It is the temperature recorded by using a conventional thermometer. The thermometer without muslin cloth in the psychrometer records dry-bulb temperature. It just reads the ordinary temperature of the air and is a measure of sensible heat content of the air. Its unit is °F or °C or kelvin (K).

Constant Dry Bulb Temperature



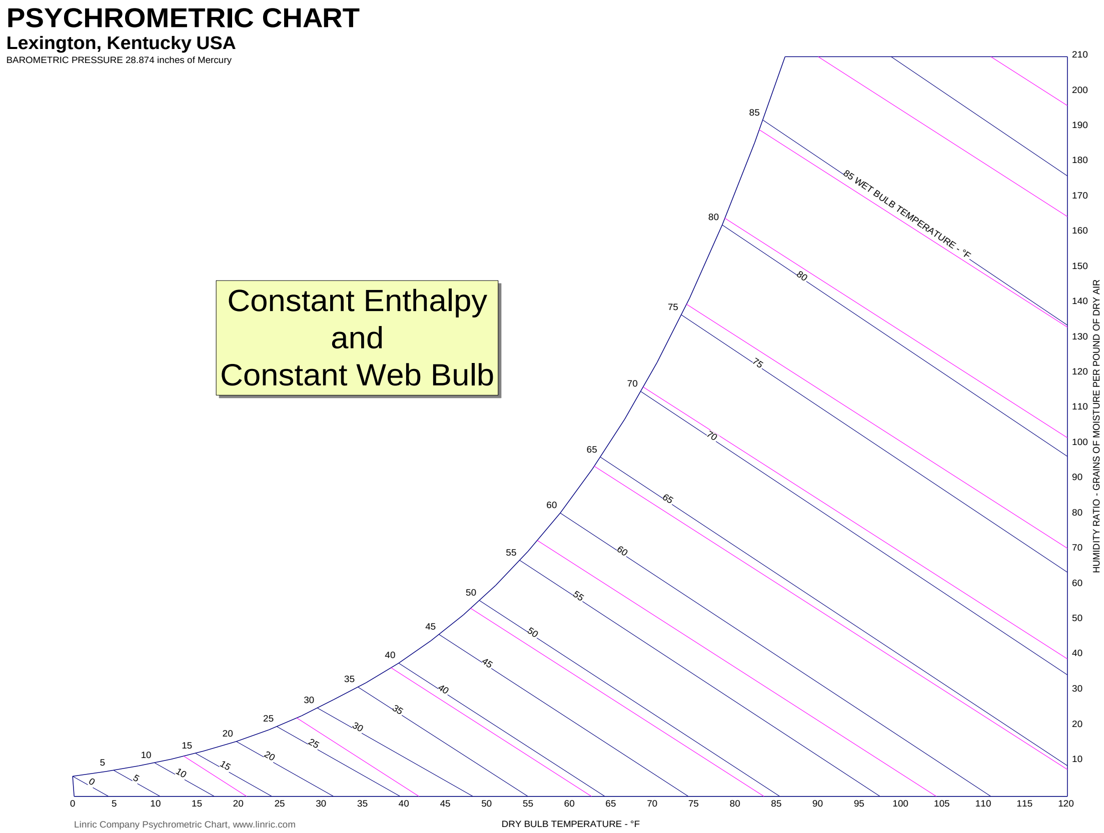
Constant Relative Humidity



WET-BULB TEMPERATURE

- It is recorded by thermometer having wet muslin cloth on its bulb. The temperature recorded is in general lower than dry-bulb temperature because of cooling effect of the evaporating water of wet muslin cloth.
- They are equal only when air is in saturation and no net evaporation of water from wet muslin cloth takes place. Wetbulb temperature can never be higher than dry-bulb temperature.
- From the definition point of view, it is defined as the temperature at which water vapour evaporating into the air can bring down the air in saturation adiabatically at that temperature.
- It is a measure of the evaporating capacity of the air. Its unit is °F or °C or kelvin (K).

Constant Enthalpy and Wet Bulb



CONCEPT OF WET-BULB TEMPERATURE

- The water molecules in the wet muslin cloth take up energy from the neighboring molecules and evaporate into the air.
- The evaporating molecules leave the thermometer surface with reduced energy. This causes depression in the temperature near the thermometer bulb.
- Thus, lower temperature is recorded.
- Thus, a difference between the temperature at the bulb and the atmosphere exists.

CONCEPT OF WET-BULB TEMPERATURE

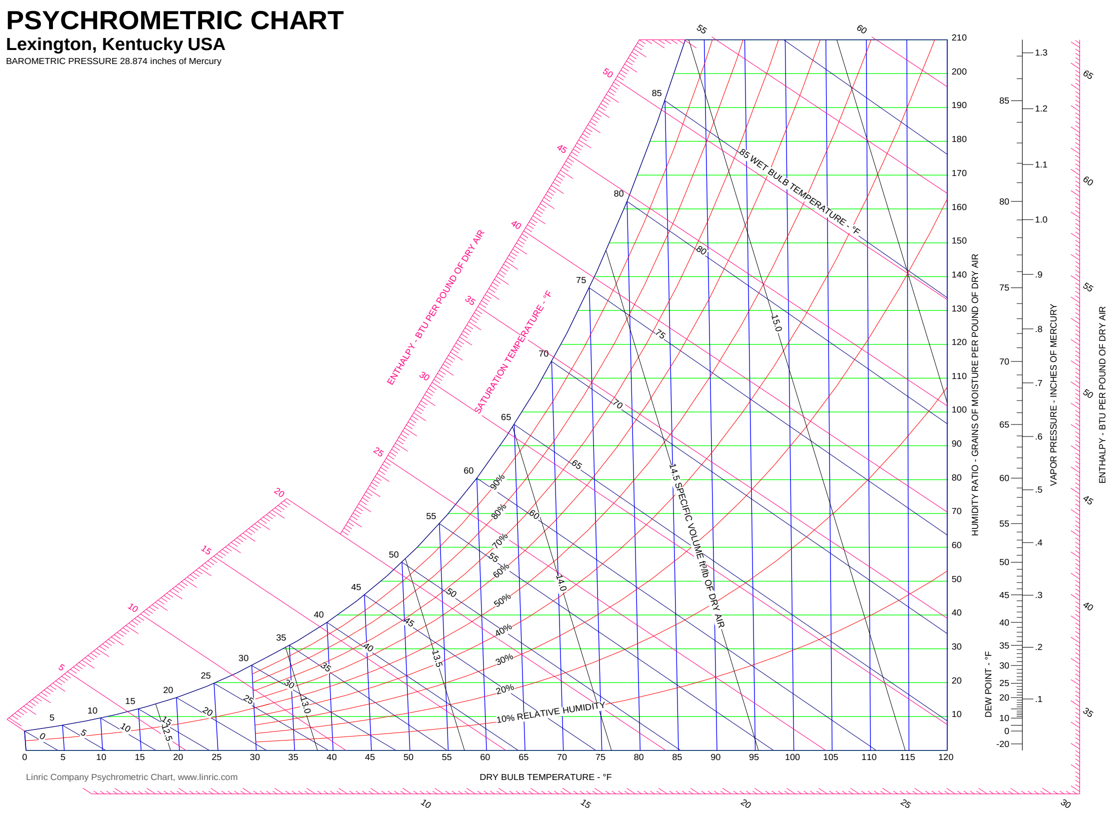
- This causes flow of heat from the air through convection. Initially this flow of heat from air to bulb with wet muslin cloth is slower than the rate of heat loss from the bulb with wet muslin due to evaporation.

- But, a stage comes when the rate of heat loss and rate of heat gained in the two opposite processes equal.

- At this point, no further depression in temperature of wet-bulb is observed.

- At equilibrium, the temperature of thermometer with wet muslin cloth on its bulb is taken as wet-bulb temperature.

