

Q8. The spark plug fires shortly before the \_\_\_\_ stroke.

Q9. Heat transferred at constant pressure \_\_\_\_\_ the enthalpy of a system.

Q10. The two-stroke engine is \_\_\_\_ the four-stroke engine.

#### KEYS

(1) zero (2) four (3) decreases (4) zero (5) Pressure, Temperature, Velocity (6) much larger (7) greater than (8) expansion (9) Increases (10) less efficient than

## 14. ASSIGNMENT TOPICS WITH MATERIALS

### UNIT-I

#### Topic 1. Macroscopic and Microscopic Approach

Microscopic approach uses the statistical considerations and probability theory, where we deal with “average” for all particles under consideration. This is the approach used in the disciplines known as kinetic theory and statistical mechanics.

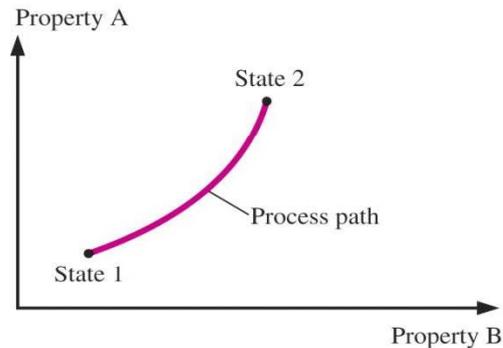
In the macroscopic point of view, of classical thermodynamics, one is concerned with the time-averaged influence of many molecules that can be perceived by the senses and measured by the instruments.

The pressure exerted by a gas is an example of this. It results from the change in momentum of the molecules, as they collide with the wall. Here we are not concerned with the actions of individual molecules but with the time-averaged force on a given area that can be measured by a pressure gage.

From the macroscopic point of view, we are always concerned with volumes that are very large compared to molecular dimensions, and therefore a system (to be defined next) contains many molecules, and this is called continuum.

The concept of continuum loses validity when the mean free path of molecules approaches the order of typical system dimension

#### Topic 2. Representation of State



## **Property**

➤ In thermodynamics a property is any characteristic of a system that is associated with the energy and can be quantitatively evaluated.

The property of a system should have a definite value when the system is in a particular state.

- Thermodynamic property is a point function.
- Properties like volume of a system that depend on the mass of a system are called extensive properties.
- Properties like pressure or temperature which do not depend on the system mass are called intensive properties.
- The ratio of extensive property to the mass of the system are called specific properties and therefore become intensive properties.
- Substance can be found in three states of physical aggregation namely, solid, liquid and vapor which are called its phases.

If the system consists of mixture of different phases, the phases are separated from each other by phase boundary.

The thermodynamic properties change abruptly at the phase boundary, even though the intensive properties like temperature and pressure are identical.

## **Process**

A process is path followed by a system in reaching a given final state of equilibrium state starting from a specified initial state.

An actual process occurs only when the equilibrium state does not exist.

An ideal process can be defined in which the deviation from thermodynamic equilibrium is infinitesimal.

All the states the system passes through during a quasi-equilibrium process may be considered equilibrium states.

For non-equilibrium processes, we are limited to a description of the system before the process occurs and after the equilibrium is restored.

Several processes are described by the fact that one property remains constant.

The prefix iso- is used to describe such processes.

A process is said to be reversible if both the system and its surroundings can be restored to their respective initial states by reversing the direction of the process.

- **Reversible:** if the process happens slow enough to be reversed.
- **Irreversible:** if the process cannot be reversed (like most processes).

- **isobaric:** process done at constant pressure
- **isochoric:** process done at constant volume
- **isothermal:** process done at constant temperature
- **adiabatic:** process where  $q=0$

### **Topic 3. Quasi-equilibrium process**

can be viewed as a sufficiently slow process that allows the system to adjust itself internally and remains infinitesimally close to an equilibrium state at all times. Quasi-equilibrium process is an idealized process and is not a true representation of the actual process. We model actual processes with Quasi- equilibrium ones. Moreover, they serve as standards to which actual processes can be compared. Process diagrams are used to visualize processes. Note that the process path indicates a series of equilibrium states, and we are not able to specify the states for a non-quasi equilibrium process.

### **Topic 4. First law of thermodynamics**

The **First Law of Thermodynamics** is

$$\Delta U = Q + W$$

That is, during a change of state of a system, the change in the system's internal energy is equal to the sum of the heat added to the system and the work done on the system by its surroundings.

Defining  $U$  in terms of the first law is: from  $\Delta U = Q + W$  we can express  $U$  in terms of measurable quantities,  $Q$  and  $W$ . This only gives a definition for  $U$ , you might say. But by assigning some value to  $U$  in a particular reference state, we can use equation to define  $U$  in any other state.

Another problem arises:  $U$  is the sum of two path-dependent quantities. How is our definition of  $U$  meaningful? It is meaningful because we find that in all cases,  $\Delta U$  is independent of path.

That is, the change in internal energy of a system during any thermodynamic process depends only on initial and final states, not on the path leading from one to another.

The First Law in differential form is

$$dU = dQ + dW$$

The bar reminds us that  $dQ$  and  $dU$  are path-independent and hence are inexact differentials.

We think of  $dQ$  as a quantity of energy being transferred by other means than by work. This negative formulation is a way of defining heat.

Just as we had a sign convention for work, so too do we have one for heat:

$dQ$  is positive for heat entering (flowing into) the system.

$dQ$  is negative for heat leaving (flowing out of) the system.

### **Topic 5. Temperature scales**

All temperature scales are based on some easily reproducible states such as the freezing and boiling point of water, which are also called the ice-point and the steam-point respectively.

A mixture of ice and water that is in equilibrium with air saturated with water vapour at 1atm pressure, is said to be at the ice-point, and a mixture of liquid water and water vapour (with no air) in equilibrium at 1atm is said to be at the steam-point.

Celsius and Fahrenheit scales are based on these two points (although the value assigned to these two values are different) and are referred as two-point scales.

such a temperature scale is called a thermodynamic temperature scale.(Kelvin in SI)

## UNIT-II

### Topic 1. Limitations of First Law of Thermodynamics

- First law does not provide a clear idea about the direction of absorption or evolution of heat.
- The information provided by the first law of thermodynamics are not enough to predict the spontaneity or feasibility of a process.
- To deal with spontaneity of chemical processes some new terms viz., entropy (S) and Gibbs free energy (G) were introduced in thermodynamics which lead way to the formulation of second and third laws of thermodynamics.
- Entropy: The degree of disorderliness or randomness is called entropy of a system. More the randomness, more will be the entropy of a system. The terms heat (q) and temperature plays a main role in arriving at the entropy of a system.

- Entropy is independent of the path followed by a reaction and hence it is state function.
- In a perfect crystalline state where the entities are orderly arranged the entropy is found to be zero.
- Example Conversion liquid water to ice.

## **Topic 2. The second law of thermodynamics:**

### **The Kelvin-Planck Statement:**

It is impossible to construct a device, that operating in a cycle will produce no other effect than the extraction of heat from a single body of uniform temperature and the performance of an equivalent amount of work.

### **The Clausius Statement:**

It is impossible to construct a device that, operating in a cycle, produces no other effect than the transfer of heat from a colder body to a hotter body.

Theorem:

- The Kelvin-Planck statement holds if and only if the Clausius statement holds.
- For, assume that the Kelvin-Planck statement does *not* hold. Then we have an engine  $E$  that works in a cycle, extracts heat  $Q_1$  from the hot reservoir and does work  $W = Q_1$  in each cycle.

We let this engine drive a refrigerator  $R$ , where  $R$  is such that  $W$  is sufficient to drive the refrigerator through one cycle.

- We have that the refrigerator extracts heat  $Q_2$  from the cold reservoir. Then, the heat it delivers to the hot reservoir is  $Q_1 + Q_2$ .
- We can consider the composite refrigerator outlined below:
- This device violates the Clausius statement of the Second Law.

We therefore conclude that the Clausius statement implies the Kelvin-Planck statement.

Assume now that the Clausius statement does not hold. This means that there exists a refrigerator  $R$  which extracts heat  $Q_2$  from the cold reservoir and delivers the same heat  $Q_2$  to the hot reservoir, with no work being done on the system. Consider now an engine  $E$  operating between the same

reservoirs, and doing an amount of work  $W$  on the surroundings. Further, let  $E$  be such that in each cycle, it extracts heat  $Q_1$  from the hot reservoir and delivers heat  $Q_2$  to the cold reservoir, and so  $W = Q_1 - Q_2$

This device violates the Kelvin-Planck statement of the Second Law.

Therefore, the Kelvin-Planck statement implies the Clausius statement.

Thus, the Kelvin-Planck statement holds iff the Clausius statement holds.

### Topic 3. Third Law of Thermodynamics

- For substances in internal equilibrium, undergoing an isothermal process, the entropy change goes to zero as  $T$  (in K) goes to zero.
- The law is valid for pure substances and mixtures.
- Close to Zero Kelvin, the molecular motions have to be treated using quantum mechanics → still it is found that quantum ideal gases obey the third law. There does not exist any finite sequence of cyclical process, which can cool a body to zero Kelvin (absolute zero).

### Topic 4. Problem

An ideal gas undergoes an isothermal expansion at  $77^\circ\text{C}$  increasing its volume from 1.3 to 3.4 L. The entropy change of the gas is 24 J/K. How many moles of gas are present?

#### Concept:-

The entropy  $\Delta S$  of an ideal gas undergoes an isothermal expansion is defined as,

$$\Delta S = Q/T$$

$$= n R \ln V_f/V_i$$

Here  $Q$  is the added heat,  $T$  is the temperature,  $n$  is the number of moles,  $R$  is the gas constant,  $V_f$  is the final volume and  $V_i$  is the initial volume.

From the equation  $\Delta S = nR \ln V_f/V_i$ , the number of moles  $n$  will be,

$$n = \Delta S / (R \ln V_f/V_i)$$

#### Solution:-

To obtain the number of moles  $n$  are present in the gas, substitute 24 J/K for  $\Delta S$ , 8.31 J/mol. K for  $R$ , 3.4 L for  $V_f$  and 1.3 L for  $V_i$  in the equation,

$$n = \Delta S / (R \ln V_f/V_i)$$

$$= (24 \text{ J/K}) / (8.31 \text{ J/mol. K}) (\ln 3.4 \text{ L}/1.3 \text{ L})$$

$$= (24 \text{ J/K}) / (8.31 \text{ J/mol. K}) (\ln (3.4/1.3))$$

$$= 3.00 \text{ mol}$$

From the above observation we conclude that, the number of moles  $n$  are present in the gas would be 3.00 mol.

### Topic 5. Problem

Water standing in the open at  $32^\circ\text{C}$  evaporates because of the escape of some of the surface molecules. The heat of vaporization is approximately equal to  $\epsilon n$ , where  $\epsilon$  is the average energy of the escaping molecules and  $n$  is the number of molecules per kilogram. (a) Find  $\epsilon$ . (b) What is the ratio of  $\epsilon$  to the average kinetic energy of  $\text{H}_2\text{O}$  molecules, assuming that the kinetic energy is related to temperature in the same way as it is for gases?

#### Concept:-

Number of molecules  $n$  is equal to the Avogadro's number  $N_A$  divided by molecular weight  $M$ .

$$E_{\text{av}} = 3/2 kT$$

Here  $k$  is the Boltzmann constant and  $T$  is the temperature.

#### Solution:-

(a) As heat of vaporization  $L_v$  is approximately equal to  $\epsilon n$ , where  $\epsilon$  is the average energy of the escaping molecules and  $n$  is the number of molecules per kilogram, so,

$$L_v = \epsilon n$$

Or,

$$\epsilon = L_v/n$$

$$= L_v / (N_A/M)$$

$$= L_v M / N_A$$

To obtain the average energy  $\epsilon$ , substitute  $2256 \times 10^3 \text{ J/kg}$  for latent heat of vaporization of water molecule ( $\text{H}_2\text{O}$ )  $L_v$ ,  $0.018 \text{ kg/mol}$  for  $M$  and  $6.03 \times 10^{23}/\text{mol}$  for  $N_A$  in the equation  $\epsilon = L_v M / N_A$ , we get,

$$\epsilon = L_v M / N_A$$

$$= (2256 \times 10^3 \text{ J/kg})(0.018 \text{ kg/mol}) / (6.03 \times 10^{23})$$

$$= 6.75 \times 10^{-20} \text{ J}$$

From the above observation we conclude that, the value of average energy  $\epsilon$  would be  $6.75 \times 10^{-20} \text{ J}$ .

(b) As,  $E_{\text{av}} = 3/2 kT$ , therefore the ratio of  $\epsilon$  to the average kinetic energy  $E_{\text{av}}$  of  $\text{H}_2\text{O}$  molecule will be,

$$\begin{aligned}\epsilon / E_{av} &= \epsilon / (3/2 kT) \\ &= 2 \epsilon / 3 kT\end{aligned}$$

To obtain the ratio of  $\epsilon$  to the average kinetic energy  $E_{av}$  of  $H_2O$  molecule, substitute  $6.75 \times 10^{-20} \text{ J}$  for  $\epsilon$ ,  $1.38 \times 10^{-23} \text{ J/K}$  for  $k$  and  $32^\circ \text{ C}$  for  $T$  in the equation  $\epsilon / E_{av} = 2 \epsilon / 3 kT$ , we get,

$$\begin{aligned}\epsilon / E_{av} &= 2 \epsilon / 3 kT \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(32^\circ \text{ C}) \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(32 + 273) \text{ K} \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(305 \text{ K}) \quad = 10.7\end{aligned}$$

## UNIT-III

### Topic 1. Work

Whenever a system interacts with its surroundings, it can exchange energy in two ways- work and heat.

In mechanics, work is defined as the product of the force and the displacement in the direction of the force.

Work done when a spring is compressed or extended: According to Hooke's law Spring force =  $-k(x - x_0)$

Where  $k$  is the spring constant,  $x_0$  is the equilibrium position, and  $x$  is the final position. The negative sign shows that the direction of the spring force is opposite the direction of the displacement from  $x_0$ . The external force is equal in magnitude but opposite in sign to the spring force, so External force (force of your hands) =  $k(x - x_0)$ .

Now, we want to calculate the work done when we stretch the spring from position 1 to position 2.

$$W = \int F dx = \int k(x - x_0) dx = \frac{1}{2} k [(x_2 - x_0)^2 - (x_1 - x_0)^2]$$

Work done when a volume is increased or decreased

## Topic 2. Equation of state:

An equation of state is an equation which relates the variables of state ( $T$ ,  $P$ ,  $V$ , and  $n$ ). It's particularly useful when you want to know the effect of a change in one of the variables of state

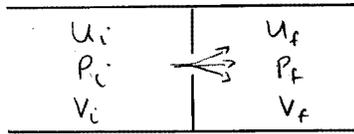
- Solids and Liquids: If the pressure on a solid or liquid is increased, the volume does not change much. If the temperature is increased, the volume doesn't change much either. Therefore, an appropriate equation of state describing such systems would be:  $V(T,P) = \text{constant}$ .
- Gases: In contrast, changing the pressure or temperature of a gas will have an easily observable effect on the volume of that gas. For an ideal gas (no intermolecular interactions and no molecular volume) an appropriate equation of state would be:  $V(T,P,n) = (nRT)/P$ .

There are many equations of state describing real gases. These equations take in consideration molecular volume and interactions. The most well-known such equations is probably the Van der Waals equation

## Topic 3. Throttling and free expansion processes

### THROTTLING

The working fluid passes through a narrow opening from a region of high pressure into a region of low pressure. In doing so, it expands adiabatically ( $Q = 0$ ) and cools. As the fluid expands, the negative potential energy of interaction among the atoms/molecules increases and the kinetic energy decreases.



From the First “Law”

$$\Delta U = U_f - U_i = Q + W = 0 + W_{left} + W_{right}$$

$$U_f - U_i = P_i V_i - P_f V_f$$

$$U_f + P_f V_f = U_i + P_i V_i$$

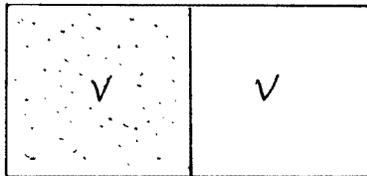
In a dense gas or a liquid,  $U_{potential} + U_{kinetic} + PV = \text{constant}$ . Therefore, as the gas expands,

$\Delta U_{potential} > 0$  so that  $\Delta U_{kinetic} < 0 \rightarrow$  the gas/liquid cools.

