UNIT I

BASIC CONCEPTS AND FIRST LAW

INTRODUCTION TO THERMODYNAMICS:

The term thermodynamics derived from Greek words. Therme means heat and dynamics means power. Thermodynamics can be defined as the study of relationship between work, heat and energy. The flow of energy is of a great importance to engineers involved in the design of equipment in power generation and process industries. Thermodynamics provides an understanding the nature and degree of energy transformations so that they can be understood and suitably utilized. Today, the conversion of heat energy into power plays an important role in power generation, refrigeration, turbines, compressors, heat pumps, automobiles, jet propulsion systems, biomedical applications, etc.,

Thermodynamics is a field of science which deals the:

ⓐ Energies possessed by gases and vapours

ⓑ interaction of a system and its surroundings

ⓒ conversion of energies in terms of heat and mechanical work and

ⓓ relationship with properties of the system.

THERMODYNAMIC PROPERTIES:

Thermodynamic properties describe the measurable characteristics of a substance. The knowledge of these properties is essential to the understanding of thermodynamics. The following are the thermodynamic properties.

① Mass (m) and Weight (W)

Mass (m) of a body is the measure of the amount of material present in the same body. In S.I. unit it is represented by kg.

Weight (W) of a body is the force exerted by the body when its mass is accelerated in a gravitational field. In S.I. unit it is represented by N.

$$\text{Weight } W = m \times g$$

where m is the mass of the body
g is the local gravitational acceleration.

② Density (ρ)

Density is defined as the mass per unit volume. It is denoted by 'ρ' (rho). In S.I unit it is represented by kg/m^3.

$$\text{Density } \rho = \frac{\text{Mass}}{\text{Total Volume}} = \frac{m}{V}$$

It is also denoted by specific mass or mass density.

③ Specific Volume (v)

It is defined as the volume occupied by unit mass of the substances. It is the reciprocal of density. In S.I. unit it is expressed as m^3/kg.

$$\text{Specific volume } v = \frac{\text{Total Volume}}{\text{Mass}} = \frac{V}{m}$$

④ Specific Weight (w)

It is defined as the weight per unit volume. In S.I. unit it is expressed as N/m^3 or kN/m^3.

$$\text{Specific weight } w = \frac{\text{Total Weight}}{\text{Total Volume}} = \frac{W}{V}$$

⑤ Specific Gravity (s):

It is defined as the ratio of density of a substance to the density of some standard substance at a specified temperature.

$$\text{Specific gravity } (s) = \frac{\text{Density (or) Specific Weight of the given substance}}{\text{Density (or) Specific Weight of the standard substance}}$$

⑥ Pressure (p):

It is defined as the force exerted per unit area.

The pressure is considered as a property when a gas or a liquid is dealt. In the case of solids, the pressure is called as stress.

$$\text{Pressure}, \ p = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

$1 \text{ Pascal} = 1 \text{ N/m}^2$

$1 \text{ Bar} = 10^5 \text{ N/m}^2 = 100 \text{ kN/m}^2$

$1 \text{ Torr} = 1 \text{ mm of mercury } (Hg) = 133.3 \text{ N/m}^2$

$1 \text{ mm of water } (H_2O) = 9.80665 \text{ N/m}^2$

Atmospheric Pressure (P_{atm}):

It is the pressure exerted by the air on the atmosphere. Its value taken at mean Sea level is 1.01325 bar.

Gauge Pressure (P_g):

It is the pressure recorded by the pressure gauge. All pressure gauges read 'zero' pressure at atmospheric level. Hence they actually measure the difference of fluid pressure and atmospheric pressure.

Vacuum Pressure (P_{vac}):

The pressure below atmospheric pressure is called as vacuum pressure. It is also called as negative pressure. Vacuum gauge is used to measure vacuum pressure.

Absolute Pressure (P_{abs}):

The pressure measured from absolute zero pressure is called as absolute pressure.

$$P_{abs} = P_{atm} + P_g$$

$$P_{abs} = P_{atm} - P_{vac}$$

⑧ Specific heat capacity (C):

It is defined as "the quantity of heat transfer required for raising or lowering the temperature of unit mass of the substanc through one degree when the volume remains constant. It is denoted by C and is expressed in J/kg k or kJ/kg k.

TYPES OF THERMODYNAMIC SYSTEMS:

The thermodynamic systems may be classified into the following three categories:

ⓐ Closed system

ⓑ Open system

ⓒ Isolated system.

ⓐ CLOSED SYSTEM:

A closed system does not permit any mass transfer. But only the energy transfer takes place. It is also known as control mass.

ⓑ OPEN SYSTEM:

In open systems, both the mass and energy transfer take place. It is also known as control volume.

ⓒ ISOLATED SYSTEM:

A system which is not affected by surroundings is called isolated system. It can simply be stated, there is no heat, work and mass transfer. It is an imaginary system.

During a flow process 5 kW paddle wheel work is supplied while the internal energy of the system increases in one minute as 200 kJ. Find the heat transfer when there is no other form of energy transfe

Given data:

$$W = -5\,\text{kW}, \quad \Delta U = 200\ \text{kJ/min} = \frac{200}{60} = 3.33\ \text{kJ/s}$$

Tofind:

Q

Solution:

$$Q = W + \Delta U$$

$$= -5 + 3.33$$

$$Q = -1.67 \text{ kW}$$

A liquid of mass 18 kg is heated from 25°c to 85°c. How much heat transfer is required? Assume C_p for water is 4.2 kJ/kg.k

Given data:

$m = 18$ kg

$T_1 = 25°c = 25 + 273 = 298$ k

$T_2 = 85°c = 85 + 273 = 358$ k

Tofind:

Q

Solution:

$$Q = m C_p \left(T_2 - T_1\right)$$

$$= 18 \times 4.2 \times \left(358 - 298\right)$$

$$Q = 4536 \text{ kJ}$$

A closed system receives an input heat of 450 kJ and increases the internal energy of the system for 325 kJ. Determine the work done by the system.

Given data:

$Q = 450$ kJ

$\Delta U = 325$ kJ

To find:

Q

Solution:

$$Q = W + \Delta U$$

$$450 = W + 325$$

$$W = 450 - 325 = 125 \text{ kJ}$$

25 People attended a farewell party in a small room of size 10 m X 8 m and has a 5m ceiling. Each person gives up about 350 kJ of heat per hour. Assuming that the room is completely sealed off and insulated. Calculate the air temperature rise occurring within 10 minutes. Assume C_v of air 0.718 kJ/kgK and R = 0.287 kJ/kgK and each person occupies a volume of 0.05 m³.

Given data:

No of persons = 25

Room size = 10 X 8 m

Ceiling height = 5 m

Heat / person = 350 kJ/hr

Time t = 10 min

C_v = 0.718 kJ/kgK.