Typical Chart With Enthalpy Lines



Humidity Ratio

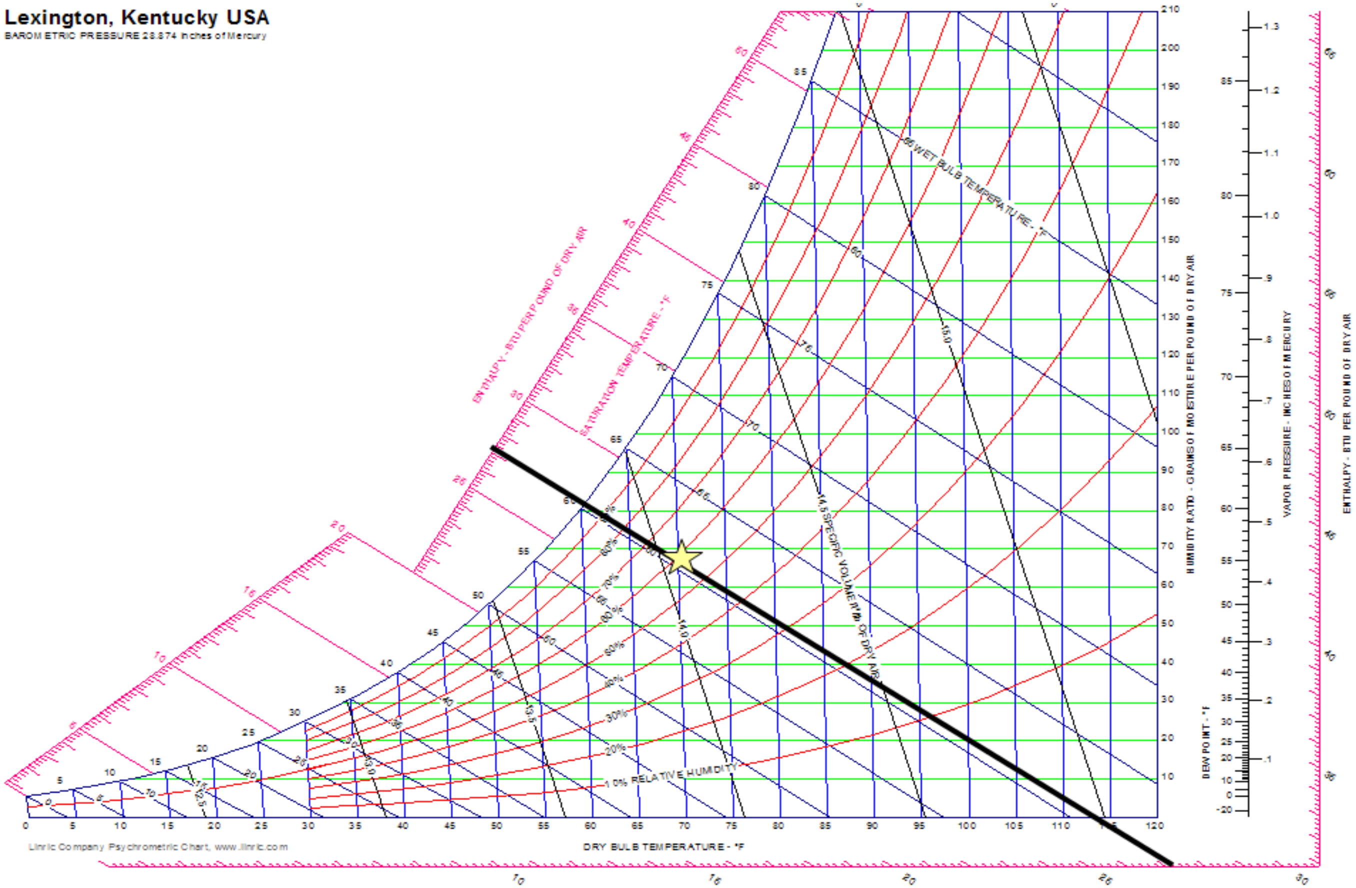
Sea Level Chart
Dry-bulb temperature = 70 F
Relative humidity = 60%

Humidity ratio = 0.0094 lb water / lb dry air
or
7000 grains = 1 lb water
7000 x 0.0094 = 65.8

Enthalpy

Sea Level Chart
Dry-bulb temperature = 70 F
Relative humidity = 60%

Enthalpy



Lexington, Kentucky USA
BAROMETRIC PRESSURE 28.874 inches of Mercury
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
10% RELATIVE HUMIDITY
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
Linric Company Psychrometric Chart, www.linric.com

DEW POINT TEMPERATURE

- It is defined as the temperature at which air attains saturation.
- a further addition of water vapour leads to dew formation because of condensation of water vapour.
- It is rarely used to indicate the moisture content of the air/atmosphere.
- The temperature recorded in this case is dry bulb temperature.

THERMODYNAMIC WET BULB TEMPERATURE

- The thermodynamic wet-bulb temperature is the temperature a volume of air would have if cooled adiabatically to saturation by evaporation of water into it, all latent heat being supplied by the volume of air.

- The temperature of an air sample that has passed over a large surface of the liquid water in an insulated channel is called the thermodynamic wet-bulb temperature—the air has become saturated by passing through a constant-pressure, ideal, adiabatic saturation chamber.

DEGREE OF SATURATION

- It is stated as the ratio of weight of water vapour in air at given conditions to the weight of the water vapour in air at saturation, keeping temperature constant.
- Mathematically, it can be expressed as:

Degree of saturation= 0.622($/Pb - e$)/(0.622 $esd\ /Pb - esd$)× 100%
= ($e/\ Pb - e$)/($esd/\ Pb - esd$) × 100%

Where,
e = Vapour pressure or Partial pressure due to water vapour (kPa)
Pb = Barometric pressure (kPa)
esd = Saturation vapour pressure at wet bulb temperature (kPa)
.

DEGREE OF SATURATION

- We can see that e and esd are very small compared to Pb , so we can neglect them and equation becomes equal to equation.

- From this, we can take degree of saturation approximately equal to relative humidity, but numerically they are not similar.

- Of all the humidity terminology discussed, specific humidity is most widely used. Now, let us discuss some of the very conceptual points.

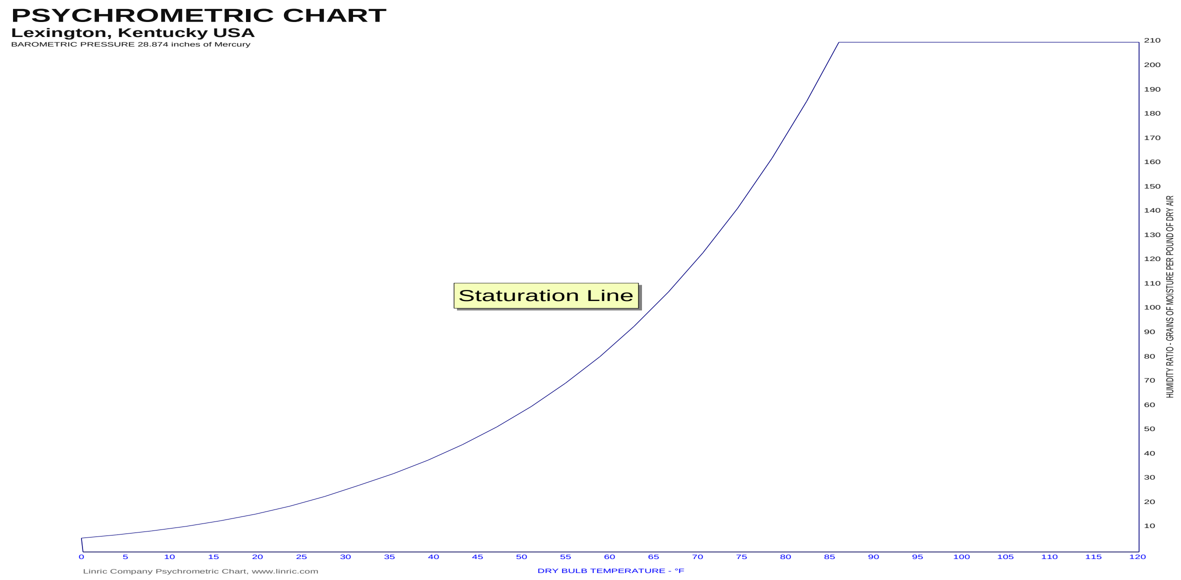
DEGREE OF SATURATION

- Water vapour is not a chemical constituent of air. It is like an impurity to air like dust, smog, etc.