Subsequently, the chilled fluid absorbs heat from the cold reservoir and vaporizes. Therefore, the working fluid must be a substance with a low boiling point. The compressor does the work of compressing the gas to raise its temperature, as well as maintains the pressure difference required for the throttle valve to work.

### Free expansion

Imagine a container of volume  $2V$ , isolated from its surroundings, and with a partition that divides the container in half. An ideal gas is confined to one side of the container. The gas is in equilibrium, with temperature  $T$  and Pressure  $P$ . Now, imagine removing the partition. Over time, the gas molecules will diffuse to fill the larger volume.



However, in expanding the gas does no work, hence the phrase *free expansion*. Because the container is isolated, no heat flows into or out of the gas, nor does the number of molecules,  $N$ , change..

$$\Delta U = Q + W = 0 + 0 = 0$$

#### Topic 4. Problem

A 0.1 m<sup>3</sup> rigid tank contains steam initially at 500 kPa and 200°C. The steam is now allowed to cool until the temperature drops to 50°C. Determine the amount of heat transfer during this process and the final pressure in the tank.

**State 1:**  $P_1 = 500 \text{ kPa}$ ,  $T_1 = 200^\circ\text{C}$   
 $v_1 = 0.4249 \text{ m}^3/\text{kg}$ ,  $u_1 = 2642.9 \text{ kJ/kg}$

**State 2:**  $v_2 = v_1 = 0.4269 \text{ m}^3/\text{kg}$   
 $T_2 = 50^\circ\text{C} \rightarrow v_f = 0.001 \text{ m}^3/\text{kg}$   
 $v_g = 12.03 \text{ m}^3/\text{kg}$   
 $u_f = 209.32 \text{ kJ/kg}$   
 $u_g = 2443.5 \text{ kJ/kg}$

$P_2 = P_{sat} @ 50^\circ\text{C} = \mathbf{12.349 \text{ kPa}}$

$v_2 = v_f + x_2 v_{fg}$   
 $0.4249 = 0.001 + x_2(12.03 - 0.001)$   
 $x_2 = 0.0352$

$u_2 = u_f + x_2 u_{fg}$   
 $= 209.32 + (0.0352)(2443.5 - 209.32)$   
 $= 288.0 \text{ kJ/kg}$

$m = V/u = (0.1 \text{ m}^3/\text{kg}) / (0.4249 \text{ m}^3/\text{kg})$   
 $= 0.235 \text{ kg}$

$-Q_{out} = \Delta U = m(u_2 - u_1)$   
 $Q_{out} = m(u_1 - u_2)$   
 $= (0.235)(2642.9 - 288)$   
 $= \mathbf{553.4 \text{ kJ}}$

## Topic 5. Problem

A piston/cylinder contains 50 kg of water at 200 kPa with a volume of  $0.1 \text{ m}^3$ . Stop in the cylinder is placed to restrict the enclosed volume to  $0.5 \text{ m}^3$ . The water is now heated until the piston reaches the stops. Find the necessary heat transfer.

At 200 kPa,

$$v_f = 0.001061 \text{ m}^3/\text{kg}$$

$$v_{fg} = 0.88467 \text{ m}^3/\text{kg}$$

$$h_f = 504.68 \text{ kJ/kg}$$

$$h_{fg} = 2201.96 \text{ kJ/kg}$$

$$Q = \Delta H$$

The specific volume initially,

$$v_i = 0.1 / 50 = 0.002 \text{ m}^3/\text{kg}$$

$$v = v_f + x v_{fg}$$

$$= 0.001061 + x (0.88467)$$

$$\text{Therefore, } x = (0.002 - 0.001061) / 0.88467 \\ = 0.001061$$

$$h = h_f + x h_{fg}$$

$$= 504.68 + 0.001061(2201.96)$$

$$= 507.017 \text{ kJ/kg}$$

$$v_{final} = 0.5 / 50 = 0.01 \text{ m}^3/\text{kg}$$

$$v = v_f + x v_{fg}$$

$$\text{Therefore, } x = (0.01 - 0.001061) / 0.88467 \\ = 0.01$$

$$h_{final} = 504.68 + 0.01(2201.96)$$

$$= 526.69 \text{ kJ/kg}$$

$$Q = \Delta H = 50 (526.69 - 507.017)$$

$$= \underline{\underline{983.65 \text{ kJ/kg}}}$$

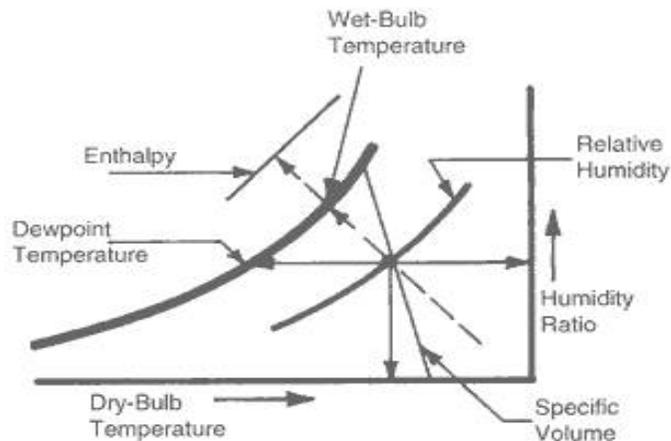
## UNIT-IV

### Topic 1. The psychrometric chart

At first appearance the psychrometric chart is quite confusing, however with some practice it becomes an extremely useful tool for rapidly evaluating air-conditioning processes. The most popular chart in common usage is that developed by ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers), however we feel that the construction of a simplified version of the chart based on approximations of the various equations can be a very useful tool for developing an understanding of its usage.

#### DEW POINT

- Dew point is also known as saturation temperature.
- Dew point temperature is determined by moving from a state point horizontally to the left along lines of constant humidity ratio until the upper, curved, saturation temperature boundary is reached.



### Topic 2. degree of saturation, adiabatic saturation, cooling & humidification

- a) Degree of saturation  $\mu$ : The degree of saturation is the ratio of the humidity ratio  $W$  to the humidity ratio of a saturated mixture  $W_s$  at the same temperature and pressure.

b) Adiabatic saturation:  $t_w = t_{WBT}$ . Here the sensible heat transfer from air to water is exactly equal to latent heat transfer from water to air. Hence, no external cooling or heating of water is required. That is this is a case of pure water recirculation.

c) Cooling and humidification:  $t_{DPT} < t_w < t_{WBT}$ . Here the sensible heat transfer is from air to water and latent heat transfer is from water to air, but the total heat transfer is from air to water, hence, water has to be cooled externally.

d) Cooling and humidification:  $t_{WBT} < t_w < t_{DPT}$ . Here the sensible heat transfer is from air to water and latent heat transfer is from water to air, but the total heat transfer is from water to air, hence, water has to be heated externally. This is the process that takes place in a cooling tower. The air stream extracts heat from the hot water coming from the condenser, and the cooled water is sent back to the condenser.

### **Topic 3. Atmospheric air, psychrometric properties, dbt, wbt, dew point temperature**

Determination of moisture content

Moisture content or percentage saturation is found using a wet & dry bulb thermometer (*psychrometer*)

In its simplest form a psychrometer consists of two thermometers one of which has its bulb wetted (usually by a wick with one end immersed in water).

The air whose '%sat' we wish to measure is caused to flow over both (wet & dry) bulbs of the psychrometer.

The dry bulb will register the ordinary air temperature. The wet bulb behaviour depends upon the extent to which the air/steam mixture is saturated, i.e. its % saturation.

if the mixture is 100% saturated no evaporation of the water wetting the wet bulb can occur - it will therefore register the same temperature as the dry bulb.

if the mixture is 0% saturated (i.e. dry) it will cause maximum evaporation from the wet bulb. The enthalpy of evaporation will be drawn from the remaining water depressing its temperature. An equilibrium situation will occur when the heat and mass transfer rates stabilise. ~if the mixture is between 0 & 100%, the wet bulb will register an intermediate depression.

#### Topic 4. Problem

A cooling tower is used for cooling the condenser water of a refrigeration system having a heat rejection rate of 100 kW. In the cooling tower air enters at 35°C (DBT) and 24°C (WBT) and leaves the cooling tower at a DBT of 26°C relative humidity of 95%. What is the required flow rate of air at the inlet to the cooling tower in m<sup>3</sup>/s. What is the amount of make-up water to be

supplied? The temperature of make-up water is at 30°C, at which its enthalpy ( $h_w$ ) may be taken as 125.4 kJ/kg. Assume the barometric pressure to be 1 atm.

At the inlet to cooling tower: DBT = 35°C and WBT = 24°C

From psychrometric chart/equations the following values are obtained for the inlet:

$$\text{Humidity ratio, } W_i = 0.01426 \text{ kgw/kg}$$

$$\text{Enthalpy, } h_i = 71.565 \text{ kJ/kg}$$

$$\text{Sp. volume, } v_i = 0.89284 \text{ m}^3/\text{kg}$$

At the outlet to cooling tower: DBT = 26°C and RH = 95%

From psychrometric chart/equations the following values are obtained for the outlet:

$$\text{Humidity ratio, } W_o = 0.02025 \text{ kgw/kg}$$

$$\text{Enthalpy, } h_o = 77.588 \text{ kJ/kg}$$

From mass and energy balance across the cooling tower:

$$Q_c = m_a \{ (h_o - h_i) - (W_o - W_i) h_w \} = 100 \text{ kW}$$

Substituting the values of enthalpy and humidity ratio at the inlet and outlet of cooling tower and enthalpy of make-up water in the above expression, we obtain:

$$m_a = 18.97 \text{ kg/s,}$$

$$\text{hence, the volumetric flow rate, } V_i = m_a \times v_i = 16.94 \text{ m}^3/\text{s} \text{ (ans.)}$$

Amount of make-up water required  $m_w$  is obtained from mass balance as:

$$m_w = m_a(W_o - W_i) = 18.97(0.02025 - 0.01426) = 0.1136 \text{ kg/s} = 113.6 \text{ grams/s} .$$

#### Topic 5. Problem

In an air conditioning system air at a flow rate of 2 kg/s enters the cooling coil at 25°C and 50% RH and leaves the cooling coil at 11°C and 90% RH. The apparatus dew point of the cooling coil

is 7°C. Find a) The required cooling capacity of the coil, b) Sensible Heat Factor for the process, and c) By-pass factor of the cooling coil. Assume the barometric pressure to be 1 atm. Assume the condensate water to leave the coil at ADP ( $h_w = 29.26$  kJ/kg)

Ans). At the inlet to the cooling coil;  $T_i = 25^\circ\text{C}$  and  $\text{RH} = 50\%$

From psychrometric chart;  $W_i = 0.00988$  kgw/kgda and  $h_i = 50.155$  kJ/kgda

At the outlet of the cooling coil;  $T_o = 11^\circ\text{C}$  and  $\text{RH} = 90\%$

From psychrometric chart;  $W_o = 0.00734$  kgw/kgda and  $h_o = 29.496$  kJ/kgda a) From mass balance across the cooling coil, the condensate rate,  $m_w$  is:

$$m_w = m_a(W_i - W_o) = 2.0(0.00988 - 0.00734) = 0.00508 \text{ kg/s}$$

From energy balance across the cooling tower, the required capacity of the cooling coil,  $Q_c$  is given by;

$$Q_c = m_a(h_i - h_o) - m_w \cdot h_w = 2.0(50.155 - 29.496) - 0.00508 \times 29.26 = 41.17 \text{ kW}$$

b) The sensible heat transfer rate,  $Q_s$  is given by:

$$Q_s = m_a c_{pm}(T_i - T_o) = 2.0 \times 1.0216 \times (25 - 11) = 28.605 \text{ kW}$$

The latent heat transfer rate,  $Q_l$  is given by:

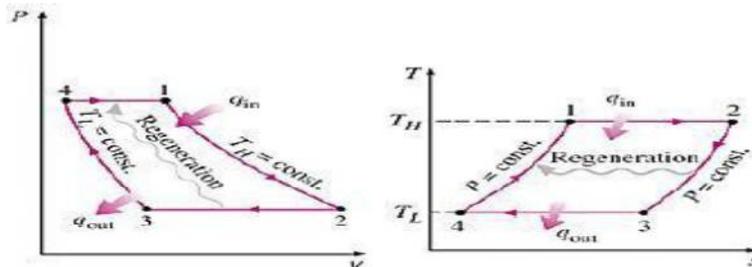
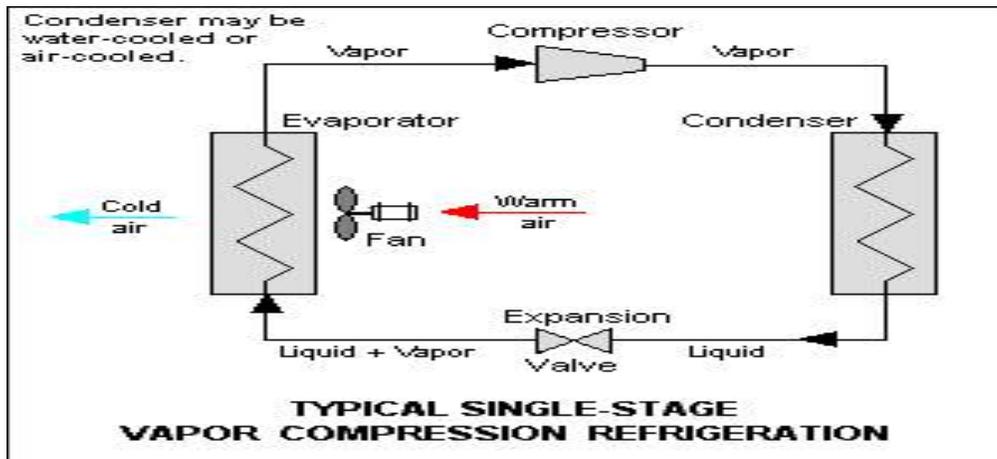
$$Q_l = m_a h_{fg}(W_i - W_o) = 2.0 \times 2501.0 \times (0.00988 - 0.00734) = 12.705 \text{ kW}^1$$

The Sensible Heat Factor (SHF) is given by:

$$\text{SHF} = Q_s / (Q_s + Q_l) = 28.605 / (28.605 + 12.705) = 0.692$$

## UNIT-V

### Topic 1. Vapor compression cycles



Processes: -

1-2: Isentropic compression from state 1 (wet vapour) to state 2 (saturated vapour)

2-3: Heat rejection ( $Q_H$ ) in the condenser

3-4: Isentropic expansion from state 3 (saturated liquid)

4-1: Heat absorption ( $Q_L$ ) in the evaporator

$$(COP)_R = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

vapor-compression refrigeration or vapor-compression refrigeration system (vcrs),<sup>[1]</sup> in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial

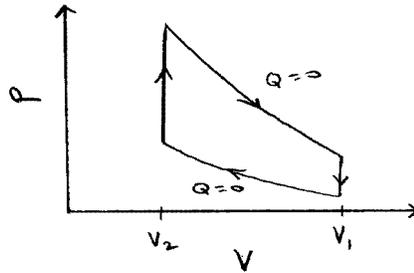
services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

## Topic 2. Otto cycle

The Otto cycle is the basis for the ordinary 4-stroke gasoline engine.

- i) air-fuel mixture is compressed adiabatically from  $V_1$  to  $V_2$ ; pressure rises from  $P_1$  to  $P_2$ .
- ii) air-fuel mixture is ignited, the pressure rises isochorically from  $P_2$  to  $P_3$ .
- iii) combustion products expand adiabatically from  $V_2$  to  $V_1$ ; pressure falls from  $P_3$  to  $P_4$ .
- iv) pressure falls isochorically from  $P_4$  to  $P_1$ .



The temperatures also change from step to step. The efficiency is given by

$$e = 1 - \left( \frac{V_2}{V_1} \right)^{\gamma-1} = 1 - \frac{T_1}{T_2} = 1 - \frac{T_4}{T_3}$$

The quotient  $\frac{V_1}{V_2}$  is the compression ratio. The greater the compression ratio, the greater is the efficiency of the engine. However, so is  $T_3$  greater. If  $T_3$  is too great, the air-fuel mixture will ignite prematurely, before the piston reaches the top of its stroke. This reduces power, and damages the piston and cylinder. Up to a point, chemical additives to the fuel can alleviate the premature detonation.