R = 0.287 kJ/kgK

V_p = 0.05 m³

To find:

Δt

Solution:

$$V_r = 10 \times 8 \times 5 = 400 \text{ m}^3$$

$$V_a = V_r - V_p \times n = 400 - 0.05 \times 25 = 398.75 \text{ m}^3$$

$$m = \frac{pV_a}{RT} = \frac{1.013 \times 100 \times 398.75}{0.287 \times 293} = 472.29 \text{ kg}$$

$$Q = W + \Delta U$$

Assume heat addition at constant volume process

$$\therefore W = 0$$

$$Q = \Delta U = \text{Heat / Person} \times \text{No of persons}$$

$$= 350 \times 25 = 8750 \text{ kJ/hr}$$

Heat loss for 10 minutes $Q = \frac{8750}{60} \times 10 = 1458.33$ kJ

Heat gained by air $Q = m C_v \Delta T$

$$1458.33 = 472.29 \times 0.718 \times \Delta T$$

$$\Delta T = 4.22^\circ C$$

Mass of 15 kg of air in a piston cylinder device is heated from 25°C to 90°C by passing current through a resistance heater inside the cylinder. The pressure inside the cylinder is held constant at 300 kPa during the process and a heat loss of 60 kJ occurs. Determine the electrical energy supplied in kW-hr and change in internal energy.

Given data:

$m = 15\ kg$

$T_1 = 25°c = 25+273 = 298\ k$

$T_2 = 90°c = 90 + 273 = 363\ k$

$P_1 = P_2 = 300\ kPa = 300\ kN/m^2$

$Q = -60\ kJ$

Tofind:

i, Electrical energy supplied

ii, Change in internal energy.

Solution:

$W = mR\left(T_2 - T_1\right)$

$= 15 \times 0.287\left(363 - 298\right)$

$W = 279.825\ kJ = 279.825 \times 3600 = 1007.37 \times 10^3\ kW\text{-}hr$

$\Delta U = Q - W = -60 - 279.825 = -339.825\ kJ$

0.25 kg of air at a pressure of 1 bar occupies a volume of 0.3 m^3. If this air expands isothermally to a volume of 0.9 m^3. Find i, the initial temperature ii, the final temperature iii, external work done iv, heat absorbed by the air and v, change in internal energy. Assume $R = 0.29\ kJ/kgk$.

Given data:

$m = 0.25\ kg$

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

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

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

To find:

T_1, T_2, W, Q and ΔU

Solution:

$$p_1 V_1 = m R T_1$$

$$T_1 = \frac{100 \times 0.3}{0.25 \times 0.287} = 418.12 \text{ k}$$

$$T_1 = T_2 = 418.12 \text{ k.}$$

$$W_1 = m\, p_1 V_1 \ln\left(\frac{P_1}{P_2}\right)$$

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

$$W_1 = 32.96 \text{ kJ}$$

$$Q = W = 32.96 \text{ kJ}$$

$$\Delta U = 0$$

A boiler produces steam from water at 35°C. The enthalpy of steam is 2675 kJ/kg. Calculate the heat transferred per kg. The specific heat capacity of water is 4.19 kJ/kg. Neglect the potential and kinetic energies.

Given data:

$$T_W = 35^\circ\text{C} = 35 + 273 = 308 \text{ k.}$$

$$h = 2675 \text{ kJ/kg}$$

$C_{pw} = 4.19 \text{ kJ/kgK}$

Tofind:

Q

Solution:

$$h_1 = C_{pw} T_w = 4.19 \times 308 = 1290.52 \text{ kJ/kg}$$

$$Q = h_2 - h_1 = 2675 - 1290.52 = 1384.48 \text{ kJ/kg}.$$

In a steady flow of air through a nozzle the enthalpy decreases by 50 kJ between two sections. Assuming that there are no other energy changes than the kinetic energy determine the increases in velocity at section 2, if the initial velocity is 90 m/s.

Given data:

$$h_1 - h_2 = 50 \text{ kJ} = 50{,}000 \text{ J}$$

$$C_1 = 90 \text{ m/s}.$$

Tofind:

$C_2 - C_1$

Solution:

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

$$C_2 = \sqrt{2(h_1 - h_2) + C_1^2} = \sqrt{2 \times 50 \times 10^3 + 90^2}$$

$$C_2 = 328.78 \text{ m/s}$$

$$C_2 - C_1 = 328.78 - 90 = 238.78 \text{ m/s}$$

At the inlet of the nozzle the enthalpy and velocity of the fluid are 3000 kJ/kg and 50 m/s respectively. There is negligible heat loss from the nozzle. At the outlet of the nozzle enthalpy is 2450 kJ/kg. If the nozzle is horizontal, find the velocity of the fluid at exit.

Given data:

$h_1 = 3000$ kJ/kg

$C_1 = 50$ m/s

$Q = 0$

$Z_1 = Z_2$

$h_2 = 2450$ kJ/kg

To find:

C_2

Solution:

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

$$C_2 = \sqrt{2(h_1 - h_2) + C_1^2}$$

$$= \sqrt{2\ (3000 - 2450) \times 10^3 + 50^2}$$

$$C_2 = 1050 \text{ m/s}$$

A gas whose original pressure, volume and temperature were 140 kN/m³, 0.1 m³ and 25°c respectively. It is compressed such that new pressure is 700 kN/m² and its new temperature is 60°c. Determine the new volume of the gas.

Given data:

$P_1 = 140 \text{ kN/m}^2$

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

$T_1 = 25°\text{c} = 25 + 273 = 298 \text{ k}$

$P_2 = 700 \text{ kN/m}^2$

$T_2 = 60°\text{c} = 60 + 273 = 333 \text{ k}.$

To find:

V_2

Solution:

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2}$$

$$\frac{140 \times 0.1}{298} = \frac{700 \times V_2}{333}$$

$$V_2 = 0.0223 \text{ m}^3$$

UNIT II

SECOND LAW AND AVAILABILITY ANALYSIS

HEAT RESERVOIR, SOURCE AND SINK, HEAT ENGINE

The ideal body having large thermal energy capacity which either continuously supplies or absorbs the infinite amount of heat without changing its temperature is called thermal energy reservoir or heat reservoir.

If the reservoir continuously supplies heat energy to the system it is called a source. The source is always at higher temperature. If the reservoir continuously absorbs heat energy from the system it is called a sink.

Heat engine is a device which operates a thermodynamic cycle and produces work by supplying heat from hot reservoir. Examples are I.C. engines, Boiler etc.

REFRIGERATOR

Refrigerator is a device which is used to remove heat from a cold system. In other words it is used to maintain the temperature of the body lower than that of surroundings. Examples are Air conditioners, Freezers etc

The efficiency of a refrigerator is expressed in terms of the 'Coefficient of performance' (COP). It is the ratio of heat extracted to the work input.

$$\text{COP} = \frac{\text{Desired heat output}}{\text{Required work input}}$$

HEAT PUMP:

Heat pump is a device which is used to supply heat to a hotter system. In other words it is used to maintain the temperature of the body higher than the surroundings. Example Room heater used during winter season.

$$\text{COP of heat pump} = \frac{\text{Desired work output}}{\text{Required heat input}}$$

KELVIN - PLANCK STATEMENT:

It is impossible for any device that operates on a cyclic process to receive heat from a single reservoir and produce an equivalent amount of work.