- Instead of saying air is saturated, it is better to say that space is saturated. Actually it is the space which becomes saturated, and not air.

- It means that even if we evacuate a system and fill it with water vapour, the system can hold the same amount of water vapour that air of the same volume can hold at that temperature

Saturation Line



The only value that can not be calculated from air and water vapor equations is the saturation line. The saturation line is point at which the air can hold no additional water vapor. This line will represent several air values: Dew point, Web Bulb Temperature. With the saturation line, the bottom axis is the air temperature and the right side axis is the quantity of moisture in the air.

Adiabatic saturation

Adiabatic saturation temperature refers to a temperature at which water converts into air by the process of evaporation adiabatically. The device used for this type of process is known as adiabatic saturator.

The adiabatic saturator device is shown below in Figure .

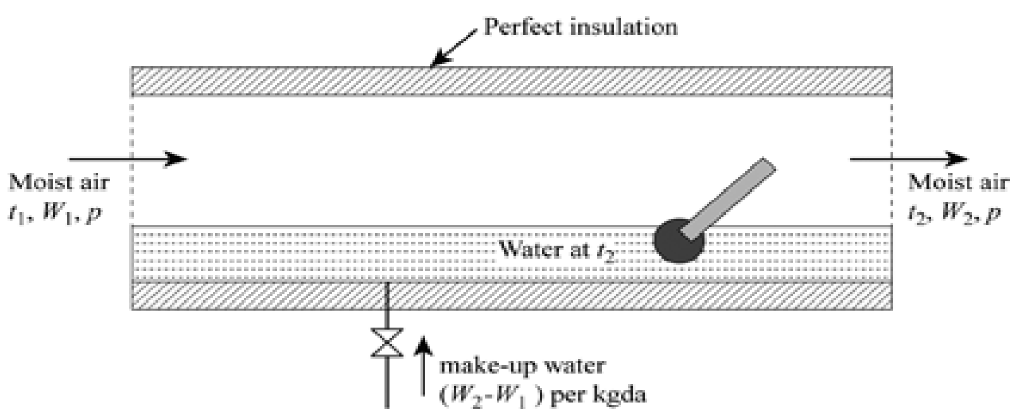


Fig 3.7 Adiabatic saturation

As seen in Figure (3.7), moist air is entering into the saturator device duct from the left and exiting at the right. When air comes in contact with water, heat and mass transformation takes place. For a perfect equilibrium condition, the duct should be long so that air can be fully saturated. To proceed with the procedure, make-up water must be given to adjust for the measure of water dissipated into the air.

The temperature of the make-up water is controlled with the goal that it is the same as that in the channel. After the adiabatic saturator has accomplished an equilibrium state condition, the temperature demonstrated by the thermometer drenched in the water is the thermodynamic wet-bulb temperature.

CARRIER'S EQUATION

When DBT and WBT are given, for calculating the partial pressure of water vapour in air many equations have been proposed of which Dr. Carriers equation is most widely used.

$$p_v = (p_g) - \frac{(p - p_g) - (t_{db} - t_{wb})1.8}{2800 - 1.3(1.8t_{db}) + 32}$$

Where,

$(p_g)_{wb}$ = saturation pressure at wet bulb temperature.

p_v = partial pressure of water vapour

p_g = partial pressure of saturated vapour

p = total pressure of moist air

t_{db} = dry bulb temperature, ^{0}C

t_{wb} = wet bulb temperature, ^{0}C

PSYCHOMETRIC CHART.

- A Psychometric chart graphically represents the thermodynamic properties of moist air.
- Standard psychometric charts are bounded by the dry-bulb temperature line (abscissa) and the vapor pressure or humidity ratio (ordinate).
- The Left Hand Side of the psychometric chart is bounded by the saturation line. Figure 3.8 shows the schematic of a psychometric chart.

PSYCHOMETRIC CHART.

- Psychometrics charts are readily available for standard barometric pressure of 101.325 kPa at sea level and for normal temperatures (0-50o C).

- ASHRAE has also developed psychometrics charts for other temperatures and barometric pressures (for low temperatures: -40 to 10o C, high temperatures 10 to 120o C and very high temperatures 100 to 120o C)

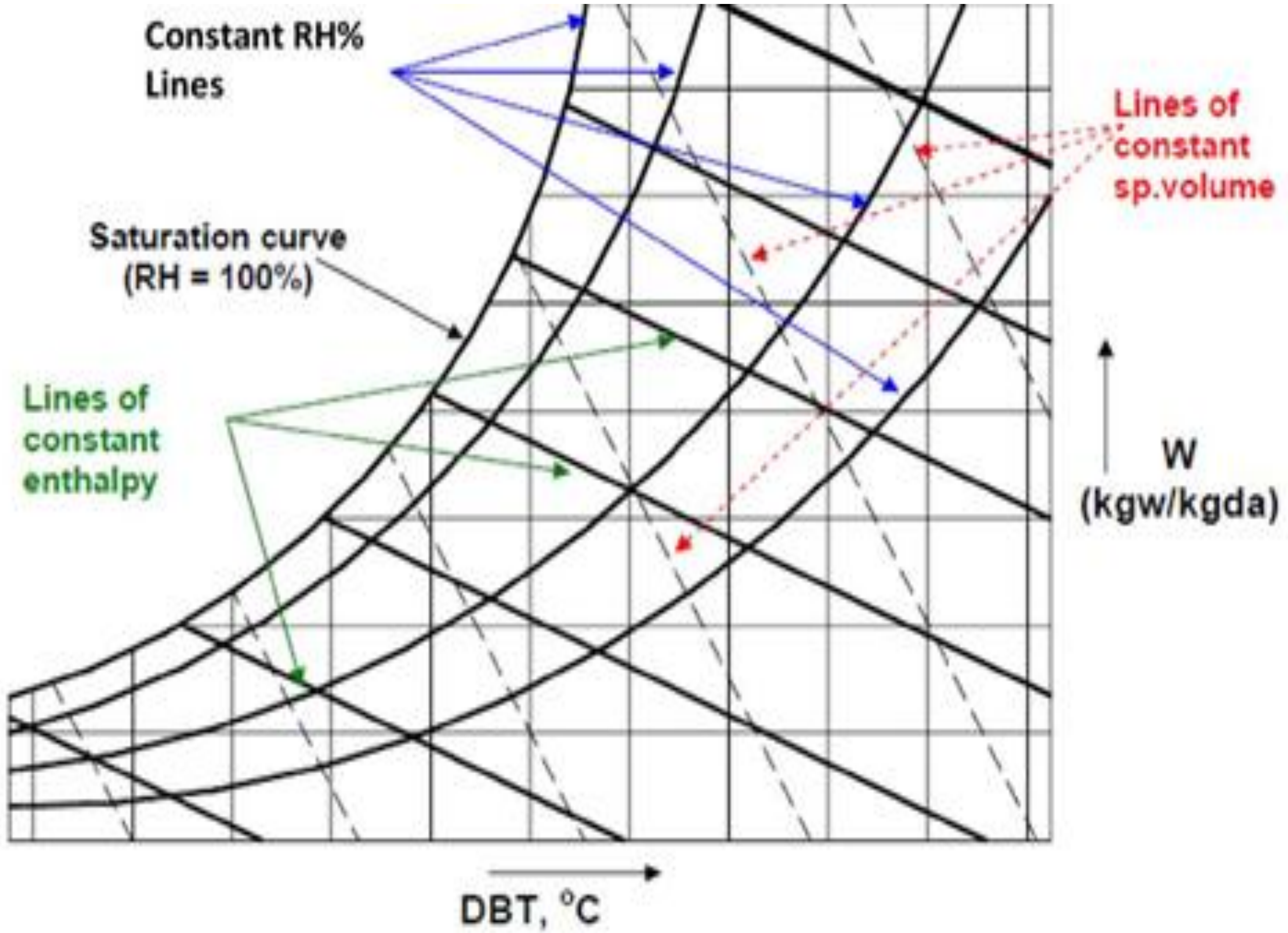
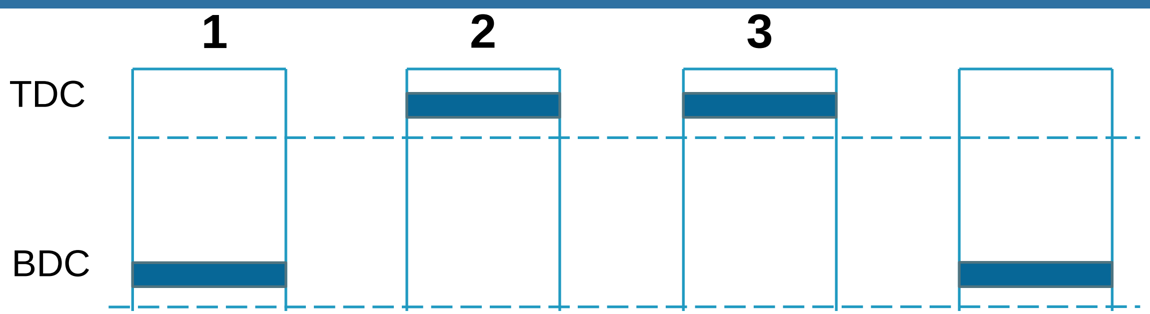
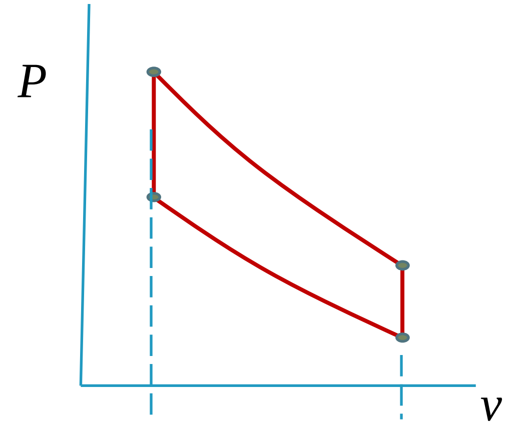