*Processes:* -

0-1: a fresh mixture of fuel-air is drawn into the cylinder at constant pressure

1-2: isentropic compression

2-3: energy addition at constant volume

3-4: isentropic expansion

4-1: combustion products leave the cylinder

1-0: the piston pushes out the remaining combustion products at constant pressure

Since the net work done in processes 0-1 and 1-0 is zero, for thermodynamic analysis, we consider the 1-2-3-4 only.

**Topic 3. Mean effective Pressure:** Net workdone = mep / Displacement volume

**Brake Mean Effective Pressure** We have presented the topics of Thermal Efficiency and Volumetric Efficiency as methods for estimating the potential output of a given engine configuration. Brake Mean Effective Pressure (BMEP) is another very effective yardstick for comparing the performance of an engine of a given type to another of the same type, and for evaluating the reasonableness of performance claims or requirements. The definition of BMEP is:

the average (mean) pressure which, if imposed on the pistons uniformly from the top to the bottom of each power stroke, would produce the measured (brake) power output. Note that BMEP is purely theoretical and has nothing to do with actual cylinder pressures. It is simply a tool to evaluate the efficiency of a given engine at producing torque from a given displacement.

#### **Topic 4. Problem**

An inventor claims to have created a heat pump that draws heat from a lake at 3.0°C and delivers heat at a rate of 20 kW to a building at 35°C, while using only 1.9 kW of electrical power. How would you judge the claim?

#### **Concept:-**

Coefficient of performance ( $K$ ) of a heat pump is defined as,

$$K = T_L / (T_H - T_L)$$

Where,  $T_L$  is the lower temperature and  $T_H$  is the higher temperature of the reservoir.

Again, coefficient of performance ( $K$ ) of a heat engine is defined as,

$$K = Q_L / W$$

$$= (Q_H - W) / W$$

We can write above equation  $K = (Q_H - W) / W$ ,

$$K = (Q_H - W) / W$$

$$= (Q_H/t - W/t) / (W/t)$$

$$= (P_H - P) / P \quad (\text{Since Power } (P) = W/t)$$

#### **Solution:-**

To obtain the Coefficient of performance ( $K$ ) of a heat pump, substitute 3.0 °C for  $T_L$  and 35 °C for  $T_H$  in the equation  $K = T_L / (T_H - T_L)$ ,

$$K = T_L / (T_H - T_L)$$

$$= 3.0 \text{ }^\circ\text{C} / (35 \text{ }^\circ\text{C} - 3.0 \text{ }^\circ\text{C})$$

$$= (3+273) \text{ K} / ((35+273) \text{ K} - (3+273) \text{ K})$$

$$= 276 \text{ K} / (308 \text{ K} - 276 \text{ K})$$

$$= 8.62$$

To find out the coefficient of performance  $K$  of the machine which the inventor claims, substitute 20 kW for  $P_H$  and 1.9 kW for  $P$  in the equation  $K = (P_H - P) / P$ ,

$$K = (P_H - P) / P$$

$$= (20 \text{ kW} - 1.9 \text{ kW}) / 1.9 \text{ kW}$$

$$= 9.53$$

Since the coefficient of performance  $K$  of the machine which the inventor claims is greater than the coefficient of performance ( $K$ ) of a heat pump, therefore it cannot be done.

### **Topic 5. Problem**

The motor in a refrigerator has a power output of 210 W. The freezing compartment is at  $-3.0^{\circ}\text{C}$  and the outside air is at  $26^{\circ}\text{C}$ . Assuming that the efficiency is 85% of the ideal, calculate the amount of heat that can be extracted from freezing compartment in 15 min.

#### **Concept:-**

Coefficient of performance  $K$  of a Carnot refrigerator is defined as,

$$K = T_L / T_H - T_L$$

Here  $T_L$  is the lower temperature of sink and  $T_H$  is the higher temperature of source.

Since here the efficiency is 85% of the ideal, therefore the coefficient of performance  $K$  of the refrigerator will be,

$$K = 0.85 (T_L / T_H - T_L)$$

A refrigerator would like to extract as much heat  $Q_L$  as possible from the low-temperature reservoir (“what you want”) for the least amount of work  $W$  (“what you pay for”).

$$= Q_L/W$$

and this is called coefficient of performance. The larger the value of  $K$ , the more efficient is the refrigerator.

From the above equation  $K = Q_L/W$ ,  $Q_L$  will be,

$$Q_L = (K) (W)$$

Work done ( $W$ ) is equal to the product of power ( $P$ ) and time ( $t$ ).

$$W = (P) (t)$$

#### **Solution:-**

First we have to find out the coefficient of performance  $K$  and work done  $W$ .

To obtain coefficient of performance  $K$ , substitute 270 K for  $T_L$  and 299 K for  $T_H$  in the equation  $K = 0.85 (T_L / T_H - T_L)$ ,

$$K = 0.85 (T_L / T_H - T_L)$$

$$= 0.85 (270 \text{ K} / 299 \text{ K} - 270 \text{ K})$$

$$= 7.91$$

To obtain work done  $W$ , substitute 210 W for power  $P$  and 15 min for time  $t$  in the equation  $W = (P) (t)$ ,

$$\begin{aligned}W &= (P) (t) \\&= (210 \text{ W}) (15 \text{ min}) \\&= (210 \text{ W}) (15 \text{ min}) (60 \text{ s/1 min}) \\&= (210 \text{ W}) (900 \text{ s}) \\&= (1.89 \times 10^5 \text{ Ws}) (1 \text{ J/1 Ws}) \\&= 1.89 \times 10^5 \text{ J}\end{aligned}$$

To obtain the amount of heat  $Q_L$  that can be extracted from the freezing, substitute 7.91 for coefficient performance  $K$  and  $1.89 \times 10^5 \text{ J}$  for work done  $W$  in the equation

$$\begin{aligned}Q_L &= (K) (W), \\Q_L &= (K) (W) \\&= (7.91) (1.89 \times 10^5 \text{ J}) \\&= 1.50 \times 10^6 \text{ J}\end{aligned}$$

From the above observation we conclude that, the amount of heat  $Q_L$  that can be extracted from the freezing compartment in 15 min would be  $1.50 \times 10^6 \text{ J}$ .

## 15. Tutorial topics and Questions

### UNIT-I

1. When a stationary mass of gas was compressed without friction at constant pressure, its initial state of  $0.4 \text{ m}^3$  and  $0.105 \text{ MPa}$  was found to change to final state of  $0.20 \text{ m}^3$  and  $0.105 \text{ MPa}$ . There was a transfer of  $42.5 \text{ kJ}$  of heat from the gas during the process. How much did the internal energy of the gas change?
2.  $0.44 \text{ kg}$  of air at  $180^\circ \text{C}$ , expands adiabatically to 3 times its original volume and during the process

there is a falling temperature to  $15^{\circ}\text{C}$ . The work done during the process 52.5kJ. Calculate  $C_p$  and  $C_v$ ?

3. Two thermometers on centigrade and other Fahrenheit are immersed in a fluid, after the thermometers reached equilibrium with the fluid, it is noted that both the thermometers indicate the same numerical values. Find that the identical numerical values shown by the thermometers? What would be the corresponding temperature of the fluid, expressed in degrees Kelvin and degrees
4. A fluid is confined in a cylinder by a spring loaded frictionless piston, so the pressure in the fluid is a linear function of volume ( $p=a+bV$ ). The internal energy of the fluid is given by the following equation  $U=34+3.15pV$ . Where  $U$  is in kJ,  $p$  in kPa and  $V$  is in  $\text{m}^3$ . If the fluid changes from initial state of 170kPa,  $0.03\text{m}^3$  to a final state of 400kPa,  $0.06\text{m}^3$  with no work other than that done on the piston. Find the direction and magnitude of work and heat transfer.
5. A piston cylinder device operates 1kg of fluid at 20 atm pressure with initial volume is  $0.04\text{m}^3$ . Fluid is allowed to expand reversibly following  $pV^{1.45}=C$ . So that the volume becomes double. The fluid is cooled at constant pressure until the piston comes back. Determine the work done in each process?
6. A fluid contained in a horizontal cylinder with a frictionless leakproof piston is continuously agitated by a stirrer passing through the cylinder cover. The diameter of the cylinder is 50cm and the piston is held against the fluid due to atmospheric pressure equal to 100kPa. The stirrer turns 8000 revolutions with an average torque of 1.5Nm. If the piston slowly moves out towards by 60cm. Determine the network transfer to the system

A Piston and cylinder machine contains a fluid System which passes through a complete cycle of four processes. During a cycle the sum of all heat transfers is -170kJ. The system completes 100cycles/minute. Complete the following table showing the method for each item and

Process	Q(kJ/min)	W(kJ/min)	$\Delta E(\text{kJ/min})$
a-b	0	2170	----
b-c	21000	0	----



c-d	-2100	----	-36600
d-a	----	----	----

7. Air flows steadily at the rate of 0.5kg/sec through an air compressor, entering at 7m/sec velocity, 100kpa pressure and  $0.95\text{m}^3/\text{kg}$  volume and leaving at 5m/sec, 700kpa and  $0.19\text{m}^3/\text{kg}$ . The internal energy of air leaving is 90kJ/kg greater than that of air entering. Cooling water in the compressor jacket absorbs heat from the air at the rate of 58kw. Compute the rate of shaft work input to the air in KW.

## UNIT-II

1. A heat engine working on Carnot cycle converts  $1/5^{\text{th}}$  of the heat input into work. When the temperature of the sink is reduced by  $80^{\circ}\text{C}$ , the efficiency gets doubled. Make calculations for temperature of sink?
2. 1kg of ice at  $-5^{\circ}\text{C}$  expose to the atmosphere which, is at  $20^{\circ}\text{C}$ . The ice melts and comes into thermal equilibrium with the atmosphere. Determine the entropy increase of Universe.  $C_p$  for ice

is  $2.039 \text{ kJ/kg K}$ , and the enthalpy of fusion of ice is  $333.3 \text{ kJ/kg}$ .

3. A domestic food freezer maintains a temperature of  $-15^{\circ}\text{C}$ , the ambient air temperature is  $30^{\circ}\text{C}$ , if heat leaks into the freezer at the continuous rate of  $1.75 \text{ kJ/sec}$ . What is the least power necessary to pump this heat out continuous?
4. A heat engine is operating between two reservoirs  $1000 \text{ K}$  and  $300 \text{ K}$  is used to drive a heat pump which extracts heat from the reservoir at  $300 \text{ K}$  at a rate twice that at which the engine rejects the heat to it. If the efficiency of the engine is  $40\%$  of the maximum possible and COP of heat pump is  $50\%$  of the maximum possible, then determine the temperature of the reservoir to which the heat pump rejects heat. Also determine the rate of heat rejection from the heat pump, if the rate of heat supply to the heat engine is  $50 \text{ Kw}$
5. Three Carnot engine are arranged in series. The first engine takes  $4000 \text{ kJ}$  of heat from a source at  $2000 \text{ K}$  and delivers  $1800 \text{ kJ}$  of work. The second and third engines deliver  $1200 \text{ kJ}$  and  $500 \text{ kJ}$  of work respectively. Make calculations for the exhaust temperature of
7. A heat engine is supplied with  $2512 \text{ kJ/min}$  of heat at  $650^{\circ}\text{C}$ . Heat rejection takes place at  $100^{\circ}\text{C}$ . Specify which of the following heat rejection represent a reversible, irreversible or impossible result. i)  $867 \text{ kJ/min}$  ii)  $1015 \text{ kJ/min}$  iii)  $1494 \text{ kJ/min}$
8. Heat flows from a hot reservoir at  $800 \text{ K}$  to another reservoir at  $250 \text{ K}$ . If the entropy change of overall process is  $4.25 \text{ kJ/K}$ , make calculation for the heat flowing out of the high temperature reservoir?

### UNIT-III

1. The volume of a high altitude chamber is  $40 \text{ m}^3$ . It is put into operation by reducing pressure from  $1 \text{ bar}$  to  $0.4 \text{ bar}$  and temperature from  $25^{\circ}\text{C}$  to  $5^{\circ}\text{C}$ . How many kg of air must be removed from the chamber during the process? Express this mass as a volume measured at  $1 \text{ bar}$  and  $25^{\circ}\text{C}$
2. A fluid at  $200 \text{ kPa}$  and  $300^{\circ}\text{C}$  has a volume of  $0.8 \text{ m}^3$  in a frictionless process at constant volume, the

- Derive the changes in enthalpy during a process with variable specific heats. pressure changes to 100kPa. Find the final temperature and heat transfer, if the fluid is air
3. A fluid at  $250^{\circ}\text{C}$  and  $300\text{kPa}$  is compressed reversibly and isothermally to  $1/16^{\text{th}}$  of its original volume. Find the final pressure, work done and change of internal energy per kg of fluid, if the fluid is air?
4. A constant volume of  $0.3\text{m}^3$  capacity contains  $2\text{kg}$  of this gas at  $5^{\circ}\text{C}$ . Heat is transferred to the gas until the temperature is  $100^{\circ}\text{C}$ . Find the work done, the heat transfer and changes in internal energy, enthalpy and entropy
5. A reversible adiabatic process begins at  $p_1=10\text{bar}$ ,  $T_1=300^{\circ}\text{C}$  and ends with  $p_2=1\text{bar}$ . Find the specific volume and the work done per kg of fluid, if the fluid is air?

### UNIT-IV

1. The analysis by weight of a perfect gas mixture at  $20^{\circ}\text{C}$  and  $1.3\text{bar}$  is  $10\%\text{O}_2$ ,  $70\%\text{N}_2$ ,  $15\%\text{CO}_2$  and  $5\%\text{CO}$ . For a reference state of  $0^{\circ}\text{C}$  and  $1\text{bar}$ , determine partial pressure of the constituent and gas constant of mixture.

2. In an engine cylinder a gas has a volumetric analysis of 13% CO<sub>2</sub>, 12.5% O<sub>2</sub> and 74.5% N<sub>2</sub>. The temperature at the beginning of expansion is 950<sup>0</sup>C and gas mixture expands Reversibly through a volume ratio of 8:1. According to the law  $pV^{1.2} = \text{constant}$ . Calculate per kg of gas, the work done and the heat flow. Take  $C_p$  for CO<sub>2</sub> = 1.235 kJ/kg K and O<sub>2</sub> = 1.088 kJ/kg K and N<sub>2</sub> is 1.172 kJ/kg K
3. The following is the volumetric analysis of a producer gas:  
CO = 28%, H<sub>2</sub> = 13%, CH<sub>4</sub> = 4%, CO<sub>2</sub> = 4%, N<sub>2</sub> = 51%. The values of  $C_p$  for the constituent CO, H<sub>2</sub>, CH<sub>4</sub>, CO<sub>2</sub> and N<sub>2</sub> are 29.27 kJ/mol.K, 28.89 kJ/mol.K, 35.8 kJ/mol.K, 37.22 kJ/mol.K, 29.14 kJ/mol.K
4. A mixture of hydrogen and oxygen is to be made, so that the ratio of H<sub>2</sub> to O<sub>2</sub> is 2:1 by volume. If the pressure and temperature are 1 bar and 25<sup>0</sup>C, respectively. Calculate mass of oxygen required and volume of the container?
5. Air at 20<sup>0</sup>C, 40% RH is mixed adiabatically with air at 40<sup>0</sup>C, 40% RH in the ratio of 1 kg of the former with 2 kg of later ( on dry basis). Find the final condition of air?
6. Saturated air at 21<sup>0</sup>C is passed through a dryer, so that its final relative humidity is 20%. The dryer uses silica gel absorbent. The air is then pass through a cooler until its final temperature is 21<sup>0</sup>C without a change in specific humidity. Find out
- the temperature of air at the end of the drying process,
  - the relative humidity at the end of the cooling process,
  - The dew point temperature at the end of the drying process?