It can also be expressed as no heat engine can have a thermal efficiency of 100 percent.

CLAUSIUS STATEMENT:

It is impossible to construct an operating device working on a cyclic process which produces no other effect than the transfer of energy as heat from a low temperature body to a high temperature body.

REVERSIBILITY:

A process is performed in such a way that it should trace the same path when the process is reversed known as reversible process.

IRREVERSIBILITY:

Practically all thermodynamic processes are irreversible process. When any process is reversed, it definitely will not follow the same path as the original process. At the same time, it produces a change in the universe. Sothe path traced by the reverse process is different. Therefore, the work involved due to this process is called irreversible work. Irreversibility is produced due to various reasons

① Lack of equilibrium

② Heat transfer through a finite temperature difference

③ Lack of pressure equilibrium within the interior of the system

④ Free expansion

⑤ Dissipative effects.

CARNOT CYCLE:

It is also called as constant temperature cycle. This cycle was introduced by Sadi Carnot. It consists of four processes such as two isentropic or reversible adiabatic and two isothermal processes

CARNOT THEOREM:

It states that No heat engine operating in a cyclic process between two fixed temperatures can be more efficient than a reversible engine which is operating between the same temperatures limit

THERMODYNAMIC TEMPERATURE SCALE:

A temperature scale which is independent of the properties of the substances that are used to measure temperature is called a thermodynamic temperature scale.

An inventor claims to have developed an efficient heat engine which would have a heat source at 1000°C and reject heat to a sink at 50°C and gives an efficiency of 90%. Justify whether his claim is possible or not.

Given data:

$$T_H = 1000^\circ C = 1273\ k.$$

$$T_L = 50^\circ c = 323\ k.$$

$$\eta = 90\ \%$$

To find:

Whether the inventor's claim is correct or not

Solution:

$$\eta_{max} = \frac{T_H - T_L}{T_H}$$

$$= \frac{1273 - 323}{1273}$$

$$= 0.746$$

$$\eta_{max} = 74.6\ \%$$

Maximum efficiency (74.6%) is less than proposed engine efficiency (90%). Therefore his claim is impossible.

A Carnot heat engine cycle works at maximum and minimum temperature of 1000°c and 40°c respectively. Calculate thermal efficiency and work done if $Q_S = 1010$ kJ.

Given data:

$T_H = 1000°c = 1273$ k.

$T_L = 40°c = 313$ k.

$Q_S = 1010$ kJ

To find:

η and W

Solution:

$$\eta = \frac{T_H - T_L}{T_H}$$

$$= \frac{1273 - 313}{1273}$$

$$= 0.754$$

$$\eta = 75.4\%$$

$$\eta = \frac{W}{Q_S}$$

$$W = \eta \times Q_S = 0.754 \times 1010 = 761.54 \text{ kJ}$$

A Carnot heat engine receives heat from 600°c source. The efficiency of the engine is 59%. Find the amount of heat supplied and heat rejected per kW of work output.

Given data:

$\eta = 59\%$

$T_H = 600°C$

$W = 1\ kW$

To find:

Q_S and Q_R

Solution:

$$\eta = \frac{W}{Q_S}$$

$$Q_S = \frac{W}{\eta}$$

$$= \frac{1}{0.59}$$

$$Q_S = 1.695\ kW$$

$$W = Q_S - Q_R$$

$$Q_R = Q_S - W$$

$$= 1.695 - 1$$

$$Q_R = 0.695\ kW$$

The temperature in a domestic refrigerator is to be maintained at $-10°c$. The ambient air temperature is $30°c$. If the heat leaving through the refrigerator is 3 kW, determine the least power necessary to pump out this heat continuously

Given data:

$$T_L = -10°c = 263\ k.$$

$$T_H = 30°c = 303\ k.$$

$$Q_S = 3\ kW$$

To find:

W

Solution:

A refrigerator removes heat at the same rate at which the heat leaks from it.

$$\frac{Q_R}{T_L} = \frac{Q_S}{T_H}$$

$$Q_R = \frac{T_L}{T_H} \times Q_S$$

$$Q_R = \frac{263}{303} \times 3 = 2.6\ kW$$

$$W = Q_S - Q_R = 3 - 2.6 = 0.396\ kW$$

CLAUSIUS INEQUALITY:

It states that "when a system undergoes a cyclic process, the summation of dQ/T around a closed cycle is less than or equal to zero".

$$\eta = \frac{dQ_S - dQ_R}{dQ_S}$$

$$\eta_{rev} = \frac{T_H - T_L}{T_H}$$

An inventor claims that his new engine will develop 3 kW for a heat addition of 240 kJ/min. The highest and the lowest temperature of the cycle are 1527°c and 327°c respectively. Would you agree his claim? Use Clausius inequality method.

Given data:

$W = 3\,kW = 30 \times 60 = 1800\ kJ/min$

$Q_1 = 240\ kJ/min$

$T_1 = 1527°C$

$T_2 = 327°C$

To find:

Agreement his claim

Solution:

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} + \frac{Q_2}{T_2}$$

$$W = Q_1 - Q_2$$

$$1800 = 240 - Q_2$$

$$-Q_2 = 1800 - 240$$

$$Q_2 = -1560 \text{ kJ/min}$$

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2} = \frac{240}{1800} - \frac{1560}{600}$$

$$= -2.47 \text{ kJ/min}$$

$\oint \frac{dQ}{T} < 0$. So we agree his claim

One kg of air in a closed system initially at 5°c occupying a volume of 0.3 m^3 undergoes a constant pressure heating process to 100°c. There is no work other than pdV work. Find the work transfer, heat transfer and the entropy change of the gas.

Given data:

$m = 1$ kg

$T_1 = 5°c$

$V_1 = 0.3 \; m^3$

$T_2 = 100°c.$

To find:

W, Q and ΔS

Solution:

$$W = p(V_2 - V_1)$$

$$= mR(T_2 - T_1)$$

$$= 1 \times 0.287 (100 - 5)$$

$$W = 27.26 \text{ kJ}$$

$$Q = m C_p (T_2 - T_1)$$

$$= 1 \times 1.005 (100 - 5)$$

$$Q = 95.48 \text{ kJ}$$

$$\Delta S = m C_p \ln\left(\frac{T_2}{T_1}\right)$$

$$= 1 \times 1.005 \ln\left(\frac{373}{278}\right)$$

$$\Delta S = 0.295 \text{ kJ}|\text{k}$$

1 kg of air is compressed according to the law $pV^{1.25} = C$ from 1 bar and 15°c to 17 bar. Calculate the change in entropy. $C_p = 1.005$ kJ/kg k and $C_v = 0.72$ kJ/kg k.