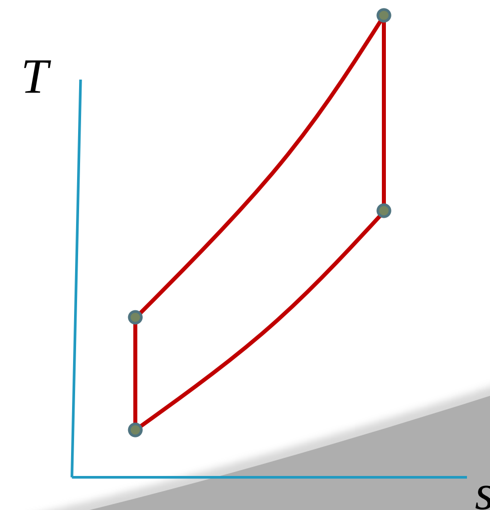
Fig 3.8 Psychometric chart graphically represents the thermodynamic properties of moist air

POWER CYCLES

SI Engine - Otto Cycle







- **1-2** Isentropic compression from BDC to TDC

$$W_{12} = m(u_2 - u_1)$$

- **1-2** Isentropic compression from BDC to TDC

$$Q_{23} = m(u_3 - u_2)$$

- **2-3** Isochoric heat input (combustion)

$$W_{34} = m(u_3 - u_4)$$

- **3-4** Isentropic expansion (power stroke)

$$Q_{41} = m(u_4 - u_1)$$

- **4-1** Isochoric heat rejection (exhaust)