## UNIT-V

1. An engine working on Otto cycle has a volume of 0.45 m<sup>3</sup> pressure 1 bar and temperature 30<sup>0</sup>C at the beginning of the compression stroke. At the end of the compression stroke the pressure is

- 11bar.210kJ of heat is added at constant volume. Determine efficiency and mean effective pressure?
- An engine with 200mm cylinder diameter and 300mm stroke working on theoretical diesel cycle. The initial pressure and temperature of air used are 1bar and  $27^{\circ}\text{C}$ . The cut off is 8% of the stroke. Determine air standard efficiency, mean effective pressure and power of the engine if the working cycles per minute are 300? Assume the compression ratio is 15 and the working fluid is air
  - An inventor claims that a new heat cycle will develop 0.4kw for a heat addition of 32.5kJ/min. The temperature of heat source is 1990K and that of sink is 850K.
  - The stroke and cylinder diameter of Compression Ignition engine are 250 mm and 150mm respectively. If the clearance volume is  $0.0004\text{m}^3$  and fuel injection takes place at constant pressure for 5% of the stroke. Determine the efficiency of the engine. Assume the engine working on Diesel cycle?
  - An engine of 250mm bore and 375mm stroke works on Otto cycle. The clearance volume is  $0.00263\text{m}^3$ . The initial pressure and temperature are 1bar and  $5^{\circ}\text{C}$ . The maximum pressure is limited to 25bar. Find the air standard efficiency and the mean effective pressure of the cycle? Assume ideal conditions?
  - 28 tonnes of ice from and at  $0^{\circ}\text{C}$  is produced per day in an Ammonia refrigerator. The temperature range in the compressor is from  $25^{\circ}\text{C}$  to  $-15^{\circ}\text{C}$ . The vapour is dry and saturated at the end of the compression and expansion valve is used. Assuming the C.O.P of 62% of the theoretical. Calculate power required to drive the compressor?

## 16. Unit wise-Question bank

### UNIT-I

## **Two marks of questions with answers**

**Q1.** What is meant by thermodynamic system?

Thermodynamic system is defined as the any space or matter or group of matter where the energy transfer or energy conversions are studied OR thermodynamic system is defined as a quantity of matter or a region in space, on which the analysis of the problem is concentrated.

**Q2.** How do you classify thermodynamic system?

It may be classified into three types.

- i. Closed system (only energy transfer and no mass transfer)
- ii. Open system (Both energy and mass transfer)
- iii. Isolated system (No mass and energy transfer)

**Q3.** What is meant by Point function?

The quantity which is independent on the process or path followed by the system is known as point functions.

Example: Pressure, volume, temperature, etc.

**Q4.** What is meant by reversible process?

A process is said to be reversible, it should trace the same path in the reverse direction when the process is reversed. It is possible only when the system passes through a continuous series of equilibrium state.

**Q5.** What is Quasi Static process?

The process is said to be quasi static, it should proceed infinitesimally slow and follows continuous series of equilibrium states. A quasi- static process is that a succession of equilibrium states. A quasi-static process is also called as reversible process

## **Three marks of questions with answers**

**Q1. Write about matter in Thermodynamics**

Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes, that is, a continuum.

The continuum idealization allows us to treat properties as point functions and to assume the properties vary continually in space with no jump discontinuities.

This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules.

**Q2. What is meant by Macroscopic & Microscopic approach in thermodynamics?**

**Ans:** Macroscopic thermodynamics deals with the effects of the action of many molecules concerned

Microscopic approach in thermodynamics deals with the study of the behavior of the system by summing up the behavior of each molecule

**Q3. What are the three types of Thermodynamic System?**

**Closed System:** When a system has only heat and work transfer, but there is no mass transfer, it is called as closed system.

Example: Piston and cylinder arrangement.

Compression of a gas in a piston-cylinder arrangement.

**Open System:** When a system has both mass and energy transfer it is called as open system.

Example: Air Compressor.

**Isolated system** is not affected by surroundings. There is no heat; work and mass transfer take place. In this system total energy remains constant.

Example: Entire Universe

**Q4. Give few applications of thermodynamic laws and principles:**

The laws and principles are applied in the  
Steam and nuclear power plants

IC Engines

Gas turbines

Refrigeration

**Q5.** What is Quasi-equilibrium process?

Quasi- Equilibrium Process can be viewed as a sufficiently slow process that allows the system to adjust itself internally and remains infinitesimally close to an equilibrium state at all times. Quasi-equilibrium process is an idealized process and is not a true representation of the actual process. We model actual processes with Quasi- equilibrium ones. Moreover, they serve as standards to which actual processes can be compared. Process diagrams are used to visualize processes. Note that the process path indicates a series of equilibrium states, and we are not able to specify the states for a non-quasi equilibrium process.

## Five marks of questions with answers

### Q1. Explain First Law Thermodynamics

The First Law of Thermodynamics is

$$\Delta U = Q + W$$

That is, during a change of state of a system, the change in the system's internal energy is equal to the sum of the heat added to the system and the work done on the system by its surroundings.

Defining  $U$  in terms of the first law is: from  $\Delta U = Q + W$  we can express  $U$  in terms of measurable quantities,  $Q$  and  $W$ . This only gives a definition for  $U$ , you might say. But by assigning some value to  $U$  in a particular reference state, we can use equation to define  $U$  in any other state.

Another problem arises:  $U$  is the sum of two path-dependent quantities. How is our definition of  $U$  meaningful? It is meaningful because we find that in all cases,  $\Delta U$  is independent of path.

That is, the change in internal energy of a system during any thermodynamic process depends only on initial and final states, not on the path leading from one to another.

The First Law in differential form is

$$dU = dQ + dW \quad (4)$$

The bar reminds us that  $dQ$  and  $dU$  are path-independent and hence are inexact differentials.

We think of  $dQ$  as a quantity of energy being transferred by other means than by work. This negative formulation is a way of defining heat.

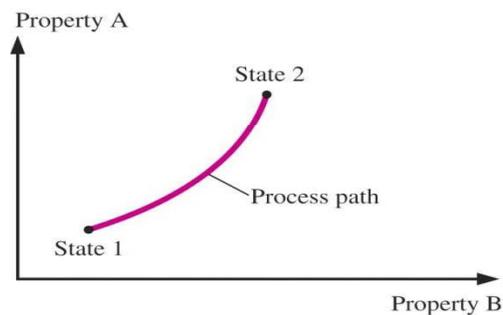
Just as we had a sign convention for work, so too do we have one for heat:

$dQ$  is positive for heat entering (flowing into) the system.

$dQ$  is negative for heat leaving (flowing out of) the system.

## Q2. What is state in Thermodynamics?

### Representation of State



### Property

➤ In thermodynamics a property is any characteristic of a system that is associated with the energy and can be quantitatively evaluated.

The property of a system should have a definite value when the system is in a particular state.

- Thermodynamic property is a point function.
- Properties like volume of a system that depend on the mass of a system are called extensive properties.
- Properties like pressure or temperature which do not depend on the system mass are called intensive properties.
- The ratio of extensive property to the mass of the system are called specific properties and therefore become intensive properties.
- Substance can be found in three states of physical aggregation namely, solid, liquid and vapor which are called its phases.

If the system consists of mixture of different phases, the phases are separated from each other by phase boundary.

The thermodynamic properties change abruptly at the phase boundary, even though the intensive properties like temperature and pressure are identical..

## Q3. Briefly explain the Process in Thermodynamics

A process is path followed by a system in reaching a given final state of equilibrium state starting from a specified initial state.

An actual process occurs only when the equilibrium state does not exist.

An ideal process can be defined in which the deviation from thermodynamic equilibrium is infinitesimal.

All the states the system passes through during a quasi-equilibrium process may be considered equilibrium states.

For non-equilibrium processes, we are limited to a description of the system before the process occurs and after the equilibrium is restored.

Several processes are described by the fact that one property remains constant.

The prefix iso- is used to describe such processes.

A process is said to be reversible if both the system and its surroundings can be restored to their respective initial states by reversing the direction of the process.

- **Reversible:** if the process happens slow enough to be reversed.
- **Irreversible:** if the process cannot be reversed (like most processes).
- **isobaric:** process done at constant pressure
- **isochoric:** process done at constant volume
- **isothermal:** process done at constant temperature
- **adiabatic:** process where  $q=0$

**Q4. Problem :** To make some ice, a freezer extracts 185 kJ of heat at  $-12.0^{\circ}\text{C}$ . The freezer has a coefficient of performance of 5.70. The room temperature is  $26.0^{\circ}\text{C}$ , (a) How much heat is delivered to the room? (b) How much work is required to run the freezer?

**Concept:-**

A freezer would like to extract as much heat  $Q_L$  as possible from the low-temperature reservoir (“what you want”) for the least amount of work  $W$  (“what you pay for”). So the efficiency of a freezer is defined as,

$$K = \frac{\text{(what you want)}}{\text{(what you pay for)}} \\ = Q_L/W$$

and this is called coefficient of performance. The larger the value of  $K$ , the more efficient is the refrigerator.

Thus,  $W = Q_L/K$

The first law of thermodynamics, applied to the working substance of the freezer, gives

$$W = Q_H - Q_L$$

Here  $Q_H$  is the exhausted heat.

Thus exhausted heat will be,

$$Q_H = W + Q_L$$

**Solution:-**

(a) To obtain the heat that is delivered to the room, first we have to find out the required work  $W$  to run the freezer.

To obtain the required work  $W$  to run the freezer, substitute 185 kJ for extracted heat  $Q_L$  and 5.70 for the coefficient of performance  $K$  in the equation  $W = Q_L/K$ ,

$$\begin{aligned} W &= Q_L/K \\ &= 185 \text{ kJ}/5.70 \\ &= 32.5 \text{ kJ} \end{aligned}$$

To obtain the heat that is delivered to the room, substitute 32.5 kJ for work  $W$  which is required to run the freezer and 185 kJ for extracted heat  $Q_L$  and in the equation  $Q_H = W + Q_L$ ,

$$\begin{aligned} Q_H &= W + Q_L \\ &= 32.5 \text{ kJ} + 185 \text{ kJ} \\ &= 217.5 \text{ kJ} \end{aligned}$$

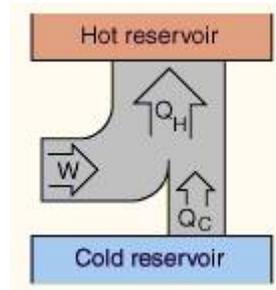
Rounding off to three significant figures, the heat delivered to the room would be 218 kJ.

(b) To obtain the required work  $W$  to run the freezer, substitute 185 kJ for extracted heat  $Q_L$  and 5.70 for the coefficient of performance  $K$  in the equation  $W = Q_L/K$ ,

$$\begin{aligned} W &= Q_L/K \\ &= 185 \text{ kJ}/5.70 \\ &= 32.5 \text{ kJ} \end{aligned}$$

Therefore the required work  $W$  to run the freezer would be 32.5 kJ.

**Q5 Problem :** How much work must be done to extract 10.0 J of heat (a) from a reservoir at  $7^\circ\text{C}$  and transfer it to one at  $27^\circ\text{C}$  by means of a refrigerator using a Carnot cycle; (b) from one at  $-73^\circ\text{C}$  to one at  $27^\circ\text{C}$ ; (c) from one at  $-173^\circ\text{C}$  to one at  $27^\circ\text{C}$ ; and (d) from one at  $-223^\circ\text{C}$  to one at  $27^\circ\text{C}$ ?



**Concept:-**

Coefficient of performance  $K$  of a Carnot refrigerator is defined as,

$$K = T_L / T_H - T_L \quad \dots\dots (1)$$

Here  $T_L$  is the lower temperature of sink and  $T_H$  is the higher temperature of source.

A refrigerator would like to extract as much heat  $Q_L$  as possible from the low-temperature reservoir (“what you want”) for the least amount of work  $W$  (“what you pay for”). So the efficiency of a refrigerator is defined as,

$$K = (\text{what you want})/(\text{what you pay for})$$

$$= Q_L/W$$

and this is called coefficient of performance. The larger the value of  $K$ , the more efficient is the refrigerator.

$$\text{Thus, } W = Q_L/K \quad \dots\dots (2)$$

Substitute the value of  $K$  from equation (1) in the equation  $W = Q_L/K$ ,

$$W = Q_L/K$$

$$= Q_L / (T_L / T_H - T_L)$$

$$= Q_L (T_H / T_L - 1)$$

**Solution:-**

(a) To obtain work  $W$ , substitute 10.0 J for  $Q_L$ , 27° C for  $T_H$  and 7° C for  $T_L$  in the equation  $W = Q_L (T_H / T_L - 1)$ ,

$$W = Q_L (T_H / T_L - 1)$$

$$= 10.0 \text{ J } (27^\circ \text{ C} / 7^\circ \text{ C} - 1)$$

$$= 10.0 \text{ J } ((27+273) \text{ K} / (7+273) \text{ K} - 1)$$

Therefore the work done would be 0.714 J.

(b) To obtain work  $W$ , substitute 10.0 J for  $Q_L$ , 27° C for  $T_H$  and -73° C for  $T_L$  in the equation  $W = Q_L (T_H / T_L - 1)$ ,

$$W = Q_L (T_H / T_L - 1)$$

$$= 10.0 \text{ J } (27^\circ \text{ C} / (-73^\circ \text{ C}) - 1)$$

$$= 10.0 \text{ J } ((27+273) \text{ K } /(-73+273) \text{ K } -1)$$

$$= 10.0 \text{ J } (300 \text{ K}/200 \text{ K} - 1)$$

$$= 5.00 \text{ J}$$

Therefore the work done would be 5.00 J.

(c) To obtain work  $W$ , substitute 10.0 J for  $Q_L$ ,  $27^\circ \text{ C}$  for  $T_H$  and  $-173^\circ \text{ C}$  for  $T_L$  in the equation  $W = Q_L (T_H/ T_L - 1)$ ,

$$W = Q_L (T_H/ T_L - 1)$$

$$= 10.0 \text{ J } (27^\circ \text{ C}/ (-173^\circ \text{ C}) -1)$$

$$= 10.0 \text{ J } ((27+273) \text{ K } /(-173+273) \text{ K } -1)$$

$$= 10.0 \text{ J } (300 \text{ K}/100 \text{ K} - 1)$$

$$= 20.0 \text{ J}$$

Therefore the work done would be 20.0 J.

d) To obtain work  $W$ , substitute 10.0 J for  $Q_L$ ,  $27^\circ \text{ C}$  for  $T_H$  and  $-223^\circ \text{ C}$  for  $T_L$  in the equation  $W = Q_L (T_H/ T_L - 1)$ ,

$$W = Q_L (T_H/ T_L - 1)$$

$$= 10.0 \text{ J } (27^\circ \text{ C}/ (-223^\circ \text{ C}) -1)$$

$$= 10.0 \text{ J } ((27+273) \text{ K } /(-223+273) \text{ K } -1)$$

$$= 10.0 \text{ J } (300 \text{ K}/50 \text{ K} - 1)$$

$$= 50.0 \text{ J}$$

Therefore the work done would be 50.0 J.

### Multiple choice questions with answers

- Q1. When a body A is in thermal equilibrium with a body B, and also separately with a body C, then B and C will be in thermal equilibrium with each other.  
a) True                                      b) Fals
- Q2. Which of the following were used as fixed points before 1954?  
a) The ice point    b) The steam point    c) All of the mentioned    d) None of the mentioned
- Q3. All gases and vapours approach ideal gas behaviour at?  
a) High pressure and high density                      b) Low pressure and low density  
c) High pressure and low density                      d) Low pressure and high density
- Q4. Work done on a system is taken to be  
a) positive    b) negative    c) zero    d) varies according to situation
- Q5. The differentials of point functions are  
a) perfect differentials                      b) exact differentials  
c) all of the mentioned                      d) none of the mentioned
- Q6. Energy has different forms which include  
a) heat                      b) work                      c) all of the mentioned                      d) none of the mentioned
- Q7. By first law of thermodynamics,  
a)  $Q=\Delta E-W$     b)  $Q=\Delta E+W$     c)  $Q=-\Delta E-W$     d)  $Q=-\Delta E+W$

- Q8. Which of the following types of energy can be present in molecules?  
a) translational and rotational kinetic energy    b) electronic energy and vibrational energy  
c) chemical energy and nuclear energy    d) all of the mentioned
- Q9. Which of the following is true in regard to the energy of an isolated system?  
a)  $dQ \neq 0$     b)  $dW \neq 0$     c)  $E = \text{constant}$     d) all of the mentioned
- Q10. The specific energy,  $e = E/m$  is an extensive property.  
a) true    b) false

**Answer (1) a, (2) c, (3) b, (4) b, (5) c, (6) c, (7) b, (8) d, (9) c, (10) b**

### **Fill in the blanks questions with answers**

- Q1. The temperature interval from the oxygen point to the gold point is divided into \_\_\_\_\_ parts?
- Q2. Celsius temperature of the triple point of water is \_\_\_\_\_
- Q3. For a constant volume process, work done is \_\_\_\_\_
- Q4. The power available at crankshaft is always \_\_\_\_\_ indicated power.
- Q5. Heat flow into a system is taken to be \_\_\_\_\_, and heat flow out of the system is taken as \_\_\_\_\_
- Q6. In the equation  $dV = (1/p)dW$ ,  $(1/p)$  is known as \_\_\_\_\_
- Q7. The value of constant of proportionality,  $J$ , has the value \_\_\_\_\_
- Q8. The specific energy,  $e = E/m$  is an \_\_\_\_\_ property
- Q9. \_\_\_\_\_ is chosen as the standard thermometric substance?
- Q10. The value of ratio of the steam point temperature to the ice point temperature is \_\_\_\_\_.