Given data:

$m = 1$ kg

$n = 1.25$

$P_1 = 1$ bar $= 100$ kN/m²

$P_2 = 17$ bar $= 1700$ kN/m²

$T_1 = 15°c = 288$ k

$C_p = 1.005$ kJ/kgk

$C_v = 0.72$ kJ/kgk

$R = C_p - C_v = 1.005 - 0.72 = 0.285$ kJ/kgk

To find:

ΔS

Solution:

$$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \times T_1 = \left(\frac{1700}{100}\right)^{\frac{1.25-1}{1.25}} \times 288 = 507.55 \text{ k}.$$

$$\Delta S = mR \ln\left(\frac{P_1}{P_2}\right) + mC_p \ln\left(\frac{T_2}{T_1}\right)$$

$$= 1 \times 0.285 \times \ln\left(\frac{1}{17}\right) + 1 \times 1.005 \times \ln\left(\frac{507.55}{288}\right)$$

$$\Delta S = -0.238 \text{ kJ/k}$$

A constant volume chamber of 0.3 m^3 capacity contains 1 kg of air at 56°C. Heat is transferred to the air until the temperature is 100°C. Find the work transfer, heat transfer and the change in internal energy, enthalpy and entropy.

Given data:

$V_1 = 0.3\ m^3$

$m = 1\ kg$

$T_1 = 56°C$

$T_2 = 100°C$

To find:

$W, Q, \Delta U, \Delta H$ and ΔS

Solution:

$W = 0$ for constant volume process

$$Q = \Delta U = m C_v (T_2 - T_1)$$

$$= 1 \times 0.718 (100 - 56)$$

$$Q = 31.59\ kJ$$

$$\Delta H = \Delta U = 31.59\ kJ$$

$$\Delta S = m C_v \ln\left(\frac{T_2}{T_1}\right)$$

$$= 1 \times 0.718 \ln\left(\frac{373}{329}\right)$$

$$\Delta S = 0.09\ kJ/k$$

10 kg of water 90°c mixes with 2.5 kg of water at 20°c under adiabatic condition. Find the final temperature and entropy generation.

Given data:

$m_1 = 10\,kg$

$T_1 = 90^\circ C$

$m_2 = 2.5\,kg$

$T_2 = 20^\circ C$

To find:

T_f and ΔS

Solution:

$$T_f = \frac{m_1 C_1 T_1 + m_2 C_2 T_2}{m_1 C_1 + m_2 C_2}$$

$$C_p = 4.187\ kJ/kgk$$

$$T_f = \frac{10 \times 4.187 \times 363 + 2.5 \times 4.187 \times 293}{1 \times 4.187 + 2.5 \times 4.187} = 349\,k = 76^\circ c$$

$$\Delta S = m_1 C_1 \ln\left(\frac{T_f}{T_1}\right) + m_2 C_2 \ln\left(\frac{T_f}{T_2}\right)$$

$$= 10 \times 4.187 \times \ln\left(\frac{349}{363}\right) + 2.5 \times 4.187 \times \ln\left(\frac{349}{293}\right)$$

$$\Delta S = 0.184\ kJ/k$$

A Carnot heat engine receives 650 kJ of heat from a source of unknown temperature and rejects 250 kJ of it to a sink as 297 k. Determine the temperature of the source and the thermal efficiency of the heat engine.

Given data:

$Q_H = 650$ kJ

$Q_L = 250$ kJ

$T_L = 297$ k.

Solution:

$$\eta_{max} = \frac{Q_S - Q_R}{Q_S}$$

$$\eta_{max} = \frac{T_H - T_L}{T_H}$$

$$\frac{650 - 250}{650} = \frac{T_H - 297}{T_H}$$

$$T_H = 772.2\,k$$

$$\eta_{max} = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{650 - 250}{650}$$

$$\eta_{max} = 61.54\,\%$$

UNIT III

PROPERTIES OF PURE SUBSTANCE AND STEAM POWER CYCLE

PROPERTIES OF PURE SUBSTANCE

Pure substance is a substance which has a fixed chemical composition throughout its mass. Examples: Water, nitrogen, carbon dioxide and helium. A pure substance does not have to be of a single chemical element or compound. A mixture of various chemical elements or compounds also called as a pure substance as long as the mixture is homogeneous. For example air is a mixture of several gases but it is considered as a pure substance because it has uniform chemical composition throughout.

A mixture of two or more phases of a pure substance is also called as a pure substance. For example a mixture of ice and liquid water is a pure substance because both phases have the same chemical composition. But the mixture of liquid air and gaseous air is not a pure substance because the chemical composition of vapour is different from the composition of gaseous air

DRYNESS FRACTION:

It is defined as the ratio of the mass of the dry steam actually present to the mass of the total steam. It is denoted by x.

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

m_g - mass of dry steam in kg

m_f - mass of water vapour in suspension.

WETNESS FRACTION:

It is defined as the ratio of the mass of water vapour in suspension to the total steam.

$$\text{Wetness Fraction} = \frac{m_f}{m_f + m_g}$$

$$= 1 - x$$

The wetness fraction expressed in percentage i.e $100(1-x)$ is called Priming

PHASE RULE:

The number of independent variables associated with a multi-component, multiphase system is given by the phase rule. It is also called as Gibbs phase rule. It is expressed by the equation as

$$n = C - \phi + 2$$

where

n = the number of independent variable

C = the number of components

ϕ = the number of phases present in equilibrium.

DETERMINATION OF DRYNESS FRACTION:

The dryness fraction can experimentally be measured by using calorimeters. They are with four types.

① Bucket or barrel calorimeter

② Throttling calorimeter

③ Separating calorimeter

④ Combined separating and throttling calorimeter.

Determine the state of steam at a pressure of 12 bar with its specific volume of 0.175 m^3/kg.

Given data:

$p = 12$ bar

$v = 0.175\ m^3/kg$.

To find:

state of steam.

Solution:

$$V_{sup} = V_g \left(\frac{T_{sup}}{T_s} \right)$$

$$T_{sup} = \frac{V_{sup}}{V_g} \times T_s$$

$$= \left(\frac{0.175}{0.16321} \right) \times 188$$

$$T_{sup} = 201.58°C$$

The steam is superheated to 201.58°c

Determine the condition of steam at a temperature of 220°c and enthalpy of 2750 kJ/kg.

Given data:

$T = 220°C$

$h = 2750\ kJ/kg$

Tofind:

State of steam.

Solution:

From Steam Table of temperature scale at 220°c

$$h_f = 943.7 \text{ kJ/kg}$$

$$h_{fg} = 1856.2 \text{ kJ/kg}$$

$$h_g = 2799.9 \text{ kJ/kg}$$

Since $h < h_g$, the steam is in wet condition

$h > h_g \rightarrow$ Super heated steam

$h = h_g \rightarrow$ Dry steam

$h < h_g \rightarrow$ Wet steam

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

$$x = \frac{h_{wet} - h_f}{h_{fg}}$$

$$= \frac{2750 - 943.7}{1856.2}$$

$$x = 0.973$$

Steam initially at 400 kPa and 0.6 dry is heated in a rigid vessel of 0.1 m^3 volume. The final condition is 600 kPa. Find the amount of heat added and mass of steam.