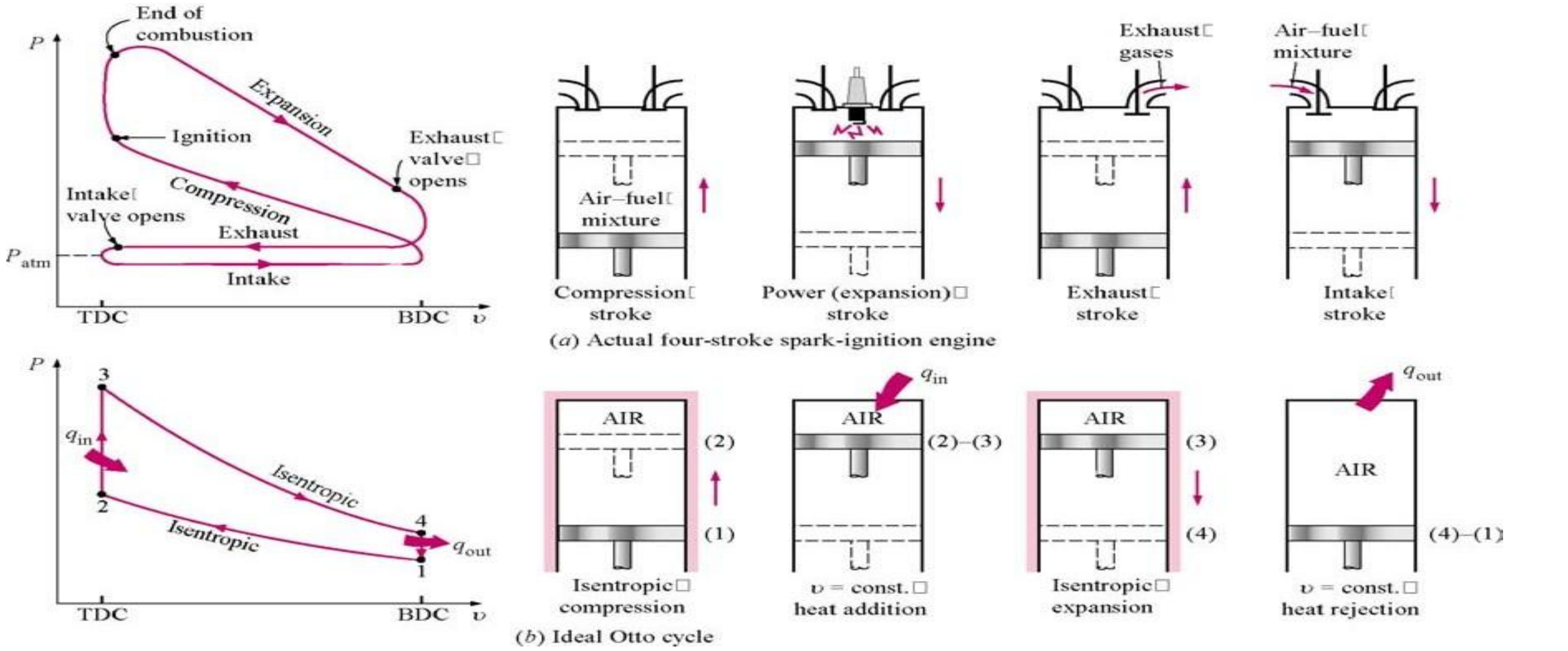


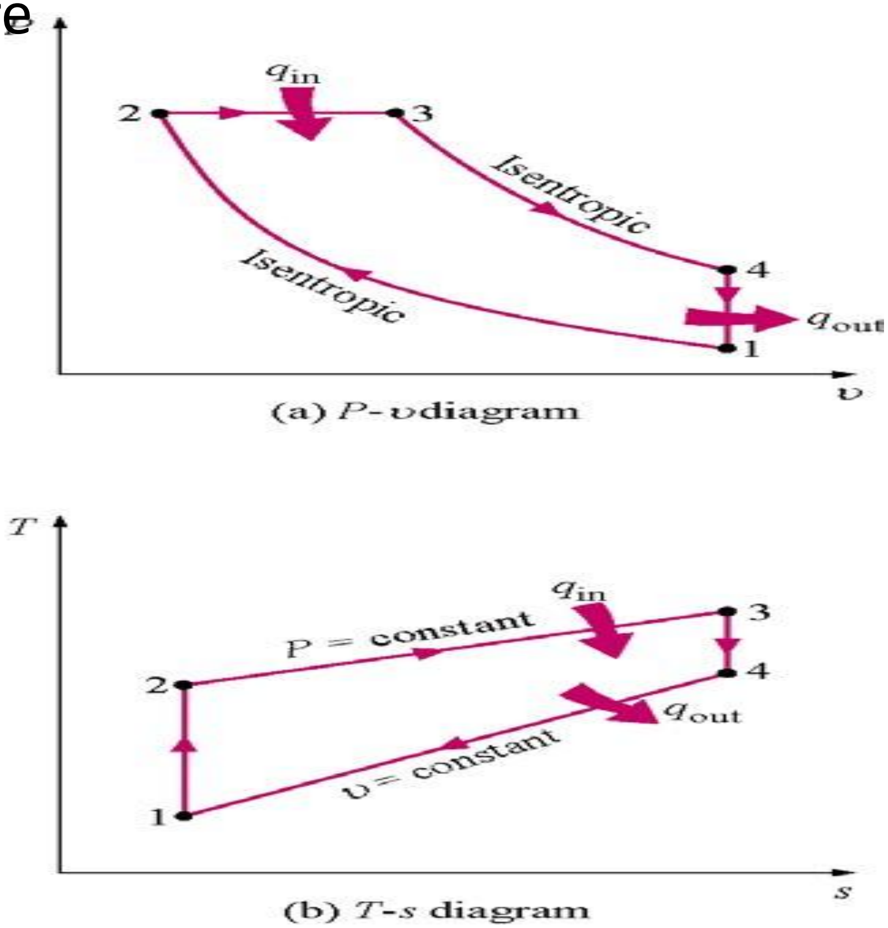
Fig 4.2 The ideal cycle for spark-ignition engines

DIESEL CYCLE

The air-standard Diesel cycle is the ideal cycle that approximates the Diesel combustion engine

Process	Description
1-2	Isentropic compression
2-3	Constant pressure heat addition
3-4	Isentropic expansion
4-1	Constant volume heat rejection The *P*-*v* and

T-s diagrams are



(a) *P*-υ diagram

(b) *T*-*s* diagram

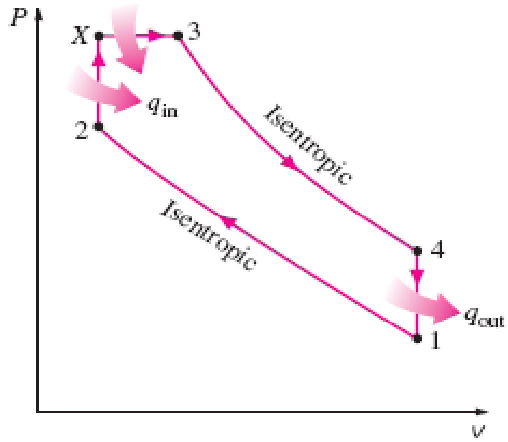
Dual combustion or Limited pressure or Mixed cycle

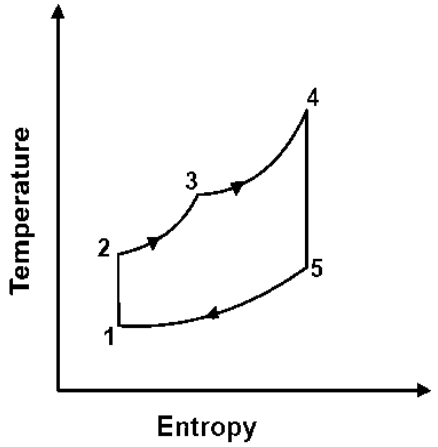
This cycle is a combination of Otto and Diesel cycles.

It is also called semi-diesel cycle because semi-diesel engines work on this cycle.

In this cycle heat is absorbed partly at constant volume and partly at constant pressure.

It consists of two reversible adiabatic or isentropic, two constant volume and a constant pressure processes as shown in P-v and T-s diagrams.



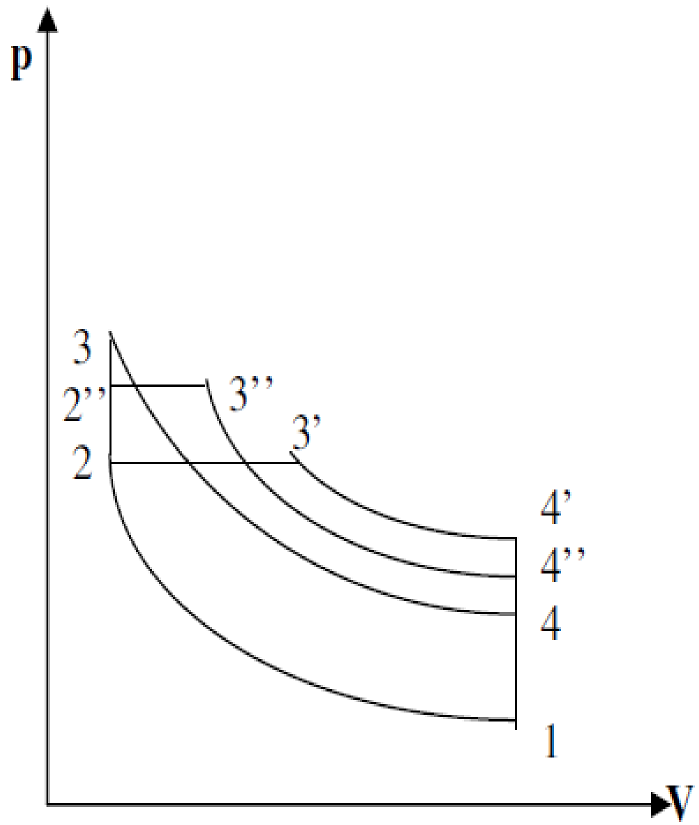


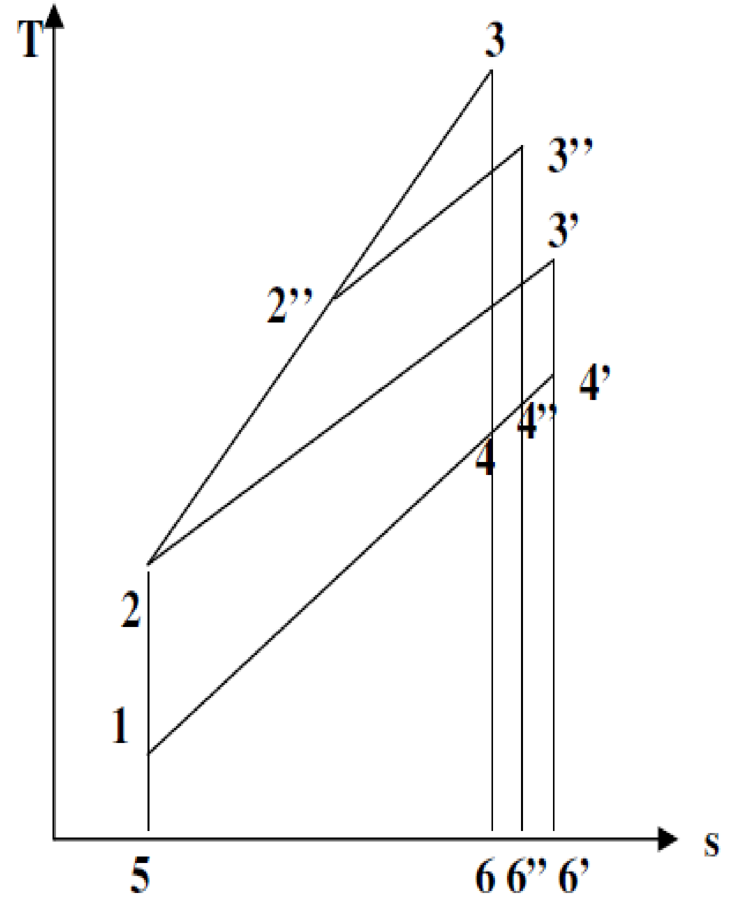
Comparison between Otto, Diesel and Dual combustion cycles

- The important variables which are used as the basis for comparison of the cycles are compression ratio, peak pressure, heat supplied, heat rejected and the net work output.