**Answers**

(1)3, (2) 0.01(3) zero (4) less, (5) Positive, Negative. (6) Integration factor, (7) 1 (8) Intensive  
(9) Gas (10) 1.366

## **UNIT-II**

### **Two marks of questions with answers**

**Q1.** State second law of thermodynamics.

Second law of thermodynamics state that:

The entropy of the system is constantly increasing for every spontaneous process.

Heat energy cannot be transferred from colder to hotter bodies.

It is impossible to convert all of its energy into work without losing heat.

**Q2.** What are the limitations of Carnot cycle?

i.No friction is considered for moving parts of the engine.

ii. There should not be any heat loss.

**Q3.** Define available energy and unavailable energy.

Available energy is the maximum thermal useful work under ideal condition.

The remaining part, which cannot be converted into work, is known as unavailable energy

**Q4.** State Helmholtz function.

Helmholtz function is the property of a system and is given by subtracting the product of absolute temperature (T) and entropy (S) from the internal energy (U).

Helmholtz function =  $U - TS$

**Q5.** What are thermodynamic properties?

Thermodynamic properties are  
pressure (p), temperature (T), volume (V),  
internal Energy (U), enthalpy(H), entropy (S),  
Helmholtz function (H) and Gibbs function (G)

### **Three marks of questions with answers**

**Q 1.** Define third law of thermodynamics. Discuss the importance of third law of thermodynamics.

The third law of thermodynamics states that:

“The entropy of all the perfect crystalline solids is zero at absolute zero temperature”. The third law of thermodynamics is also referred to as Nernst law. It provides the basis for the calculation of absolute entropies of the substances.

Mathematically,

$$\lim_{T \rightarrow 0} S = 0$$

If the entropy is zero at temperature  $T = 0$ , then this law states that the absolute entropy  $S_{ab}$  of a substance at temperature T and pressure P is expressed by the following expression:

$$S_{ab}(T) = \int_0^T (\delta Q)_{rev} / T$$

**Q2. What are the limitations of first law of thermodynamics?**

- First law does not provide a clear idea about the direction of absorption or evolution of heat.
- The information provided by the first law of thermodynamics are not enough to predict the spontaneity or feasibility of a process.
- To deal with spontaneity of chemical processes some new terms viz., entropy (S) and Gibbs free energy (G) were introduced in thermodynamics which lead way to the formulation of second and third laws of thermodynamics.

**Q3. Write brief about Second law of Thermodynamics**

The second law of thermodynamics states that the total entropy of an isolated system can only increase over time. It can remain constant in ideal cases where the system is in a steady state (equilibrium) or undergoing a reversible process. The increase in entropy accounts for the irreversibility of natural processes, and the asymmetry between future and past.

Historically, the second law was an empirical finding that was accepted as an axiom of thermodynamic theory. Statistical thermodynamics, classical or quantum, explains the microscopic origin of the law.

The second law has been expressed in many ways. Its first formulation is credited to the French scientist Sadi Carnot in 1824, who showed that there is an upper limit to the efficiency of conversion of heat to work in a heat engine.

**Q4. Define Entropy with example?**

**Entropy:** The degree of disorderliness or randomness is called entropy of a system. More the randomness, more will be the entropy of a system. The terms heat (q) and temperature plays a main role in arriving at the entropy of a system.

- Entropy is independent of the path followed by a reaction and hence it is state function.

- In a perfect crystalline state where the entities are orderly arranged the entropy is found to be zero. Example : Conversion liquid water to ice.

**Q5.** Define an isentropic process, throttling process & free expansion process.

Isentropic process is also called as reversible adiabatic process. It is a process which follows the law of  $pV^\gamma = C$  is known as isentropic process. During this process entropy remains constant and no heat enters or leaves the gas.

Throttling process: When a gas or vapor expands and flows through an aperture of small size, the process is called as throttling process.

free expansion process: When a gas expands suddenly into a vacuum through a large orifice is known as free expansion process.

### **Five marks of questions with answers**

**Q1.** Explain about Flow & Non flow process

(a) Availability Function for Non-Flow process:-

Let  $P_0$  be the ambient pressure,  $V_1$  and  $V_0$  be the initial and final volumes of the system respectively.

If in a process, the system comes into equilibrium with the surroundings, the work done in pushing back the ambient atmosphere is  $P_0(V_0 - V_1)$ .

$$\text{Availability} = W_{\text{useful}} = W_{\text{max}} - P_0(V_0 - V_1)$$

Consider a system which interacts with the ambient at  $T_0$ . Then,

$$W_{\text{max}} = (U_1 - U_0) - T_0(S_1 - S_0)$$

$$\text{Availability} = W_{\text{useful}} = W_{\text{max}} - P_0(V_0 - V_1)$$

$$= (U_1 - T_0 S_1) - (U_0 - T_0 S_0) - P_0(V_0 - V_1)$$

$$= (U_1 + P_0 V_1 - T_0 S_1) - (U_0 + P_0 V_0 - T_0 S_0)$$

$$= \phi_1 - \phi_0$$

where  $\phi = U + P_0 V - T_0 S$  is called the availability function for the non-flow process. Thus, the availability:  $\phi_1 - \phi_0$

If a system undergoes a change of state from the initial state 1 (where the availability is  $(\phi_1 - \phi_0)$ ) to the final state 2 (where the availability is  $(\phi_2 - \phi_0)$ ), the change in the availability or the change in maximum useful work associated with the process, is  $\phi_1 - \phi_2$ .

(b) Availability Function for Flow process:-

The maximum power that can be obtained in a steady flow process while the control volume exchanges energy as heat with the ambient at  $T_0$ , is given by:

$$W_{sh(\text{max})} = (H_1 - H_0) - T_0(S_1 - S_0)$$

$$W_{sh(\text{max})} = (H_1 - T_0 S_1) - (H_0 - T_0 S_0)$$

**Q2.** Brief about PMM-I of first kind and second kind

Perpetual Motion Machine (PMM) of the First Kind (PMM1) would be one to violate the 1st Law of Thermodynamics, to permanently produce useful energy (work) without any energy source, or to produce more 'energy' than consumed and Perpetual Motion Machine of the Second Kind (PMM2) would be one to violate the 2nd Law of Thermodynamics, to permanently produce useful energy (work) from a single reservoir in equilibrium only,.

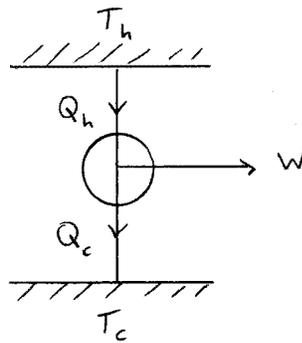
The name, "perpetual motion (PM)" is somewhat misleading, since everything in *Nature* is in perpetual motion, but PM machine (PMM) means a machine (engine) producing a useful energy (work), i.e., moving under load (extracting work, load important). A friction-

less pendulum or wheel will permanently move but without extracting (producing) work, thus NOT violating any Law and not being PMM.

of course, neither PMM1 nor PMM2 are possible (will violate conservational- and forced-transformational existence, respectively) , although we may be misled to believe so due to lack of our proper and full observation and/or comprehension of coupled energy transfers and conversions from the surroundings and/or within interacting system(s).

**Q3. Explain Heat Engines & Heat Pumps**

A heat engine is a device that absorbs heat from a reservoir and converts part of it to work. The engine carries a working substance through a PVT cycle, returning to the state at which it starts. It expels “waste” heat into a cold reservoir, or into its environment. It must do this in order that the entropy of the engine itself does not increase with every cycle.



a. Efficiency

The efficiency of the heat engine is defined as the ratio of work done by the engine to the heat absorbed by the engine.

$$e \equiv \frac{W}{Q_h}$$

We’d like to express  $e$  in terms of the temperatures of the hot and cold reservoirs. The First “Law” says that  $Q_h = Q_c + W$ . The Second “Law” says that  $\frac{Q_c}{T_c} \geq \frac{Q_h}{T_h}$ . Putting these together, we

obtain  $e \leq 1 - \frac{T_c}{T_h}$ . Firstly, notice that  $e$  cannot be greater than one. Secondly,  $e$  cannot be one

unless  $T_c = 0$  K, which cannot be achieved. Thirdly,  $1 - \frac{T_c}{T_h}$  is the greatest  $e$  can be—in practice,  $e$

is less than the theoretical limit, since always  $\frac{Q_c}{T_c} > \frac{Q_h}{T_h}$

**Q4. Problem-** Water standing in the open at 32°C evaporates because of the escape of some of the surface molecules. The heat of vaporization is approximately equal to  $\epsilon n$ , where  $\epsilon$  is the average

energy of the escaping molecules and  $n$  is the number of molecules per kilogram. (a) Find  $\epsilon$ . (b) What is the ratio of  $\epsilon$  to the average kinetic energy of  $\text{H}_2\text{O}$  molecules, assuming that the kinetic energy is related to temperature in the same way as it is for gases?

**Concept:-**

Number of molecules  $n$  is equal to the Avogadro's number  $N_A$  divided by molecular weight  $M$ .

$$E_{\text{av}} = 3/2 kT$$

Here  $k$  is the Boltzmann constant and  $T$  is the temperature.

**Solution:-**

(a) As heat of vaporization  $L_v$  is approximately equal to  $\epsilon n$ , where  $\epsilon$  is the average energy of the escaping molecules and  $n$  is the number of molecules per kilogram, so,

$$L_v = \epsilon n$$

Or,

$$\begin{aligned} \epsilon &= L_v/n \\ &= L_v/(N_A/M) \\ &= L_v M / N_A \end{aligned}$$

To obtain the average energy  $\epsilon$ , substitute  $2256 \times 10^3 \text{ J/kg}$  for latent heat of vaporization of water molecule ( $\text{H}_2\text{O}$ )  $L_v$ ,  $0.018 \text{ kg/mol}$  for  $M$  and  $6.03 \times 10^{23}/\text{mol}$  for  $N_A$  in the equation  $\epsilon = L_v M / N_A$ , we get,

$$\begin{aligned} \epsilon &= L_v M / N_A \\ &= (2256 \times 10^3 \text{ J/kg})(0.018 \text{ kg/mol}) / (6.03 \times 10^{23}) \\ &= 6.75 \times 10^{-20} \text{ J} \end{aligned}$$

From the above observation we conclude that, the value of average energy  $\epsilon$  would be  $6.75 \times 10^{-20} \text{ J}$ .

(b) As,  $E_{\text{av}} = 3/2 kT$ , therefore the ratio of  $\epsilon$  to the average kinetic energy  $E_{\text{av}}$  of  $\text{H}_2\text{O}$  molecule will be,

$$\begin{aligned} \epsilon / E_{\text{av}} &= \epsilon / (3/2 kT) \\ &= 2 \epsilon / 3 kT \end{aligned}$$

To obtain the ratio of  $\epsilon$  to the average kinetic energy  $E_{\text{av}}$  of  $\text{H}_2\text{O}$  molecule, substitute  $6.75 \times 10^{-20} \text{ J}$  for  $\epsilon$ ,  $1.38 \times 10^{-23} \text{ J/K}$  for  $k$  and  $32^\circ \text{ C}$  for  $T$  in the equation  $\epsilon / E_{\text{av}} = 2 \epsilon / 3 kT$ , we get,

$$\begin{aligned} \epsilon / E_{\text{av}} &= 2 \epsilon / 3 kT \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(32^\circ \text{ C}) \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(32+273) \text{ K} \\ &= 2(6.75 \times 10^{-20} \text{ J}) / 3(1.38 \times 10^{-23} \text{ J/K})(305 \text{ K}) \\ &= 10.7 \end{aligned}$$

**Q5. Problem :** calculate the rate at which body heat flows out through the clothing of a skier, given the following data: the body surface area is  $1.8 \text{ m}^2$  and the clothing is  $1.2 \text{ cm}$  thick; skin surface temperature is  $33^\circ\text{C}$ , whereas the outer surface of the clothing is at  $1.0^\circ\text{C}$ ; the thermal conductivity of the clothing is  $0.040 \text{ W/m.K}$ . (b) How would the answer change if, after a fall, the skier's clothes become soaked with water? Assume that the thermal conductivity of water is  $0.60 \text{ W/m.K}$ .

**Concept:-**

The rate  $H$  at which heat flows out through the clothing of a skier,

- (a) directly proportional to the surface area ( $A$ ) of the body.
- (b) inversely proportional to the thickness of the clothing  $\Delta x$ .
- (c) directly proportional to the temperature difference  $\Delta T$ .

So,  $H = kA \Delta T / \Delta x$

Where  $k$  is the proportionality constant and is called thermal conductivity of the material.

**Solution:-**

(a) Surface area of the body,

$$A = 1.8 \text{ m}^2$$

Temperature difference,

$$\begin{aligned} \Delta T &= (\text{skin surface temperature}) - (\text{outer surface temperature of clothing}) \\ &= 33^\circ \text{C} - 1^\circ \text{C} = (32+273) \text{ K} = 305 \text{ K} \end{aligned}$$

Thickness,

$$\Delta x = 1.2 \text{ cm} = (1.2 \text{ cm}) (1 \text{ m}/100 \text{ cm}) = 0.012 \text{ m}$$

To find out the rate  $H$  at which heat flows out through the clothing of a skier, substitute  $1.8 \text{ m}^2$  for the area  $A$ ,  $305 \text{ K}$  for temperature difference  $\Delta T$  and  $0.012 \text{ m}$  for thickness  $\Delta x$  and  $0.040 \text{ W/m. K}$  for the thermal conductivity  $k$  in the equation  $H = kA \Delta T / \Delta x$ ,

$$\begin{aligned} H &= kA \Delta T / \Delta x \\ &= (0.040 \text{ W/m. K}) (1.8 \text{ m}^2) (305 \text{ K}) / (0.012 \text{ m}) = 1830 \text{ W} \end{aligned}$$

From the above observation we conclude that, the rate  $H$  at which heat flows out through the clothing of a skier would be  $1830 \text{ W}$ .

(b) From the equation  $H = kA \Delta T / \Delta x$ , we observed that rate  $H$  at which heat flows out through the clothing of a skier is directly proportional to the thermal conductivity  $k$  of clothing.

Now the thermal conductivity of water is changed to  $0.60 \text{ W/m. K}$ .

Thus thermal conductivity  $k$  is increased by a factor of,

$$= (0.60 \text{ W/m. K}) / (0.04 \text{ W/m. K}) = 15$$

Since that rate  $H$  at which heat flows out through the clothing of a skier is directly proportional to the thermal conductivity  $k$  of clothing, therefore the rate  $H$  would increase by a factor of 15.

### Objective type questions with answers

Q1. The limitation of the first law is

- a) does not indicate the possibility of a spontaneous process proceeding in a definite direction
- b) it assigns a quality to different forms of energy
- c) indicates the direction of any spontaneous process
- d) none of the mentioned

Q2. Which of the following can be a cause of irreversibility?

- a) friction, viscosity
- b) inelasticity
- c) electrical resistance, magnetic hysteresis
- d) all of the mentioned

Q3. The continual motion of a movable device in the complete absence of friction is known as

- a) PMM2
- b) PMM3
- c) PMM1
- d) PMM0

Q4. Which of the following is irreversible?