Given data:

$P_1 = 400$ kPa

$x_1 = 0.6$

$V_1 = 0.1 \, m^3$

$P_2 = 600$ kPa

To find:

Q and m

Solution:

From steam tables, corresponding to 4 bar

$h_{f_1} = 604.7$ kJ/kg

$h_{fg_1} = 2132.9$ kJ/kg

$v_{g_1} = 0.4622 \, m^3/kg$

Specific volume $v_1 = x_1 v_{g_1}$

$$v_1 = 0.6 \times 0.4622 = 0.277 \, m^3/kg$$

$$h_1 = h_{f_1} + x_1 h_{fg_1}$$

$$= 604.7 + 0.6 \times 2132.9$$

$$h_1 = 1884.44 \text{ kJ/kg}$$

Mass of steam $m = \frac{V_1}{v_1}$

$$= \frac{0.1}{0.278}$$

$$m = 0.36 \text{ kg}$$

For rigid vessel $v_1 = v_2$

$$v_2 = 0.277 \text{ m}^3/\text{kg}$$

From steam tables corresponding to 6 bar

$$h_{f_2} = 670.4 \text{ kJ/kg}$$

$$v_{g_2} = 0.31546 \text{ m}^3/\text{kg}$$

$$h_{fg_2} = 2085.1 \text{ kJ/kg}$$

$v_{g_2} > v_2$ ∴ The steam is in wet condition

$$v_2 = x_2 v_{g_2}$$

$$0.277 = x_2 \times 0.31546$$

$$x_2 = 0.88$$

$$h_2 = h_{f_2} + x_2 h_{fg_2}$$

$$= 670.4 + 0.88 \times 2085.1$$

$$h_2 = 2505.2 \text{ kJ/kg}$$

$$Q = W + \Delta U \quad (W=0) \Rightarrow Q = \Delta U$$

$$Q = m\left[U_2 - U_1\right] = m\left[\left(h_2 - P_2 v_2\right) - \left(h_1 - P_1 v_1\right)\right]$$

$$= m\left[\left(h_2 - h_1\right) - v_1\left(P_2 - P_1\right)\right]$$

$$= 0.36\left[\left(2505.2 - 1884.44\right) - 0.277\left(600 - 400\right)\right]$$

$$Q = 203.46 \text{ kJ}$$

One kg of steam at a pressure of 700 kPa and 0.6 dry is heated at constant pressure until it becomes dry saturated. Determine change in internal energy and work done.

Given data:

$m = 1$ kg

$p = 700$ kPa $= 7$ bar

$x_1 = 0.6$

$x_2 = 1$

To find:

ΔU and W

Solution:

From steam table at 7 bar

$h_{f1} = 697.1$ kJ/kg

$h_{fg1} = 2064.9$ kJ/kg

$h_{g1} = 2762$ kJ/kg

$v_{g1} = 0.27288$ m³/kg

$V_1 = m x_1 v_{g_1}$

$= 1 \times 0.6 \times 0.27288$

$V_1 = 0.164$ m³

$h_1 = m(h_{f1} + x_1 h_{fg_1})$

$= 1(697.1 + 0.6 \times 2064.9)$

$h_1 = 1936.04$ kJ

$v_2 = v_{g1} = 0.27288 \ m^3/kg$

$V_2 = m v_{g1} = 1 \times 0.27288$

$= 0.27288 \ m^3$

$h_2 = m h_{g_1}$

$= 1 \times 2762$

$h_2 = 2762 \ kJ/kg$

Change in internal energy

$\Delta U = u_2 - u_1$

$= (h_2 - h_1) - (P_2 V_2 - P_1 V_1)$

$= (h_2 - h_1) - P_1 (V_2 - V_1)$

$= (2762 - 1936.04) - 700 (0.273 - 0.164)$

$\Delta U = 749.66 \ kJ$

$W = p (V_2 - V_1)$

$= 700 (0.273 - 0.164)$

$W = 76.3 \ kJ$

Dry saturated steam is supplied to a steam turbine at 12 bar and after the expansion its condenser pressure is 1 bar. Find the Rankine cycle efficiency, specific steam consumption. Neglect feed pump work.

Given data:

$P_1 = 12$ bar

$P_2 = 1$ bar

To find:

$\eta_{Rankine}$

SSC

η_{carnot}

Solution:

From steam table at 12 bar

$T_s = 187.99°C$

$h_1 = h_g = 2784.7$ kJ/kg

$s_1 = s_g = 6.523$ kJ/kgK

At 1 bar

$T_s = 99.63°C$

$h_{f_2} = 417.45$ kJ/kg

$h_{fg_2} = 2258$ kJ/kg

$s_{f_2} = 1.3026$ kJ/kgK

$s_{fg_2} = 6.0568$ kJ/kgK

Since the expansion process is isentropic

$$s_1 = s_2$$

$$s_1 = s_2 = s_{f_2} + x_2 \times s_{fg_2}$$

$$6.5233 = 1.3026 + x_2 \times 6.0568$$

$$x_2 = 0.86$$

$$h_2 = h_{f_2} + x_2 \times h_{fg_2}$$

$$= 417.4 + 0.86 \times 2258$$

$$h_2 = 2359.28 \text{ kJ/kg}$$

$$\eta_{Rankine} = \frac{h_1 - h_2}{h_1 - h_{f_2}}$$

$$= \frac{2784.7 - 2359.28}{2784.7 - 417.7}$$

$$= 0.1797$$

$$\eta_{Rankine} = 17.97\,\%$$

$$\text{Specific steam consumption} = \frac{3600}{W}$$

$$= \frac{3600}{h_1 - h_2}$$

$$= \frac{3600}{2784.7 - 2359.28}$$

$$SSC = 8.46 \text{ kg/kW-hr}$$

A reheat cycle works between 120 bar and 0.035 bar. The initial steam temperature is 570°C. After isentropic expansion to dry saturated conditions, the steam is reheated to 500°C. Determine the efficiency of the cycle.