- In order to compare the performance of the Otto, Diesel and Dual combustion cycles some of these variables have to be fixed.

Comparison with same compression ratio and heat su



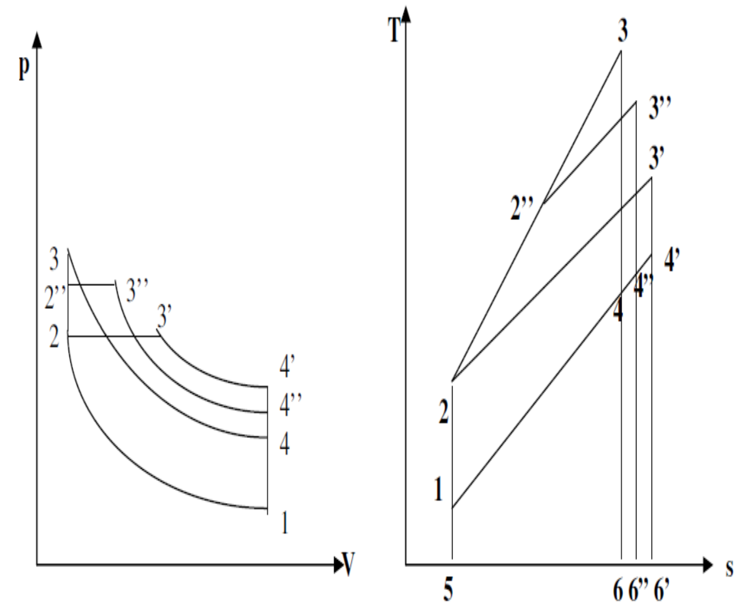


- The comparison of these cycles for the same compression ratio and same heat supply are shown in on both p – V and T – S diagrams.

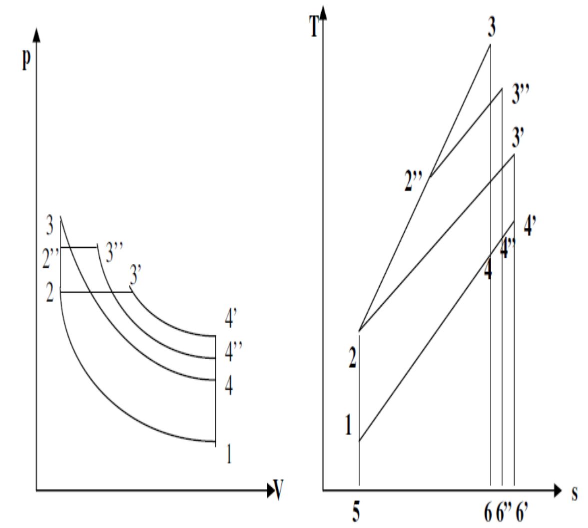
- In these diagrams, cycle 1-2-3-4-1 represents Otto Cycle, cycle 1-2-3’-4’-1 represents diesel cycle and cycle 1-2”-3”-4”-1 represents the dual combustion cycle for the same compression ratio and heat supply.

From the T-S diagram, it can be seen that area 5236 = area 522”3”6” = area 523’6’ as this area represents the heat supply which is same for all the cycles.

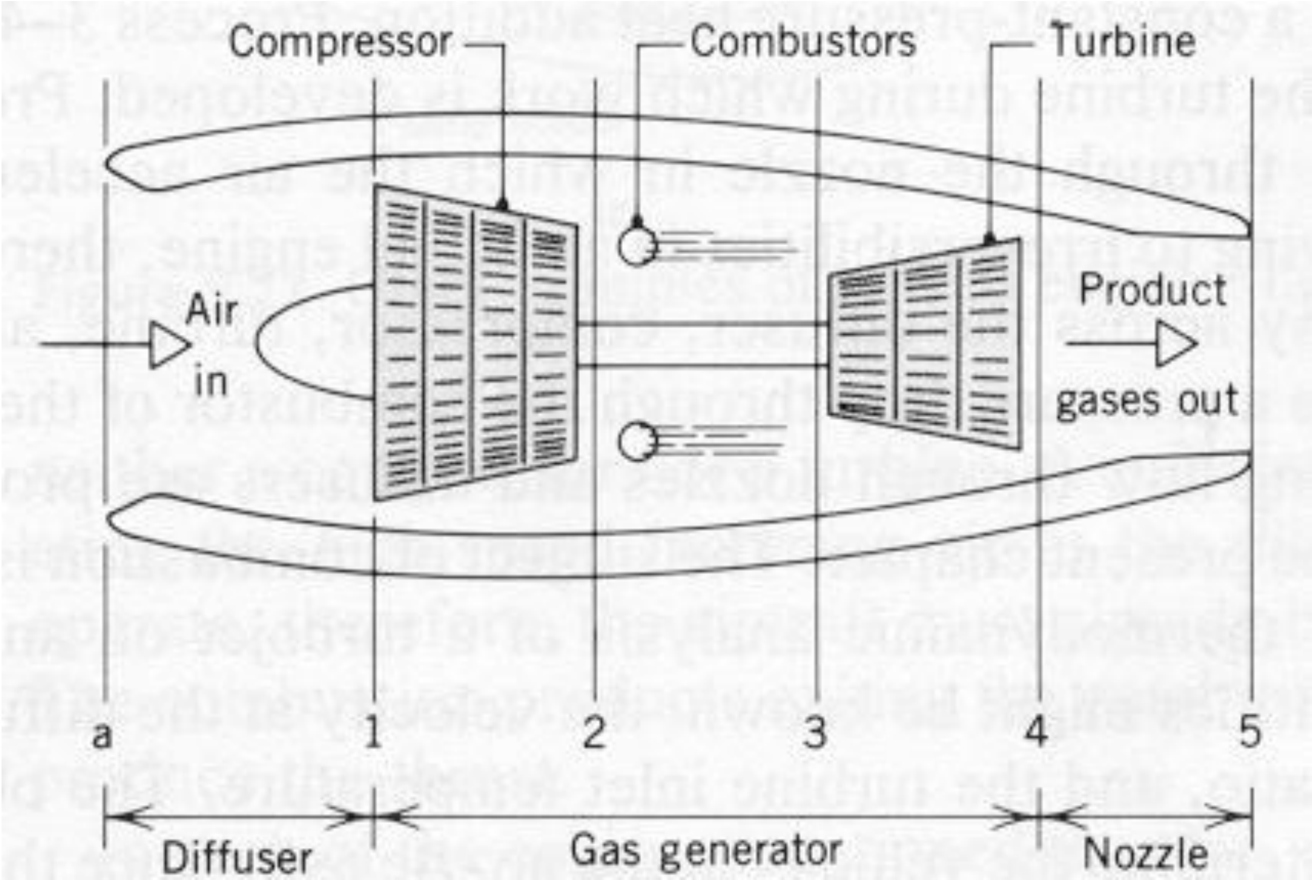
All the cycles start from the same initial point 1 and the air is compressed from state 1 to state 2 as the compression ratio is same.



It is seen from the T-s diagram, that for the same heat supply, the heat rejection in Otto cycle (area 5146) is minimum and heat rejection in Diesel cycle (area 514’6’) is maximum. Consequently Otto cycle has the highest work output and efficiency. Diesel cycle has the least efficiency and dual cycle has the efficiency between the two.