- a) stirring work
- b) friction work in moving devices
- c) current flowing through a wire
- d) all of the mentioned

Q5. Availability is a composite property.

- a) true
- b) false

Q6. The Helmholtz function  $F$  is given by

- a)  $U-TS$
- b)  $U+TS$
- c)  $-U-TS$
- d)  $-U+TS$

Q7. Gibbs function  $G$  is given by

- a)  $G=H-TS$
- b)  $G=U+pV-TS$
- c) both of the mentioned
- d) none of the mentioned

Q9. Which of the following is true?

- a) heat always from a high temperature body to a low temperature body
- b) heat always from a low temperature body to a high temperature body
- c) heat can flow from both low to high and high to low temperature body
- d) none of the mentioned

Q10. If the second law were not true

- a) a ship could be driven by extracting heat from the ocean
- b) run a power plant by extracting heat from the air
- c) both of the mentioned
- d) none of the mentioned

**KEYS**

(1) a, (2) d, (3) b, (4) d, (5) a, (6) a, (7) c, (8) d, (9) a, (10) c

### Fill in the blanks with answers

- Q1. Irreversibility can be distinguished in \_\_\_\_ types
- Q2. The availability (A) of a given system is defined as the \_\_\_\_ work that is obtainable in a process in which system comes to equilibrium with its surroundings.
- Q3. According to Kelvin-Planck statement, it is \_\_\_\_ for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at \_\_\_\_
- Q4. A heat engine has to exchange heat with \_\_\_\_ energy reservoir at \_\_\_\_ different temperatures to produce net work in a complete cycle.
- Q5. The function of a heat engine cycle is to \_\_\_\_ continuously at the expense of \_\_\_\_ to the system.
- Q6. A TER which transfers heat to system is called \_\_\_\_ and one which receives heat is called \_\_\_\_
- Q7. For proper utilization of exergy, it is desirable to make first law efficiency \_\_\_\_ and the source and use temperatures should \_\_\_\_
- Q8. Energy is \_\_\_\_ conserved and exergy is \_\_\_\_ conserved.
- Q9. When the closed system is allowed to undergo a spontaneous change from a given state to a dead state, its exergy is \_\_\_\_ destroyed \_\_\_\_ producing useful work.
- Q10. The exergy of an isolated system can \_\_\_\_

**KEYS :** (1) 2, (2) maximum useful work (3) impossible, single fixed temperature (4) two, two, (5) produce work, heat input (6) source, sink (7) as close to unity, match (8) always, not generally (9) completely, without (10) never increase

## UNIT-III

### Two marks of questions with answers

**Q1.** Define entropy of a pure substance.

Entropy is an important thermodynamic property, which increases with addition of heat and decreases with its removal. Entropy is a function of temperature only. It is an unavailability of energy during energy transfer

**Q2.** What do you understand by pure substance?

A pure substance is defined as one that is homogeneous and invariable in chemical composition throughout its mass.

**Q3.** Explain the term super heated steam and super heating.

The dry steam is further heated its temperature raises, this process is called as superheating and the steam obtained is known as superheated steam.

**Q4.** State Boyle's law & State Charle's law

Boyle's law: It states that volume of a given mass of a perfect gas varies inversely as the absolute pressure when temperature is constant.

. Charle's law: It states that if any gas is heated at constant pressure, its volume changes directly as its absolute temperature.

**Q5.** How do you determine the state of steam?

If  $V > V_g$  then super heated steam,

$V = V_g$  then dry steam and

$V < V_g$  then wet steam.

If  $S > S_g$  then super heated steam,  $S = S_g$  then dry steam and  $S < S_g$  then wet steam.

### **Three marks of questions with answers**

**Q1.** Define Specific heat capacity at constant pressure & at constant volume.

Specific heat capacity at constant pressure: It is defined as the amount of heat energy required to raise or lower the temperature of unit mass of the substance through one degree when the pressure kept constant. It is denoted by  $C_p$

Specific heat capacity at constant volume: It is defined as the amount of heat energy required to raise or lower the temperature of unit mass of the substance through one degree when volume kept constant. It is denoted by  $C_v$

**Q2.** Explain the terms, Degree of super heat, degree of sub-cooling.

Degree of super heat: The difference between the temperature of the superheated vapor and the saturation temperature at the same pressure.

Degree of sub-cooling: The temperature between the saturation temperature and the temperature in the sub cooled region of liquid.

**Q3. What is Clapeyron Equation?**

To find out the dependence of pressure on equilibrium temperature when two phases coexist..Along a phase transition line, the pressure and temperature are not independent of each other, since the system is un variant, that is, only one intensive parameter can be varied independently.

Representing in terms of Gibbs free energy, the criterion of equilibrium is:

$$d\hat{g} = 0 \text{ at constant } T \text{ and } P \text{ or,}$$

$$d\hat{g} = -\hat{s}dT + \hat{v}dP = 0$$

**Q4. What is Equation of state?**

An equation of state is an equation which relates the variables of state (T, P, V, and n). It's particularly useful when you want to know the effect of a change in one of the variables of state

Solids and Liquids: If the pressure on a solid or liquid is increased, the volume does not change much. If the temperature is increased, the volume doesn't change much either. Therefore, an appropriate equation of state describing such systems would be:  $V(T,P) = \text{constant}$ .

Gases: In contrast, changing the pressure or temperature of a gas will have an easily observable effect on the volume of that gas. For an ideal gas (no intermolecular interactions and no molecular volume) n appropriate equation of state would be:  $V(T,P,n) = (nRT)/P$ .

**Q5. Define enthalpy of steam & Evaporation**

Enthalpy of steam: It is the sum of heat added to water from freezing point to saturation temperature and the heat absorbed during evaporation.

Enthalpy of evaporation: The amount of heat added during heating of water up to dry steam from boiling point is known as Latent heat of evaporation or enthalpy of evaporation.

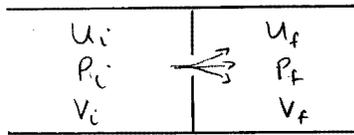
.

### Five marks of questions with answers

**Q1.** Explain throttling and free expansion processes

Throttling:

The working fluid passes through a narrow opening from a region of high pressure into a region of low pressure. In doing so, it expands adiabatically ( $Q = 0$ ) and cools. As the fluid expands, the negative potential energy of interaction among the atoms/molecules increases and the kinetic energy decreases.



From the First “Law”

$$\Delta U = U_f - U_i = Q + W = 0 + W_{left} + W_{right}$$

$$U_f - U_i = P_i V_i - P_f V_f$$

$$U_f + P_f V_f = U_i + P_i V_i$$

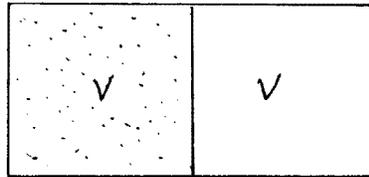
In a dense gas or a liquid,  $U_{potential} + U_{kinetic} + PV = \text{constant}$ . Therefore, as the gas expands,

$\Delta U_{potential} > 0$  so that  $\Delta U_{kinetic} < 0 \rightarrow$  the gas/liquid cools.

Subsequently, the chilled fluid absorbs heat from the cold reservoir and vaporizes. Therefore, the working fluid must be a substance with a low boiling point. The compressor does the work of compressing the gas to raise its temperature, as well as maintains the pressure difference required for the throttle valve to work.

### Free expansion

Imagine a container of volume  $2V$ , isolated from its surroundings, and with a partition that divides the container in half. An ideal gas is confined to one side of the container. The gas is in equilibrium, with temperature  $T$  and Pressure  $P$ . Now, imagine removing the partition. Over time, the gas molecules will diffuse to fill the larger volume.



However, in expanding the gas does no work, hence the phrase *free expansion*. Because the container is isolated, no heat flows into or out of the gas, nor does the number of molecules,  $N$ , change..

$$\Delta U = Q + W = 0 + 0 = 0$$

### Q2. Write the expression of work?

Whenever a system interacts with its surroundings, it can exchange energy in two ways- work and heat.

In mechanics, work is defined as the product of the force and the displacement in the direction of the force.

Work done when a spring is compressed or extended: According to Hooke's law Spring force =  $-k(x - x_0)$

Where  $k$  is the spring constant,  $x_0$  is the equilibrium position, and  $x$  is the final position. The negative sign shows that the direction of the spring force is opposite the direction of the displacement from  $x_0$ . The external force is equal in magnitude but opposite in sign to the spring force, so External force (force of your hands) =  $k(x - x_0)$ .

Now, we want to calculate the work done when we stretch the spring from position .1 to position 2.

$$W = \int F dx = \int k(x - x_0) d(x-x_0) = \frac{1}{2} k [(x_2-x_0)^2 - (x_1-x_0)^2]$$

### Work done when a volume is increased or decreased

Consider a gas in a container with a movable piston on top. If the gas expands, the piston moves out and work is done by the system on the surroundings.

Alternatively, if the gas inside contracts, the piston moves in and work is done by the surroundings on the system. Why would the gas inside contract or expand?

It would if the external pressure,  $P_{ex}$ , and the internal pressure,  $P_{in}$ , were different. To calculate the work done in moving the piston, we know that the force = pressure times area and then work equals pressure times area times distance or work equals pressure times the change in volume. So,  $W = \text{the integral of } (P_{ex}) dV$

The differential work done ( $dW$ ) associated with a differential displacement ( $dl$ ) is given by

$$dW = F dl$$

For a piston cylinder assembly,

$$dW = F dl = PA (dl) = P dV$$

If the gas is allowed to expand reversibly from the initial pressure  $P$  to final pressure  $P$ , then the work done is given by

$$W = \int p dV$$

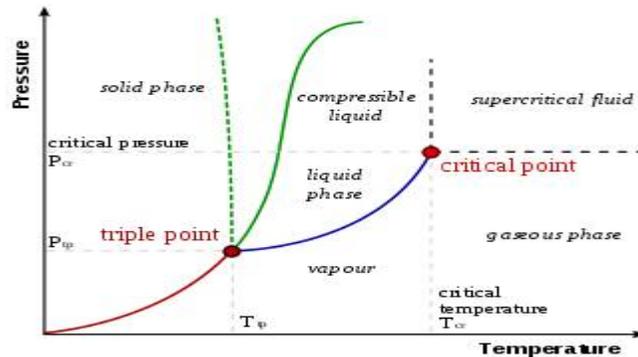
- The integral represents the area under the curve on a pressure versus volume diagram. Therefore the work depends on the path followed and work is a path function and hence not a property of the system.
- The above expression does not represent work in the case of an irreversible process.
- The thermodynamic definition of work is “ Work is said to be done by a system on the surrounding if the sole effect external to the system could be reduced to the raising of a mass through a distance” .

**Q3.** Explain the term critical point, critical temperature and critical pressure.



**KG REDDY**

College of Engineering  
& Technology



In the T-S diagram the region left of the waterline, the water exists as liquid. In right of the dry steam line, the water exists as a super heated steam. In between water and dry steam line the water exists as a wet steam. At a particular point, the water is directly converted into dry steam without formation of wet steam. The point is called critical point. The critical temperature is the temperature above which a substance cannot exist as a liquid; the critical temperature of water is  $374.15^{\circ}\text{C}$ . The corresponding pressure is called critical pressure.

**Q4. Problem :** A  $0.1\text{ m}^3$  rigid tank contains steam initially at  $500\text{ kPa}$  and  $200^{\circ}\text{C}$ . The steam is now allowed to cool until the temperature drops to  $50^{\circ}\text{C}$ . Determine the amount of heat transfer during this process and the final pressure in the tank.

State 1:  $P_1 = 500\text{ kPa}$ ,  $T_1 = 200^{\circ}\text{C}$

$$v_1 = 0.4249\text{ m}^3/\text{kg}, u_1 = 2642.9\text{ kJ/kg}$$

State 2:  $v_2 = v_1 = 0.4269\text{ m}^3/\text{kg}$

$$T_2 = 50^{\circ}\text{C} \rightarrow v_f = 0.001\text{ m}^3/\text{kg}$$

$$v_g = 12.03\text{ m}^3/\text{kg}$$

$$u_f = 209.32\text{ kJ/kg}$$

$$u_g = 2443.5\text{ kJ/kg}$$

$P_2 = P_{sat} @ 50^{\circ}\text{C} = 12.349\text{ kPa}$

$$v_2 = v_f + x_2 v_{fg}$$

$$0.4249 = 0.001 + x_2(12.03 - 0.001)$$

$$x_2 = 0.0352$$

$$u_2 = u_f + x_2 u_g$$

$$= 209.32 + (0.0352)(2443.5 - 209.32)$$

$$= 288.0\text{ kJ/kg}$$

$$m = V/u = (0.1\text{ m}^3/\text{kg})/(0.4249\text{ m}^3/\text{kg})$$

$$= 0.235\text{ kg}$$

$$-Q_{out} = \Delta U = m(u_2 - u_1)$$

$$Q_{out} = m(u_1 - u_2) = (0.235)(2642.9 - 288)$$

$$= 553.4\text{ kJ}$$



**Q5. Problem :** A piston/cylinder contains 50 kg of water at 200 kPa with a volume of  $0.1 \text{ m}^3$ . Stop in the cylinder is placed to restrict the enclosed volume to  $0.5 \text{ m}^3$ . The water is now heated until the piston reaches the stops. Find the necessary heat transfer.

At 200 kPa,

$$v_f = 0.001061 \text{ m}^3/\text{kg} \quad v_{fg} = 0.88467 \text{ m}^3/\text{kg} \quad h_f = 504.68 \text{ kJ/kg}$$

$$h_{fg} = 2201.96 \text{ kJ/kg} \quad Q = \Delta H$$

The specific volume initially,

$$v_i = 0.1 / 50 = 0.002 \text{ m}^3/\text{kg}$$

$$v = v_f + x v_{fg} = 0.001061 + x (0.88467)$$

$$\text{Therefore, } x = (0.002 - 0.001061) / 0.88467$$

$$= 0.001061$$

$$h = h_f + x h_{fg} = 504.68 + 0.001061(2201.96) = 507.017 \text{ kJ/kg}$$

$$v_{final} = 0.5 / 50 = 0.01 \text{ m}^3/\text{kg}$$

$$v = v_f + x v_{fg}$$

$$\text{Therefore, } x = (0.01 - 0.001061) / 0.88467 = 0.01$$

$$h_{final} = 504.68 + 0.01(2201.96)$$

$$= 526.69 \text{ kJ/kg}$$

$$Q = \Delta H = 50 (526.69 - 507.017) = 983.65 \text{ kJ/kg}$$

### Multiple choice questions with answers

Q1. Above the critical point, the isotherms are continuous curves.

- a) true      b) false

Q2. Which of the following represents the specific volume during phase transition.

- a)  $V_f - V_g$       b)  $V_g - V_f$       c)  $V_f + V_g$       d) none of the mentioned

Q3. Which of the following curves meet at triple point?

- a) fusion curve and vaporization curve  
b) fusion curve and sublimation curve  
c) vaporization curve and sublimation curve  
d) fusion curve and vaporization curve and sublimation curve

Q4. In the Mollier diagram, the constant pressure lines diverge from one another.

- a) true      b) false

Q5. Total volume of a liquid vapour mixture is given by

- a) volume of the saturated liquid      b) volume of the saturated vapour  
c) sum of volumes of saturated liquid and saturated vapour      d) none of the mentioned

Q6. Quality indicates the

- a) mass fraction of liquid in a liquid vapour mixture

- b) mass fraction of vapour in a liquid vapour mixture
- c) both of the mentioned
- d) none of the mentioned

Q7. At constant temperature, ( $u$  being the internal energy)

- a)  $u$  change when  $v$  or  $p$  changes
- b)  $u$  does not change when  $v$  or  $p$  changes
- c)  $u$  does not change when  $t$  changes
- d)  $u$  always remains constant

Q8. Which of the following requirement is satisfied by a phase change of the first order?

- a) there are changes of volume and entropy
- b) the first-order derivative of the Gibbs function changes discontinuously
- c) both of the mentioned
- d) none of the mentioned

Q9. Which of the following values of  $n$  are correct?