Given data:

$p_1 = 120$ bar

$p_4 = 0.035$ bar

$T_1 = 570°C$

$T_3 = 500°C$

$x_2 = 1$

To find:

η_{Reheat}

Solution:

From steam tables at 120 bar and 570°C

$h_1 = 3528.87$ kJ/kg

$s_1 = 6.7087$ kJ/kgK

At 0.035 bar

$h_{f4} = 111.8$ kJ/kg

$h_{fg4} = 2438.6$ kJ/kg

$s_{f4} = 0.391$ kJ/kgK

$s_{fg4} = 8.133$ kJ/kgK

For isentropic process

$s_1 = s_2 = 6.7087$ kJ/kgK

$s_2 = s_g \Rightarrow$ dry saturated steam

$P_2 = P_{sat}$ at s_g

$P_2 = 7$ bar

At 7 bar

$h_2 = 2762$ kJ/kg

At 7 bar and 500°C

$h_3 = 3481.6$ kJ/kg

$s_3 = 7.931$ kJ/kgk

$s_3 = s_4 = 7.931$ kJ/kgk

$s_4 = s_{f_4} + x_4 \times s_{fg_4}$

$7.934 = 0.391 + x_4 \times 8.133$

$x_4 = 0.927$

$h_4 = h_{f_4} + x_4 \times h_{fg_4}$

$= 111.8 + 0.927 \times 2438.6$

$h_4 = 2372.38$ kJ/kg

$$\eta = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_5) + (h_3 - h_2)}$$

$$= \frac{(3528.87 - 2762) + (3481.6 - 2372.8)}{(3528.87 - 111.8) + (3481.6 - 2762)} \times 100$$

$\eta = 0.4534 = 45.34\%$

The net power output of the turbine in ideal reheat regenerative cycle is 100 MW. Steam enters the HP turbine at 90 bar and 550°C. After expansion to 7 bar some of the steam goes to an open heater and balance is reheated to 400°C, after which it expands to 0.07 bar. Calculate the steam flow rate in HP turbine and thermal efficiency of cycle.

Given data:

$p_1 = 90$ bar

$p_2 = 7$ bar

$p_4 = 0.07$ bar

$T_1 = 550°C$

$T_3 = 400°C$

To find:

η and m_s

Solution:

Properties of steam from Steam Table

At 90 bar and 550°C

$h_1 = 3508.95$ kJ/kg

$s_1 = 6.0885$ kJ/kgK

At 7 bar and 400°C

$h_3 = 3269$ kJ/kg

$s_3 = 7.636$ kJ/kgK

At 7 bar

$h_f = 697.1$ kJ/kg

$h_g = 2762$ kJ/kg

$s_f = 1.992$ kJ/kgK

$s_g = 6.705$ kJ/kgK

$T_{sat} = 438$ K

At 0.07 bar

$h_{f_4} = 163.4$ kJ/kg

$h_{fg_4} = 2409.2$ kJ/kg

$s_{f_4} = 0.559$ kJ/kgK

$s_{fg_4} = 7.718$ kJ/kgK

$s_1 = s_2 = 6.8085$ kJ/kgK

$s_2 > s_g$ at 7 bar ∴ Steam is in super heated state

Enthalpy $h_2 = 2827.76$ kJ/kg

$s_3 = s_4 = 7.636$ kJ/kgK

$s_4 = s_{f_4} + x_4 \times s_{fg_4}$

$7.636 = 0.559 + x_4 \times 7.718$

$x_4 = 0.917$

$h_4 = h_{f_4} + x_4 \times h_{fg_4}$

$= 163.4 + 0.917 \times 2409.2$

$h_4 = 2372.64$ kJ/kg

$$h_6 = m_1 \times h_2 + (1-m_1) \times h_5$$

$$697.1 = m_1 \times 2827.76 + (1-m_1) \times 163.4$$

$$m_1 = 0.2003 \text{ kJ/kg of steam.}$$

Mass flow rate $P = m_{st}\left[(h_1-h_2) + (1-m_1)(h_3-h_4)\right]$

$$m_{st} = \frac{100 \times 10^3}{\left[(3058.95 - 2827.76) + (1-0.202)(3269 - 2372.64)\right]}$$

$$m_{st} = 105.654 \text{ kg/s} = 380.55 \text{ T/hr}$$

Net work output

$$W_{net} = (h_1-h_2) + (1-m_1)(h_3-h_4)$$

$$= (3058.95 - 2827.76) + (1-0.202)(3269 - 2372.64)$$

$$W_{net} = 946.46 \text{ kJ/kg}$$

Net heat supply $= (h_1-h_6) + (1-m_1)(h_3-h_2)$

$$= (3058.95 - 697.1) + (1-0.202)(3269 - 2827.76)$$

$$= 2713.96 \text{ kJ/kg}$$

$$\eta = \frac{W}{Q}$$

$$= \frac{946.46}{2713.96}$$

$$\eta = 34.874\%$$

UNIT IV

IDEAL AND REAL GASES AND THERMODYNAMIC RELATIONS

IDEAL GAS

An ideal gas is an imaginary substance that obeys the relation $pV = RT$. So the equation of state is also known as ideal-gas equation. At low pressures and high temperatures the density of a gas decreases. At that time the gas behaves as an ideal gas. A factor is introduced to account the deviation of ideal-gas behaviour known as compressibility factor. It means a measure of deviation of the ideal-gas behaviour.

REAL GAS

At high pressures, the gases start to deviate from ideal-gas behaviour. So, the deviation should be accounted. For accounting this deviation, a factor called compressibility is introduced.

$$pv = ZRT$$

where Z - Compressibility factor.

$$Z = \frac{pv}{RT}$$

$$Z = \frac{v_{actual}}{v_{ideal}}$$

$$z = \frac{\text{Specific volume of real gases}}{\text{Specific volume of ideal gases}}$$

For ideal gases $Z = 1$

For real gases, Z is greater than or less than unity.

BOYLE'S LAW

It states that the volume of given mass of a gas varies inversely with its absolute pressure when the temperature remains constant.

$$v \propto \frac{1}{p} \quad \text{or} \quad pv = \text{constant}$$

CHARLES'S LAW

It states that the volume of given mass of a gas varies directly with its absolute temperature when the pressure remains constant.

$$v \propto T$$

JOULE'S LAW

It states that the internal energy of a given quantity of a gas depends only on the temperature.

$$\Delta U = C_v \Delta T.$$

REGNAULT'S LAW:

It states that the two specific heats C_p and C_v of a gas do not change with the change of temperature and pressure.

AVOGADRO'S LAW:

It states that equal volumes of different perfect gases at the same temperature and pressure contain equal number of molecules.

1 kg mole of a gas = 22.4 m^3

CHARACTERISTIC GAS EQUATION:

The general gas equation for ideal gas is given by

$$\frac{pV}{T} = \text{Constant}$$

p - Pressure in N/m^3

V - Volume in m^3

T - Temperature in $^\circ C$

Taking R as constant

$$\frac{pV}{T} = R$$

$$pV = RT$$

If the mass of gas 'm' is considered

$$pV = mRT$$

This equation is known as characteristic gas equation.

EQUATION OF STATE FOR REAL GAS:

① VANDAR WAAL'S EQUATION

The scientist Vandar Waal considered these two corrections to analyse the behaviour of real gases during 1879.

∴ The equation of state for real gases is given by

$$\left(p+\frac{a}{v^2}\right)(v-b) = RT$$

For ideal gas, the constants a and b are zero. The values of a and b are dependent on the type of fluid or gases used.

$$a = \frac{27R^2(T_c)^2}{64\,p_c}$$

$$b = \frac{RT_c}{8\,p_c}$$

T_c = Critical Temperature

p_c = Critical Pressure.