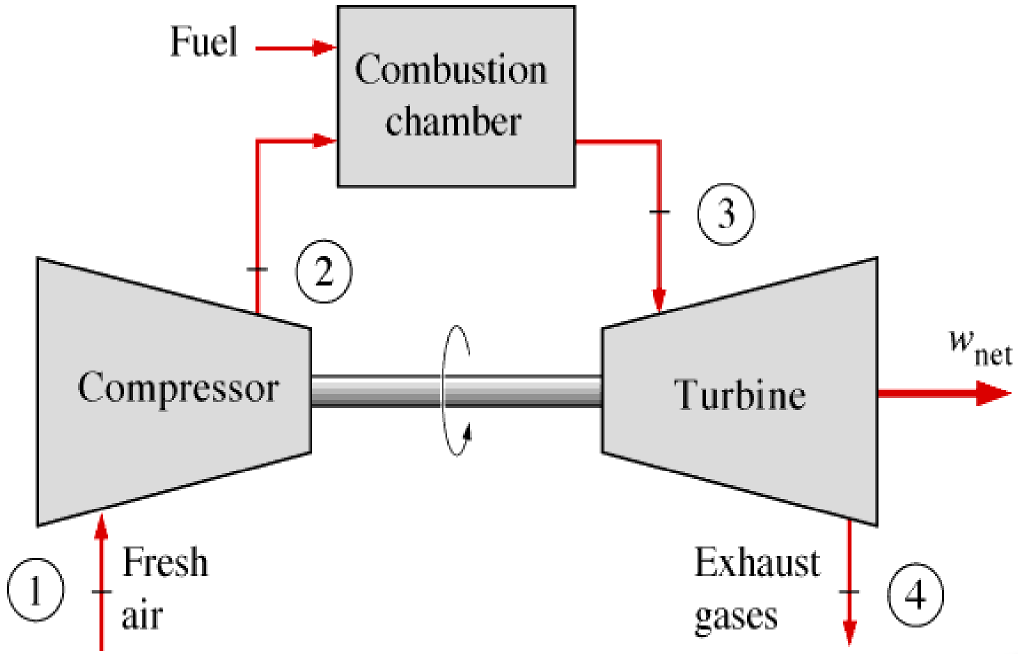


Brayton Cycle

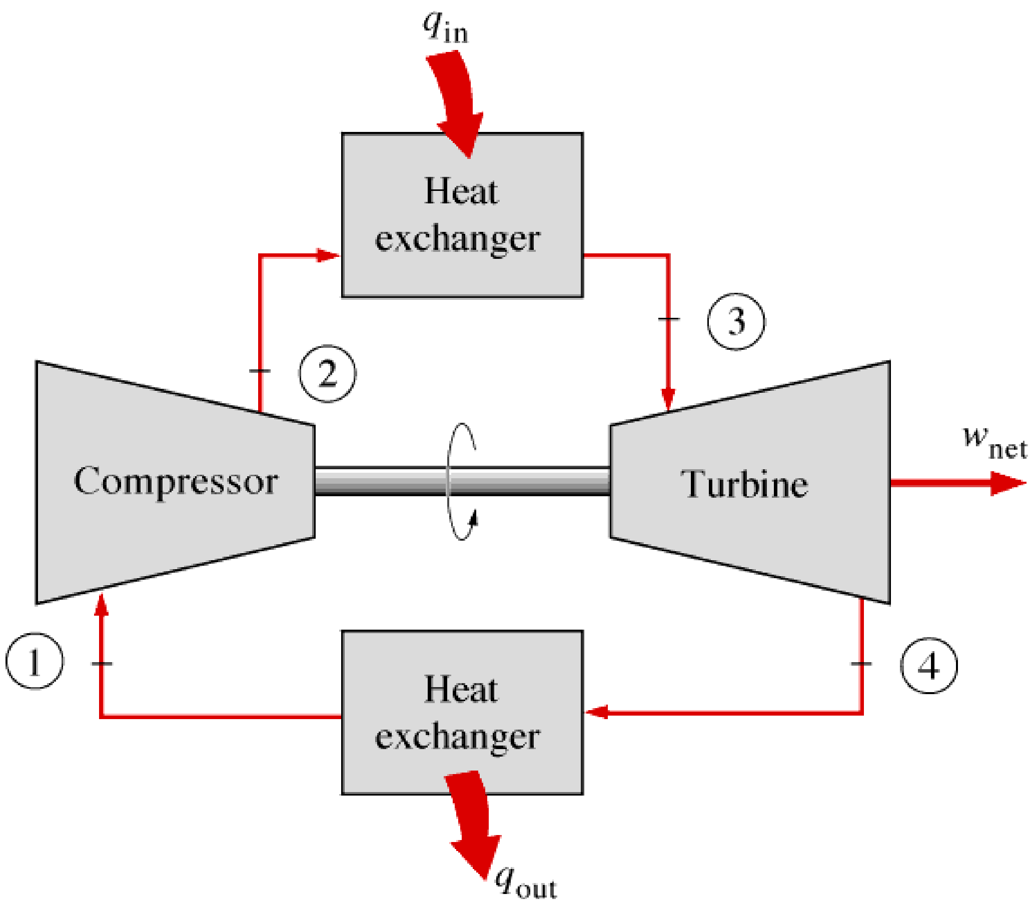


Other applications of Brayton cycle

- Power generation - use gas turbines to generate electricity
- very efficient
- Marine applications in large ships
- Automobile racing - late 1960s Indy 500 STP sponsored cars

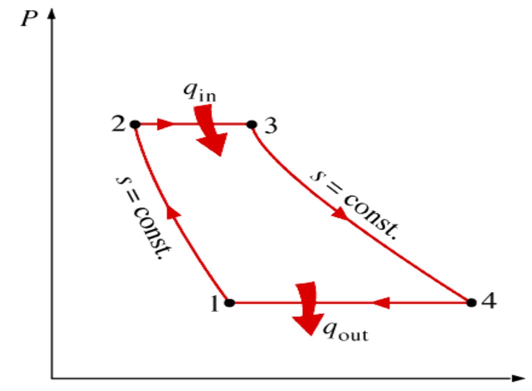


Idealized Brayton Cycle

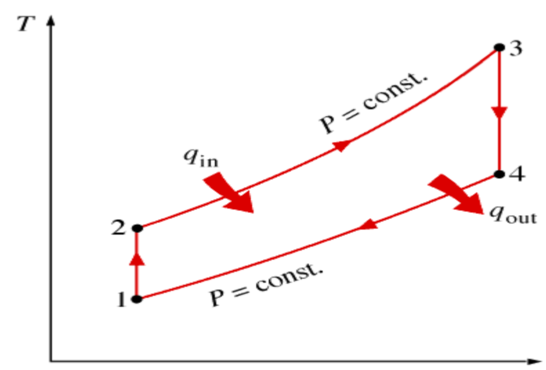


Brayton Cycle

- 1 to 2--isentropic compression
- 2 to 3--constant pressure heat addition (replaces combustion process)
- 3 to 4--isentropic expansion in the turbine
- 4 to 1--constant pressure heat rejection to return air to original state



(b) P- υdiagram



(a) T-s diagram

Brayton cycle analysis

net work:

$$w_{net} = \left|w_{turb}\right| - \left|w_{comp}\right|$$

Substituting:

$$w_{net} = (h_3 - h_4) - (h_2 - h_1)$$

BELL COLEMAN CYCLE.

- Air refrigeration system is the oldest refrigeration method. Initially it was developed by a scientist called Bell-Coleman.

- The aim of this study is to know the refrigeration effect using both Bell-Coleman cycle using air as the refrigerant and finding its COP because air is available free of cost and abundantly in nature.

BELL COLEMAN CYCLE.

- Since air is used as refrigerant is safe and it won't do any harm and no damage to atmosphere.
- Bell-Coleman cycle air refrigeration can be used in aircrafts and ships to produce refrigeration effect in them. Air refrigeration system generally uses air as medium, whereas other refrigeration systems use refrigerants (Freon's, ammonia etc.,) as medium
- By using other refrigerants like CFC's damage to atmosphere such as ozone layer depletion takes place.
- In this study compressed air is selected as the refrigerant and it is produced by compressor.