- a) for isobaric process,  $n=0$
- b) for isothermal process,  $n=1$
- c) for isentropic process,  $n=\gamma$
- d) all of the mentioned

Q10. Real gases conform more closely with the van der Waals equation of state than the ideal gas equation of state.

- a) true
- b) false

**KEYS (1) a, (2) b, (3) d, (4) a, (5) c, (6) b, (7) b, (8) c, (9) d, (10) a**

### Fill in the blanks questions with answers

Q1. At critical point, value of  $V_g - V_f$  is \_\_\_\_\_

Q2. The slopes of sublimation and vaporization curves for all substances are \_\_\_\_\_

Q3. At critical pressure, value of  $H_g - H_f$  is \_\_\_\_\_

Q4. The value of universal gas constant is \_\_\_\_\_

Q5. Water \_\_\_\_ on melting and has the fusion curve with a \_\_\_\_ slope.

Q6. For a isometric or isochoric process,  $n =$  \_\_\_\_\_ -

Q7. The slope of sublimation curve is \_\_\_\_ the slope of the vaporization curve at triple point.

Q8. For an ideal gas,  $Z$  has the value \_\_\_\_\_

Q9. Heat transferred at constant pressure \_\_\_\_\_ the enthalpy of a system.

Q10. A pure substance is said to have \_\_\_\_ degrees of freedom.

**KEYS**

(1) zero (2) positive (3) zero (4) 8.3143 (5) contracts, negative (6) infinity (7) greater than (8) one  
(9) Increases (10) two

## UNIT-IV

### Two marks of questions with answers

**Q1.** Define coefficient of volume expansion.

The coefficient of volume expansion is defined as the change in volume with the change in temperature per unit volume keeping the pressure constant.

**Q2.** Define Dalton's law of partial pressure.

The total pressure exerted in a closed vessel containing a number of gases is equal to the sum of the pressures of each gas and the volume of each gas equal to the volume of the vessel.

**Q3.** What are the assumptions made in Vanderwaal's equation of state?

i. There is no intermolecular force between particles

.ii. The volume of molecules is negligible in comparison with the gas.

**Q4.** What is compressibility factor?

The gas equation for an ideal gas is given by  $(PV/RT) = 1$ , for real gas  $(PV/RT)$  is not equal to 1  $(PV/RT) = Z$  for real gas is called the compressibility factor.

**Q5.** What is meant by adiabatic saturation temperature /thermodynamic wet bulb temperature?

It is the temperature at which the outlet air can be brought into saturation state by passing through the water in the long insulated duct (adiabatic) by the evaporation of water due to latent heat of vapourisation.

### **Three marks of questions with answers**

**Q1.** What is meant by dry bulb temperature (DBT) & wet bulb temperature (WBT)?

DBT: The temperature recorded by the thermometer with a dry bulb. The dry bulb thermometer cannot be affected by the moisture present in the air. It is the measure of sensible heat of the air.

WBT: It is the temperature recorded by a thermometer whose bulb is covered with cotton wick (wet) saturated with water. The wet bulb temperature may be the measure of enthalpy of air. WBT is the lowest temperature recorded by a moistened bulb.

**Q2.** Explain Dalton's law of partial pressure & Define dew point depression.

The pressure of a mixture of gases is equal to the sum of the partial pressures of the constituents. The partial pressure of each constituent is that pressure which the gas would exert if it occupied alone that volume occupied by the mixture at the same temperature.

**Dew Point Depression:** It is the difference between dry bulb temperature and dew point temperature of air vapor mixture.

**Q3.** Define Relative humidity, specific humidity & degree of saturation.

**Relative humidity:** It is defined as the ratio of partial pressure of water vapor ( $p_w$ ) in a mixture to the saturation pressure ( $p_s$ ) of pure water at the same temperature of mixture.

**Specific humidity:** It is defined as the ratio of the mass of water vapor ( $m_s$ ) in a given volume to the mass of dry air in a given volume ( $m_a$ ).

**Degree of saturation:** It is the ratio of the actual specific humidity and the saturated specific humidity at the same temperature of the mixture.

**Q4.** How does the Vander Waal's equation differ from the ideal gas equation of state?

The ideal gas equation  $pV=mRT$  has two important assumptions,

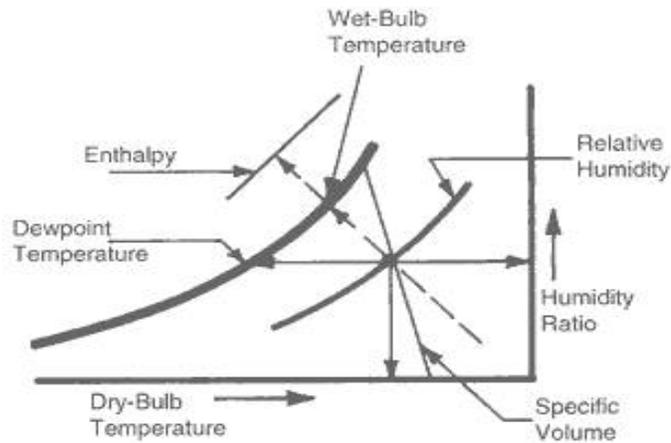
i That the volume occupied by the molecules themselves is negligibly small compared to the volume of the gas. This equation holds good for low pressure and high temperature ranges as the intermolecular attraction and the volume of the molecules are not of much significance. As the pressure increases, the inter molecular forces of attraction and repulsion increases and the volume of the molecules are not negligible.

ii. The real gas deviates considerably from the ideal gas equation

$$[p + \frac{a}{V^2}](V - b) = RT$$

**Q5.** What is psychometric chart?

It is the graphical plot with specific humidity and partial pressure of water vapor in y axis and dry bulb temperature along x axis. The specific volume of mixture, wet bulb temperature, relative humidity and enthalpy are the properties appeared in the psychometric chart.



### Five marks of questions with answers

**Q1.** Explain about pure substances and mixtures

**pure substances and mixtures:** In thermodynamics the concepts of a pure substance and a mixture (solution) is used. By a pure substance we mean a substance all molecules of which are similar, or a substance which does not change chemically. A mixture, consisting of several pure substances, is referred to as a solution. Examples of pure substances are water, ethyl alcohol, nitrogen, ammonia, sodium chloride, and iron. Examples of mixtures are air, consisting of

nitrogen, oxygen and a number of other gases, aqueous ammonia solutions, aqueous solutions of ethyl alcohol, various metal alloys. The pure substances making up a mixture are called components or constituents.

**Q2.** An air conditioned system is to be designed for a hall of 200 seating capacity when the following conditions are given:

Atmospheric condition = 30°C DBT and 50% RH

Indoor condition = 22°C DBT and 60% RH

Volume of air required = 0.4m<sup>3</sup>/min/person

The required condition is achieved first by chemical dehumidification and after that by sensible cooling.

Find the following .

1. DBT of the air leaving the dehumidifier.
2. The quantity of water vapour removed in the dehumidifier per hour.
3. The capacity of cooling coil in tons of refrigeration.
4. Surface temperature of the coil if the by pass factor of the coil is 0.25.

Solution:

Locate point 'a', 30°C DBT, 50% RH, the atmospheric condition.

Locate point 'c', 22°C DBT, 60% RH, the required indoor condition.

“Since chemical dehumidification process follows constant enthalpy line”

at a draw a line parallel to constant enthalpy line.

At 'c' draw a constant  $\omega$  line to cut the previous line at point b.

DBT of air leaving the dehumidifier  $T_b = 40.5^\circ\text{C}$

From chart

$$H_b = H_a = 65\text{kJ/kg}, \quad \omega_a = 0.013 \text{ kg/kg of dry air}$$

$$H_c = 45 \text{ kJ/kg}, \quad \omega_b = 0.009 \text{ kg/kg of dry air}, \quad V_{sa} = 0.875 \text{ m}^3/\text{min}$$

$$\text{Volume of air} = 200 \times 0.4 = 80 \text{ m}^3/\text{min}$$

$$W_a = \text{Weight of air} = V/V_{sa} = 80/0.875 = 91.42 \text{ kg/min}$$

$$\text{Quantity of water vapour removed/hour} = W_a(\omega_a - \omega_b)60$$

$$= 91.42(0.013 - 0.009)60 = 21.94 \text{ kg/hr}$$

$$\begin{aligned}\text{Capacity of cooling coil} &= W_a(H_a - H_b) / (60 \times 3.5) \\ &= 91.42(65 - 45) / (60 \times 3.5) \\ &= 8.7 \text{ tons}\end{aligned}$$

$$\text{By pass factor} = (T_c - T_d) / (T_b - T_d) = 0.25$$

$$T_d = \text{Temperature of cooling coil} = 15.83^\circ\text{C}$$

**Q3.** Explain degree of saturation, adiabatic saturation, cooling & humidification

Degree of saturation  $\mu$ : The degree of saturation is the ratio of the humidity ratio  $W$  to the humidity ratio of a saturated mixture  $W_s$  at the same temperature and pressure.

Adiabatic saturation:  $t_w = t_{wBT}$ . Here the sensible heat transfer from air to water is exactly equal to latent heat transfer from water to air. Hence, no external cooling or heating of water is required.

That is this is a case of pure water recirculation.

Cooling and humidification:  $t_{DPT} < t_w < t_{wBT}$ . Here the sensible heat transfer is from air to water and latent heat transfer is from water to air, but the total heat transfer is from air to water, hence, water has to be cooled externally.

Cooling and humidification:  $t_{wBT} < t_w < t_{DPT}$ . Here the sensible heat transfer is from air to water and latent heat transfer is from water to air, but the total heat transfer is from water to air, hence, water has to be heated externally. This is the process that takes place in a cooling tower. The air stream extracts heat from the hot water coming from the condenser, and the cooled water is sent back to the condenser.

**Q4.** In an air conditioning system air at a flow rate of 2 kg/s enters the cooling coil at 25°C and 50% RH and leaves the cooling coil at 11°C and 90% RH. The apparatus dew point of the cooling coil is 7°C. Find a) The required cooling capacity of the coil, b) Sensible Heat Factor for the process, and c) By-pass factor of the cooling coil. Assume the barometric pressure to be 1 atm. Assume the condensate water to leave the coil at ADP ( $h_w = 29.26 \text{ kJ/kg}$ )

**Ans .** At the inlet to the cooling coil;  $T_i = 25^\circ\text{C}$  and  $\text{RH} = 50\%$

From psychrometric chart;  $W_i = 0.00988$  kgw/kgda and  $h_i = 50.155$  kJ/kgda

At the outlet of the cooling coil;  $T_o = 11^\circ\text{C}$  and  $\text{RH} = 90\%$

From psychrometric chart;  $W_o = 0.00734$  kgw/kgda and  $h_o = 29.496$  kJ/kgda a) From mass balance across the cooling coil, the condensate rate,  $m_w$  is:

$$m_w = m_a(W_i - W_o) = 2.0(0.00988 - 0.00734) = 0.00508 \text{ kg/s}$$

From energy balance across the cooling tower, the required capacity of the cooling coil,  $Q_c$  is given by:;

$$Q_c = m_a(h_i - h_o) - m_w \cdot h_w = 2.0(50.155 - 29.496) - 0.00508 \times 29.26 = 41.17 \text{ kW}$$

b) The sensible heat transfer rate,  $Q_s$  is given by:

$$Q_s = m_a c_{pm}(T_i - T_o) = 2.0 \times 1.0216 \times (25 - 11) = 28.605 \text{ kW}$$

The latent heat transfer rate,  $Q_l$  is given by:

$$Q_l = m_a h_{fg}(W_i - W_o) = 2.0 \times 2501.0 \times (0.00988 - 0.00734) = 12.705 \text{ kW}^1$$

The Sensible Heat Factor (SHF) is given by:

$$\text{SHF} = Q_s / (Q_s + Q_l) = 28.605 / (28.605 + 12.705) = 0.692$$

**Q5.** A cooling tower is used for cooling the condenser water of a refrigeration system having a heat rejection rate of 100 kW. In the cooling tower air enters at  $35^\circ\text{C}$  (DBT) and  $24^\circ\text{C}$  (WBT) and leaves the cooling tower at a DBT of  $26^\circ\text{C}$  relative humidity of 95%. What is the required flow rate of air at the inlet to the cooling tower in  $\text{m}^3/\text{s}$ . What is the amount of make-up water to be supplied? The temperature of make-up water is at  $30^\circ\text{C}$ , at which its enthalpy ( $h_w$ ) may be taken as 125.4 kJ/kg. Assume the barometric pressure to be 1 atm.

**Ans:** At the inlet to cooling tower: DBT =  $35^\circ\text{C}$  and WBT =  $24^\circ\text{C}$

From psychrometric chart/equations the following values are obtained for the inlet:

$$\text{Humidity ratio, } W_i = 0.01426 \text{ kgw/kg}$$

$$\text{Enthalpy, } h_i = 71.565 \text{ kJ/kg}$$

$$\text{Sp. volume, } v_i = 0.89284 \text{ m}^3/\text{kg}$$

At the outlet to cooling tower: DBT = 26°C and RH = 95%

From psychrometric chart/equations the following values are obtained for the outlet:

$$\text{Humidity ratio, } W_o = 0.02025 \text{ kgw/kg}$$

$$\text{Enthalpy, } h_i = 77.588 \text{ kJ/kg}$$

From mass and energy balance across the cooling tower:

$$Q_c = m_a \{ (h_o - h_i) - (W_o - W_i) h_w \} = 100 \text{ kW}$$

Substituting the values of enthalpy and humidity ratio at the inlet and outlet of cooling tower and enthalpy of make-up water in the above expression, we obtain:

$$m_a = 18.97 \text{ kg/s,}$$

$$\text{hence, the volumetric flow rate, } V_i = m_a \times v_i = 16.94 \text{ m}^3/\text{s} \text{ (ans.)}$$

Amount of make-up water required  $m_w$  is obtained from mass balance as:

$$m_w = m_a(W_o - W_i) = 18.97(0.02025 - 0.01426) = 0.1136 \text{ kg/s} = 113.6 \text{ grams/s} .$$

### Multiple choice questions with answers

Q1. Which of the following property is used as the dimensionless property?

- a) reduced pressure b) reduced volume c) reduced temperature d) all of the mentioned



- Q2. The law of corresponding states is a relation among  
a) reduced pressure and reduced temperature  
b) reduced volume and reduced temperature  
c) reduced volume and reduced pressure  
d) reduced pressure and reduced temperature and reduced volume
- Q3. Which of the following produce continuous change in state of a flowing stream?  
a) wall friction      b) changes in cross-sectional area  
c) energy effects      d) all of the mentioned
- Q4. In adiabatic flow, what remains constant?  
a) stagnation temperature      b) stagnation enthalpy  
c) both of the mentioned      d) none of the mentioned
- Q5. For a supersonic flow,  
a) a convergent passage becomes diffuser and a divergent passage becomes nozzle  
b) a divergent passage becomes diffuser and a convergent passage becomes nozzle  
c) both of the mentioned      d) none of the mentioned
- Q6. In sensible heating or cooling,  
a) work done remains constant      b) dry bulb temperature or air remains constant  
c) both of the mentioned      d) none of the mentioned
- Q7. Heating and humidification is done in  
a) summer air conditioning      b) winter air conditioning  
c) both of the mentioned      d) none of the mentioned
- Q8. Cooling towers are rated in terms of  
a) approach      b) range      c) both of the mentioned      d) none of the mentioned
- Q9. The equation of state is a functional relationship between  
a) pressure      b) molar or specific volume      c) temperature      d) all of the mentioned
- Q10. Universal gas constant is given by  
a)  $\lim(pv) / 273.16$       b) R      c) 0.083 litre-atm/gmol K      d) all of the mentioned

**KEYS**

- (1) d, (2) d, (3) d, (4) c, (5) a, (6) a, (7) b, (8) c, (9) d, (10) d

**Fill in the blanks questions with answers**

- Q1. At very low pressures Z approaches \_\_\_\_\_
- Q2. The internal energy of saturated water at the triple point is \_\_\_\_\_
- Q3. Saturated liquid or the saturated vapour has \_\_\_\_\_ independent variables
- Q4. The properties of liquid \_\_\_\_\_ with pressure.
- Q5. Maxwell's equations consists of \_\_\_\_\_ equations.
- Q6. The \_\_\_\_\_ section of a nozzle or diffuser is called throat.
- Q7. When humidity ratio of air \_\_\_\_\_ air is said to be dehumidified.
- Q8. In adiabatic evaporative cooling, heat transfer between chamber and surroundings is \_\_\_\_\_
- Q9. An incompressible fluid is one for which density does not change with change in \_\_\_\_\_
- Q10. Liquids are \_\_\_\_\_ and gases are \_\_\_\_\_

**KEYS**

(1)unity (2) zero (3) one (4) vary little (5) four (6) minimum (7) decreases (8) zero (9)Pressure, Temperature, Velocity (10) incompressible, compressible

**UNIT-V**

**Two marks of questions with answerS**

**Q1.** Define overall efficiency.

It is the ratio of the mechanical work to the energy supplied in the fuel. It is also defined as the product of combustion efficiency and the cycle efficiency.

**Q2.** What is the effect of reheating the steam on the specific output and the cycle efficiency?

The specific output and the cycle efficiency are increased due to reheating the steam in vapor power cycles.

**Q3.** Define efficiency ratio.

The ratio of actual cycle efficiency to that of the ideal cycle efficiency is termed as efficiency ratio.

**Q4.** What is meant by vapor power cycle? Give some examples

Thermodynamic cycles which uses vapour as the working fluid is called vapor power cycle.

Example: Carnot cycle, Rankine cycle.

**Q5.** Define specific steam consumption of an ideal Rankine cycle.

It is defined as the mass of steam required per unit power output.

Specific steam consumption = (Steam flow kg/h) / (Power)

.

### **Three marks of questions with answers**

**Q1.** Why Rankine cycle is modified?

The work obtained at the end of the expansion is very less. The work is too inadequate to overcome the friction. Therefore the adiabatic expansion is terminated at the point before the end of the expansion in the turbine and pressure decreases suddenly, while the volume remains constant.

**Q2.** What are the various methods used to improve the efficiency of Rankine cycle?

- i. Increase the boiler pressure (or) Temperature
- ii. Decrease the condenser pressure
- iii. Increase the temperature of steam at superheated condition
- iv. Reheating the steam
- v. Adopting regeneration of steam

**Q3.** What are the assumptions made on the analysis of ideal Rankine cycle?

- i. Each component of the working fluid is internally reversible.
- ii. All processes of the working fluid are internally reversible.
- iii. The pump and turbine operate adiabatically.
- iv. Potential and kinetic energy effects are neglected.
- v. Condensate leaves the condenser as saturated liquid.

**Q4** What the advantages are of reheat cycle?

- i. It increases turbine work
- ii. It increases the efficiency of the plant
- iii. It reduces wear of turbine blades by reducing moisture content in steam.

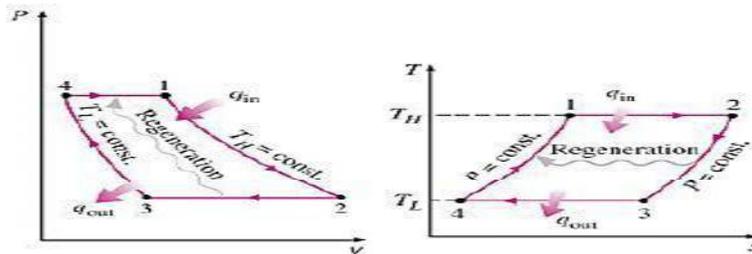
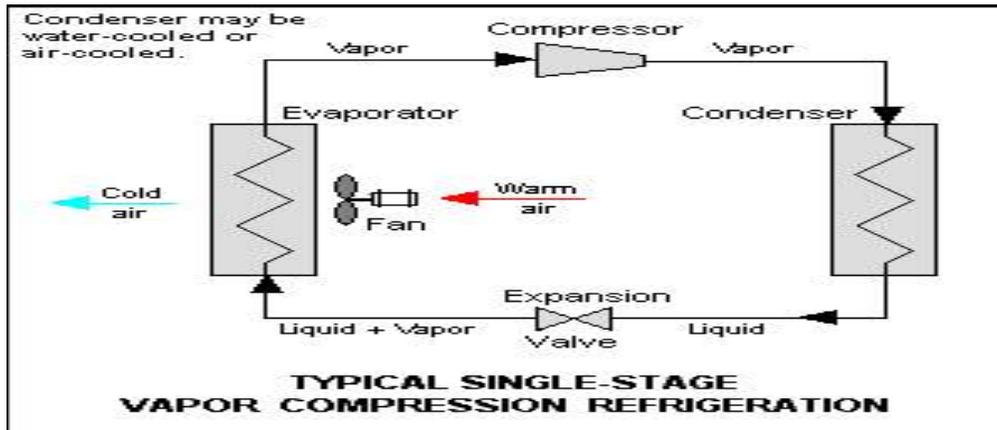
**Q5.** Define overall efficiency.& efficiency ratio

overall efficiency :It is the ratio of the mechanical work to the energy supplied in the fuel. It is also defined as the product of combustion efficiency and the cycle efficiency.

efficiency ratio:The ratio of actual cycle efficiency to that of the ideal cycle efficiency is termed as efficiency ratio.

## Five marks of questions with answers

Q1. Explain Vapor compression cycles



Processes: -

1-2: Isentropic compression from state 1 (wet vapour) to state 2 (saturated vapour)

2-3: Heat rejection ( $Q_H$ ) in the condenser

3-4: Isentropic expansion from state 3 (saturated liquid)

4-1: Heat absorption ( $Q_L$ ) in the evaporator

$$(COP)_R = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

vapor-compression refrigeration or vapor-compression refrigeration system (vcrs),<sup>[1]</sup> in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. a device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

**Q2. Explain Mean effective Pressure?**

**Mean effective Pressure**

Net workdone= mep/ Displacement volume

Brake Mean Effective Pressure We have presented the topics of Thermal Efficiency and Volumetric Efficiency as methods for estimating the potential output of a given engine configuration. Brake Mean Effective Pressure (BMEP) is another very effective yardstick for comparing the performance of an engine of a given type to another of the same type, and for evaluating the reasonableness of performance claims or requirements.

The definition of BMEP is: the average (mean) pressure which, if imposed on the pistons uniformly from the top to the bottom of each power stroke, would produce the measured (brake) power output. Note that BMEP is purely theoretical and has nothing to do with actual cylinder pressures. It is simply a tool to evaluate the efficiency of a given engine at producing torque from a given displacement.

**Q3. Problem:** A refrigerator does 153 J of work to transfer 568 J of heat from its cold compartment. (a) Calculate the refrigerator’s coefficient of performance, (b) How much heat is exhausted to the kitchen?

**Concept:-**A refrigerator would like to extract as much heat  $Q_L$  as possible from the low-temperature reservoir (“what you want”) for the least amount of work  $W$  (“what you pay for”). So the efficiency of a refrigerator is defined as,

$$K = \frac{\text{(what you want)}}{\text{(what you pay for)}} \\ = Q_L/W$$

and this is called coefficient of performance. The larger the value of K, the more efficient is the refrigerator.

The first law of thermodynamics, applied to the working substance of the refrigerator, gives

$$W = Q_H - Q_L$$

Here  $Q_H$  is the exhausted heat.

Thus exhausted heat will be,

$$Q_H = W + Q_L$$

**Solution:-**

(a) To obtain the coefficient of performance K of refrigerator, substitute 568 J for extracted heat  $Q_L$  and 153 J for the work W in the equation  $K = Q_L/W$ ,

$$K = Q_L/W \\ = 568 J/153 J$$

$$= 3.71$$

Therefore, the coefficient of performance  $K$  of refrigerator would be 3.71.

(b) To obtain exhausted heat to the kitchen by refrigerator, substitute 153 J for the work  $W$  and 568 J for extracted heat  $Q_L$  in the equation  $Q_H = W + Q_L$ ,

$$\begin{aligned} Q_H &= W + Q_L \\ &= 153 \text{ J} + 568 \text{ J} \\ &= 721 \text{ J} \end{aligned}$$

Therefore, exhausted heat to the kitchen by refrigerator would be 721 J.

**Q4.Problem:** An inventor claims to have created a heat pump that draws heat from a lake at  $3.0^\circ\text{C}$  and delivers heat at a rate of 20 kW to a building at  $35^\circ\text{C}$ , while using only 1.9 kW of electrical power. How would you judge the claim?

**Concept:-**

Coefficient of performance ( $K$ ) of a heat pump is defined as,

$$K = T_L / (T_H - T_L)$$

Where,  $T_L$  is the lower temperature and  $T_H$  is the higher temperature of the reservoir.

Again, coefficient of performance ( $K$ ) of a heat engine is defined as,

$$\begin{aligned} K &= Q_L / W \\ &= (Q_H - W) / W \end{aligned}$$

We can write above equation  $K = (Q_H - W) / W$ ,

$$\begin{aligned} K &= (Q_H - W) / W \\ &= (Q_H/t - W/t) / (W/t) \\ &= (P_H - P) / P \quad (\text{Since Power } (P) = W/t) \end{aligned}$$

**Solution:-**

To obtain the Coefficient of performance ( $K$ ) of a heat pump, substitute  $3.0^\circ\text{C}$  for  $T_L$  and  $35^\circ\text{C}$  for  $T_H$  in the equation  $K = T_L / (T_H - T_L)$ ,

$$\begin{aligned} K &= T_L / (T_H - T_L) \\ &= 3.0^\circ\text{C} / (35^\circ\text{C} - 3.0^\circ\text{C}) \\ &= (3+273) \text{ K} / ((35+273) \text{ K} - (3+273) \text{ K}) \\ &= 276 \text{ K} / (308 \text{ K} - 276 \text{ K}) \\ &= 8.62 \end{aligned}$$

To find out the coefficient of performance  $K$  of the machine which the inventor claims, substitute 20 kW for  $P_H$  and 1.9 kW for  $P$  in the equation  $K = (P_H - P) / P$ ,

$$\begin{aligned} K &= (P_H - P) / P \\ &= (20 \text{ kW} - 1.9 \text{ kW}) / 1.9 \text{ kW} \\ &= 9.53 \end{aligned}$$

Since the coefficient of performance  $K$  of the machine which the inventor claims is greater than the coefficient of performance ( $K$ ) of a heat pump, therefore it cannot be done.

**Q5. Problem:** The motor in a refrigerator has a power output of 210 W. The freezing compartment is at  $-3.0^{\circ}\text{C}$  and the outside air is at  $26^{\circ}\text{C}$ . Assuming that the efficiency is 85% of the ideal, calculate the amount of heat that can be extracted from freezing compartment in 15 min.

**Concept:-**

Coefficient of performance  $K$  of a Carnot refrigerator is defined as,

$$K = T_L / T_H - T_L$$

Here  $T_L$  is the lower temperature of sink and  $T_H$  is the higher temperature of source.

Since here the efficiency is 85% of the ideal, therefore the coefficient of performance  $K$  of the refrigerator will be,

$$K = 0.85 (T_L / T_H - T_L)$$

A refrigerator would like to extract as much heat  $Q_L$  as possible from the low-temperature reservoir (“what you want”) for the least amount of work  $W$  (“what you pay for”).

$$= Q_L / W$$

and this is called coefficient of performance. The larger the value of  $K$ , the more efficient is the refrigerator.

From the above equation  $K = Q_L / W$ ,  $Q_L$  will be,

$$Q_L = (K) (W)$$

Work done ( $W$ ) is equal to the product of power ( $P$ ) and time ( $t$ ).

$$W = (P) (t)$$

**Solution:-**

First we have to find out the coefficient of performance  $K$  and work done  $W$ .

To obtain coefficient of performance  $K$ , substitute 270 K for  $T_L$  and 299 K for  $T_H$  in the equation  $K = 0.85 (T_L / T_H - T_L)$ ,

$$\begin{aligned} K &= 0.85 (T_L / T_H - T_L) \\ &= 0.85 (270 \text{ K} / 299 \text{ K} - 270 \text{ K}) \\ &= 7.91 \end{aligned}$$

To obtain work done  $W$ , substitute 210 W for power  $P$  and 15 min for time  $t$  in the equation  $W = (P) (t)$ ,

$$\begin{aligned} W &= (P) (t) = (210 \text{ W}) (15 \text{ min}) \\ &= (210 \text{ W}) (15 \text{ min}) (60 \text{ s} / 1 \text{ min}) = (210 \text{ W}) (900 \text{ s}) \\ &= (1.89 \times 10^5 \text{ Ws}) (1 \text{ J} / 1 \text{ Ws}) = 1.89 \times 10^5 \text{ J} \end{aligned}$$

To obtain the amount of heat  $Q_L$  that can be extracted from the freezing, substitute 7.91 for coefficient performance  $K$  and  $1.89 \times 10^5 \text{ J}$  for work done  $W$  in the equation

$$\begin{aligned} Q_L &= (K) (W), \\ Q_L &= (K) (W) \\ &= (7.91) (1.89 \times 10^5 \text{ J}) \\ &= 1.50 \times 10^6 \text{ J} \end{aligned}$$

From the above observation we conclude that, the amount of heat  $Q_L$  that can be extracted from the freezing compartment in 15 min would be  $1.50 \times 10^6 \text{ J}$ .

### Multiple choice questions with answers

- Q1. For a Rankine cycle, which of the following is true?  
a) a reversible constant pressure heating process happens in steam boiler  
b) reversible adiabatic expansion of steam in turbine  
c) reversible constant pressure heat rejection in condenser  
d) all of the mentioned
- Q2. For a Rankine cycle, which of the following is true?  
a) a reversible constant pressure heating process happens in steam boiler  
b) reversible adiabatic expansion of steam in turbine  
c) reversible constant pressure heat rejection in condenser  
d) all of the mentioned
- Q3. Which of the following losses occur in a cycle?  
a) piping losses      b) pump losses      c) turbine losses      d) all of the mentioned
- Q4. The only process which is different in Carnot and Rankine cycle is  
a) compression in pump      b) expansion in turbine  
c) heat rejection process      d) heat addition process
- Q5. In a by-product power cycle,  
a) the basic need is power produced and process steam is a by-product  
b) the basic need is process steam and power produced is a by-product  
c) both process steam and power is the basic need  
d) both process steam and power is a by-product
- Q6. How can we generate required power and required quantity of steam in a single process?  
a) by modifying initial steam pressure      b) by modifying exhaust pressure  
c) both of the mentioned      d) none of the mentioned
- Q7. The Otto cycle is the  
a) air standard cycle of CI engine      b) air standard cycle of SI engine  
c) vapour power cycle of CI engine      d) vapour power cycle of SI engine
- Q8. The efficiency of Otto cycle is given by (rk is the compression ratio)  
a)  $1/(rk)^{(\gamma-1)}$       b)  $1 - 1/(rk)^{(\gamma)}$       c)  $1 - 1/(rk)^{(\gamma-1)}$       d)  $1/(rk)^{(\gamma)}$
- Q9.  $\gamma$  for air is equal to  
a) 1.0      b) 1.2      c) 1.3      d) 1.4
- Q10. In absorption refrigeration cycle, which of the following is used?  
a) refrigerant      b) absorbent      c) both of the mentioned      d) none of the mentioned

**KEYS**

(1) d, (2) b, (3) d, (4) d, (5) b, (6) c, (7) b, (8) c, (9) d, (10) c

**Fill in the blanks questions with answers**

- Q1. A power cycle continuously converts \_\_\_\_ into \_\_\_\_
- Q2. Work output of turbine is \_\_\_\_ the work input to the pump.
- Q3. The losses in condenser are \_\_\_\_
- Q4. The efficiency of Carnot cycle is \_\_\_\_ the efficiency of Rankine cycle.
- Q5. In a by-product power cycle, condenser losses is \_\_\_\_
- Q6. The fraction of energy utilized in a by-product power cycle is \_\_\_\_
- Q7. The spark plug fires shortly before the \_\_\_\_ stroke.
- Q8. The pressure in cylinder is \_\_\_\_ the atmospheric value during exhaust stroke and \_\_\_\_ it during intake stroke.
- Q9. The two-stroke engine is \_\_\_\_ the four-stroke engine.
- Q10. The efficiency of Stirling cycle is \_\_\_\_ the efficiency of Carnot cycle.

**Keys**

(1) heat, work (2) much larger (3) small (4) greater than (5) zero (6) very high (7) expansion (8) above, below (9) less efficient than (10) less than