ELEMENTS OF HEAT TRANSFER AND GAS COMPRESSORS

DIFFERENCE BETWEEN HEAT AND TEMPERATURE

- In heat transfer problems, we often interchangeably use the terms heat and temperature.
- Actually, there is a distinct difference between the two. Temperature is a measure of the amount of energy possessed by the molecules of a substance.
- It manifests itself as a degree of hotness, and can be used to predict the direction of heat transfer.
- The usual symbol for temperature is T. The scales for measuring temperature in SI units are the Celsius and Kelvin temperature scales. Heat, on the other hand, is energy in transit. Spontaneously, heat flows from a hotter body to a colder one. The usual symbol for heat is Q. In the SI system, common units for measuring heat are the Joule and calorie.

DIFFERENCE BETWEEN THERMODYNAMICSANDHEATTRANSFER

Thermodynamics tells us:

how much heat is transferred(6Q)

how much work is done(6W)

final state of thesystem

Heat transfer tells us:

how (with what **modes**) 6Q istransferred

at what **rate** 6Q istransferred

temperature distribution inside thebody

MODES OF HEATTRANSFER

Conduction:

Anenergytransferacrossasystemboundaryduetoatemperaturedifferenceby the mechanism of inter-molecular-interactions. Conduction needs matter and does not require any bulk motion of matter.

Convection:

Anenergytransferacrossasystemboundaryduetoatemperaturedifferencebythecombinedmechanismsofintermolecularinteractionsandbulktransport.Convectionneeds fluidmatter.

Radiation: Radiationheattransferinvolvesthetransferofheatbyelectromagneticradiation that arises due to the temperature of the body. Radiation does not needmatter.

THERMAL CONDUCTIVITY,K

As noted previously, thermal conductivity is a thermodynamic property of a material. From the State Postulate given in thermodynamics, it may be recalled that thermodynamic properties of pure substances are functions of two independent thermodynamic intensive properties, say temperature and pressure.

Thermal conductivity of real gases is largely independent of pressure and may be considered a function of temperature alone. For solids and liquids, properties are largely independent of pressure and depend on temperature alone.

$$k = k\,(T)$$

BASIC CONCEPTS OF: GAS COMPRESSORS

- compressor is a mechanical device that increases the pressure of a gasby reducing its volume.
- An air compressor is a specific type of gas compressor.
- Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe.
- As gases are compressible, the compressor also reduces the volume of a gas.
- Liquids are relatively incompressible; while some can be compressed, the main action of a pump is to pressurize and transport liquids.

AIR COMPRESSORS

- Air compressors collect and store air in a pressurized tank, and use pistons and valves to achieve the appropriate pressure levels within an air storage tank that is attached to the motorized unit.

- There are a few deferent types of piston compressors that can deliver even air pressures to the user.

- Automotive compressors are combustion engine compressors that use the up-and-down stroke of the piston to allow air in and pressurize the air within the storage tank.

AIR COMPRESSORS

- There piston compressors utilize a diaphragm, oil-free piston. These pull air in, and pressurize it by not allowing air to escape during the collection period.

- These are the most common types of air compressors that are used today by skilled workers and craftsmen.

- Before the day of motorized engines, air compressors were not what they are today. "unable to store pressurized air.

SINGLE-STAGE RECIPROCATING AIR COMPRESSOR

- The sectional view of an air cooled, single-stage, single-acting reciprocating air compressor. Both intake (suction) and discharge (delivery) valves are disc type and are automatic in their action. They are opened and closed by difference in the air pressure acting on their two sides.

- When the pressures are equal on their two sides, they are kept closed by light springs. During the outward or suction stroke, the pressure in the cylinder falls below the atmospheric pressure as a result of which the intake valve opens and air is drawn from the atmosphere into the cylinder.

- During the inward or compression stroke, as a result of the piston action the pressure of the air in the cylinder gradually increases and reaches a value sufficiently above the receiver pressure.

- The high pressure of air, thus produced, overcomes the resistance of the spring on the discharge valve and causes the valve to open and discharge takes place from the cylinder to the receiver.

- The receiver is a simple vessel which acts as a storage tank. The compressor is driven by some form of prime mover (electric motor or engine).

- When the compressor is to be started against tank (receiver) pressure, the prime mover will have to supply very high starting torque.

- To avoid this, hand unloaded is used for releasing pressure from the compressor cylinder when the compressor is stopped.

MULTI-STAGE COMPRESSION

- In this method, the compression of air is carried out in two or more stages in separate cylinders.

- The pressure of the air is increased in each stage.

- It is a common practice to provide intercoolers between the cylinders of multi-stage compressor, for the purpose of cooling the compressed air to atmospheric (intake) temperature before entering the succeeding (next) stage.

- It is this cooling between the cylinders that keeps the compression very near to isothermal .

Volumetric efficiency of an air compressor is the ratio of the a dual volume of the free air at standard atmospheric conditions discharged in one delivery stroke, to the volume swept by the piston during the stroke. The standard atmospheric conditions (S.T.P.) is actually taken as pressure of 760 mm Hg (1 01325 bar) and temperature 15‘C in this connection. Thus, . Volume of free air delivered per stroke .

$$\text{Volumetric efficiency} = \frac{\text{Volume of free air delivered per stroke}}{\text{Volume swept by piston per stroke}}$$

The value of volumetric efficiency varies between 70 to 85 per cent according to the type of compressor.

The clearance space is provided in an actual compressor to safeguard the piston from striking the cylinder head or cylinder cover. The events taking place in a reciprocating compressor with clearance are the same as those taking place in a compressor without clearance.

All the air compressed in the cylinder at the end of the compression stroke will not be discharged from it but some air will be left in the clearance space at the end of the delivery stroke 2-3 .

The high pressure air, thus, left in the clearance space will re-expand along the curve 3-4 to the suction pressure (pr) before the suction valve can open and the suction starts again.

The volume of air drawn into the cylinder without clearance is equal to the displacement volume corresponding to full stroke. However with clearance, the volume of fresh air drawn into the cylinder is only va corresponding to stroke 4-1.

Thus, the effect of clearance in a compressor is to decrease the amount of fresh air that can be drawn into the cylinder during the suction stroke. Therefore, there is a considerable reduction in the volumetric efficiency of the compressor due to clearance.

In practice the clearance volume is limited to, two or three per cent of the displacement or swept volume (va) of the piston.

RECIPROCATING COMPRESSED AIR MOTOR

- Air motor is in effect a reversed air compressor.

- The compressed air to be used in an air motor is taken from the compressor reservoir (receiver).

- The most common form of compressed air motor is the cylinder and double-acting piston type.

- The air is admitted into the motor cylinder through a mechanically operated inlet valve and drives the piston forward but after a portion of the stroke of the piston has been performed, the air supply is cut-off and the stroke is completed under decreasing pressure as the air expands in the cylinder.

- After the expansion stroke is completed, the air which has done the work is allowed to escape into atmospheric through a mechanically operated discharge valve.

- The return stroke is performed by compressed air acting on the other side of the piston.

- A motor of this type works like a reciprocating double-acting steam engine.

ROTARY AIR COMPRESSORS

Depending on their pressure ratio,rotary air compressors may be classified Pi as follows :

Fans (rp = 1 to 1.1) - The main purpose of a fan is to move air or to circulate air through the ducts of an air conditioning system and to supply low-pressure air blast.

As the fluid passing through the unit does not suffer appreciable change in density, it can be treated as incompressible like water.

Principally, fans are axial-flow compressors without casing around the impeller periphery.

NON-POSITIVE DISPLACEMENT ROTARY OR STEADY FLC COMPRESSORS

Centrifugal and axial flow compressors come under this heading. In all forms of turbo-machinery, whether expanders (called turbines or centrifugal and axial flow compressors), work changes are effected by means of velocity changes instead of by displacement changes of a boundary, such as with a piston.

If the air enters at the centre axially and flows radially outward towards the circumference, the compressor is known as centrifugal compressor. On the other hand if the air flows parallel to the shaft, it is called axial flow compressor.

Thank You