② BEATTIE - BRIDGEMAN EQUATION OF STATE:

This equation is based on five experimentally determined constraints in the form of

$$p = \frac{R_a T}{v^{-2}}\left(1-\frac{c}{vT^3}\right)\left(\bar{v}+B\right)-\frac{A}{v^{-2}}$$

$$A = A_0\left(1 - \frac{a}{\bar{V}}\right)$$

$$B = B\left(1 - \frac{b}{V}\right)$$

③ BENEDICT - WEBB - RUBIN EQUATION OF STATE

The equation of state is expressed as

$$p = \frac{R_U T}{\bar{V}} + \left(B_0 R_U T - A_0 - \frac{C_0}{T^2}\right)\frac{1}{V^{-2}} + \frac{b R_u T - a}{V^{-3}} + \frac{a\alpha}{V^{-6}} + \frac{c}{V^{-3} T^2}\left(1 + \frac{\gamma}{V^{-2}}\right) e^{-\frac{\gamma}{V}}$$

④ VIRIAL EQUATION OF STATE

Virial or virtual expansions are only applicable to gases of low and medium densities

The equation state of a substance is given by

$$p = \frac{RT}{V} + \frac{a(T)}{V^2} + \frac{b(T)}{V^3} + \frac{c(T)}{V^4} + \frac{d(T)}{V^5} + \cdots$$

$a(T)$, $b(T)$, $c(T)$, $d(T)$ are Virial co-efficients

A vessel of volume 0.3 m^3 contains 15 kg of air at 303 K. Determine the pressure exerted by the air using

① Perfect gas equation

② Vander Waals equation

③ Generalised compressibility chart

Take critical temperature of air is 132.8 K and critical pressure ~~of~~ of air is 37.7 bar.

Given data:

$V = 0.3\ m^3$

$m = 15\ kg$

$T = 303\ K$

$T_c = 132.8\ K$

$p_c = 37.7\ bar = 37.7 \times 100\ kN/m^2$

Solution:

① Perfect gas equation:

$$pv = mRT$$

$$p = \frac{mRT}{V}$$

$$p = \frac{15 \times 0.287 \times 303}{0.3}$$

$$p = 4348.05\ kPa$$

② Vander Waals Equation:

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

$$a = \frac{27 \times (0.287)^2 \times (132.8)^2}{64 \times (37.7) \times (100)}$$

$$a = 0.162$$

$$b = \frac{RT_c}{8p_c}$$

$$= \frac{0.287 \times 132.8}{8 \times 37.7 \times 100}$$

$$b = 1.26 \times 10^{-3}$$

$$v = \frac{\text{Volume}}{\text{mass}} = \frac{0.3}{15} = 0.02 \text{ m}^3/\text{kg}$$

$$\left(p + \frac{0.162}{(0.02)^2}\right)\left(0.02 - 1.26 \times 10^{-3}\right) = 0.287 \times 303$$

$$p = 4235.4 \text{ kN/m}^2$$

③ Generalised compressibility chart:

$$T_r = \frac{T}{T_c} = \frac{303}{132.8} = 2.28$$

$$v_r = \frac{v}{v_c} = \frac{v}{\frac{RT_c}{p_c}} = \frac{vp_c}{RT_c}$$

$$= \frac{0.02 \times 37.7 \times 100}{0.287 \times 132.8}$$

$$v_r = 1.98 \text{ m}^3/\text{kg}$$

$$Z = \frac{pv}{RT} \Rightarrow 0.99 = \frac{p \times 0.02}{0.287 \times 303}$$

$$p = 4304.6 \text{ kN/m}^2$$

The gas neon has a molecular weight of 20.183 and its critical temperature, pressure and volume are 46 K, 2.5 MPa and 0.05 m³/kg mol. Reading from a compressibility chart for a reduced pressure if 2 and a reduced temperature of 1.2, the compressibility factor Z is 0.75. What are the corresponding specific volume, pressure, temperature and reduced volume?

Given data:

$M = 20.183$

$T_c = 46\ K$

$p_c = 2.5\ MPa$

$v_c = 0.05\ m^3/kg\ mol$

$T_r = 1.2$

$p_r = 2$

$Z = 0.75$

Solution:

$$p = p_r \times p_c = 2 \times 2.5 = 5\ MPa$$

$$\frac{T}{T_c} = 1.2 \Rightarrow T = 1.2 \times T_c = 1.2 \times 46 = 55.2\ K$$

$$pv = ZRT$$

$$v = \frac{ZRT}{p}$$

$$= \frac{0.7 \times \left(\frac{8.3143}{20}\right) \times 55.2}{5 \times 10^3}$$

$$v = 3.213 \times 10^{-3}\ m^3/kg$$

$$V_r = \frac{V}{V_c}$$

$$= \frac{3.213 \times 10^{-3} \times 20}{0.5}$$

$$V_r = 0.129$$

Compute the specific volume of steam at 0.9 bar and 550 K using Vander Waals equation. Take critical temperature of steam is 647.3 K and Critical pressure is 220.9 bar.

Given data.

$p = 0.9 \text{ bar} = 0.9 \times 100 \text{ kN/m}^2 = 90 \text{ kPa}$

$T = 550 \text{ K}$

$T_c = 647.3 \text{ K}$

$p_c = 220.9 \text{ bar} = 220.9 \times 100 \text{ kN/m}^2$

Solution:

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

$$a = \frac{27R^2 (T_c)^2}{64 p_c}$$

$$b = \frac{RT_c}{8 p_c}$$

$$R = \frac{\text{Universal Gas Constant}}{\text{Molecular Weight of steam}}$$

$$R = \frac{8.314}{18} = 0.462 \text{ kJ}/\text{kgK}$$

$$a = \frac{27 \times (0.462)^2 \times (647.3)^2}{64 \times (220.9) \times 100}$$

$$a = 1.7$$

$$b = \frac{0.462 \times 647.3}{8 \times 220.9 \times 100}$$

$$b = 1.69 \times 10^{-3}$$

$$\left(0.75 \times 100 + \frac{1.70}{v^2}\right) \times \left(v - 1.69 \times 10^{-3}\right) = 0.462 \times 570$$

$$\left(75 + \frac{1.70}{v^2}\right) \left(v - 1.69 \times 10^{-3}\right) = 263.34$$

$$v = 0.25 \text{ m}^3/\text{kg}$$

A perfect gas of 0.5 kg has a pressure of 300 kPa, a temperature of 100°c and a volume of 0.06 m^3. The gas undergoes an irreversible adiabatic process to a final pressure of 400 kPa and final volume of 0.15 m^3, work done on the gas is 50 kJ. Find C_p, C_v

Given data:

$m = 0.2$ kg

$p_1 = 300$ kPa

$T_1 = 40°c + 273 = 313$ k

$V_1 = 0.06\ m^3$

$P_2 = 400\ kPa$

$V_2 = 0.15 m^3$

$W = -50\ kJ$

Solution:

$$P_1 V_1 = m R T_1$$

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

$$= \frac{300 \times 0.06}{0.2 \times 313}$$

$$R = 0.288\ kJ/kgK.$$

$$P_2 V_2 = m R T_2$$

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

$$= \frac{400 \times 0.15}{0.2 \times 0.288}$$

$$T_2 = 1041.67\ K$$

$$Q = W + \Delta U$$

$$= W + m\, C_v \left(T_2 - T_1\right)$$

$$Q = -50 + 0.2 \times C_v \left(1041.67 - 313\right)$$

For adiabatic process $Q = 0$

$$0 = -50 + 0.2 \times C_V (1041.67 - 313)$$

$$C_V = 0.343 \text{ kJ/kg.K}$$

$$R = C_P - C_V$$

$$0.288 = C_P - 0.343$$

$$C_P = 0.631 \text{ kJ/kgk.}$$

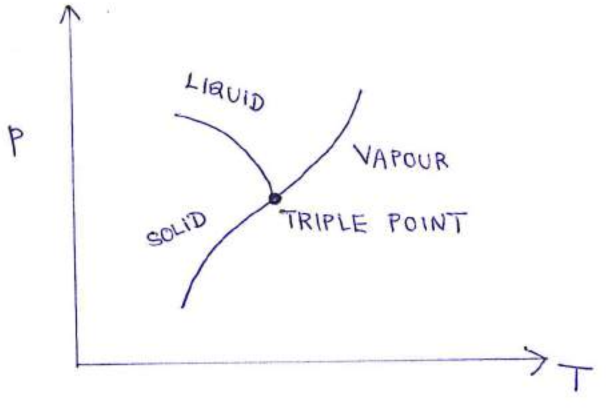
CLAUSIUS CLAPEYRON EQUATION

Claprey0n equation which involves the relationship between the saturation pressure, saturation temperature, the enthalphy of evaporation and the specific volume of the two phases involved. This equation provides a basis for calculation of properties in a two phase region. It gives the slope of a curve separating the two phases in P–T diagram.

Let the entropy (S) is a function of Temperature (T) and volume (v)

$$s = f(T, v)$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_v dT + \left(\frac{\partial s}{\partial v}\right)_T dv$$



When the phase is changing from saturated liquid to saturated vapour, temperature remains constant. So, ds equation reduces to

$$ds = \left(\frac{\partial s}{\partial v}\right)_T dv$$

From Maxwell relation, we know that

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial p}{\partial T}\right)_v$$

$$ds = \left(\frac{\partial p}{\partial T}\right)_v dv$$

The term $\left(\frac{\partial p}{\partial T}\right)$ is the slope of the saturation curve

Integrating the above equation between saturated liquid (f) and saturated vapour (g)

$$\int_{s_f}^{s_g} ds = \frac{dp}{dT} \int_{v_f}^{v_g} dv$$

$$\left[s\right]_{s_f}^{s_g} = \frac{dp}{dT}\left[v\right]_{v_f}^{v_g}$$

$$s_g - s_f = \frac{dp}{dT}\left[v_g - v_f\right]$$

Solution:

$$\frac{m_a}{m_{Me}} = 18$$

$$m_a = 18 \times m_{Me}$$

$$= 18 \times 2.5$$

$$m_a = 45 \text{ kg/s}$$

Temperature of mixture

$$T_m = \frac{m_{Me} C_{V_{Me}} T_{Me} + m_a C_{V_a} T_a}{m_{Me} C_{V_{Me}} + m_a C_{V_a}}$$

$$= \frac{2.5 \times 1.7354 \times 298 + 45 \times 0.718 \times 423}{2.5 \times 1.735 + 45 \times 0.718}$$

$$T_m = 408.2 \text{ k}$$

$$\Delta S_{Me} = m_{Me} C_{P_{Me}} \ln\left(\frac{T_m}{T_A}\right) - R_{Me} \ln\left(\frac{P_m}{P_A}\right)$$

$$= m_{Me} C_{P_{Me}} \ln\left(\frac{T_m}{T_A}\right) \qquad (P_m = P_A)$$

$$= 2.5 \times 2.2537 \ln\left(\frac{408.2}{298}\right)$$

$$\Delta S_{Me} = 1.773 \text{ kJ/k}$$

Methane at 1 bar and 25 °c enters an insulated mixing chamber at a rate of 2.5 kg/s. It is mixed with air at 1 bar in an air/methane mass ratio of 18. The flow is steady and kinetic energy changes are negligible. The ambient pressure and temperature are 1 bar and 25°C, determine the ⓐ temperature of the mixture leaving the chamber and ⓑ irreversibility of the mixing per kilogram of methane. Take C_v and C_p of methane as 1.7354 kJ/kgk and 2.2537 kJ/kgk respectively.

Given data:

$m_{ME} = 2.5$ kg/s

$P_{me} = 1$ bar $= 101.3$ kPa

$T_{me} = 25°c = 273+25 = 298$ K

$C_{vme} = 1.7354$ kJ/kgk

$P_a = 1$ bar $= 101.3$ kPa

$C_{pme} = 2.2537$ kJ/kgk

$T_a = 150°c = 150+273 = 423$ K

$$\frac{m_a}{m_{Me}} = 18$$

⑦ GAS CONSTANT:

$$R_m = \frac{m_A}{m_m} R_A + \frac{m_B}{m_m} R_B + \frac{m_C}{m_m} R_C$$

The gas constant of the mixture can also be obtained by

$$R_m = \frac{\overline{R}}{M_m}$$

M_m = Molar mass of the mixture.

⑧ ENTROPY:

Entropy for a gas mixture per unit mass is given by

$$s_m = \frac{S_m}{m_m}$$

$$= \frac{m_A s_A + m_B s_B + m_C s_C}{m_m}$$

GIBBS FUNCTION:

By Gibbs function

$$G = h - Ts$$

$$dg = dh - d(Ts)$$

$$dg = dh - Tds - s\,dT$$

④ Internal Energy:

INTERNAL ENERGY of a gas mixture per unit mass is given by

$$U_m = \frac{u_m}{m_m}$$

$$= \frac{U_A + U_B + U_C}{m_m}$$

$$U_m = \frac{m_A u_A + m_B u_B + m_C u_C}{m_m}$$

⑤ ENTHALPY:

Enthalpy of a gas mixture per unit mass is given by

$$h_m = \frac{H_m}{m_m}$$

$$= \frac{m_A h_A + m_B h_B + m_c h_c}{m_m}$$

⑥ SPECIFIC HEATS:

For a mixture of ideal gases, specific heats are given by

$$C_{v_m} = \frac{m_A C_{vA} + m_B C_{vB} + m_c C_{vc}}{m_m}$$

UNIT V

GAS MIXTURES AND PSYCHROMETRY

GAS MIXTURES:

Pure substance is defined as a substance which is homogeneous and unchanging in chemical composition. In many important thermodynamics applications, it requires homogeneous mixture of several pure substances rather than a single pure substance. Therefore it is important to develop an understanding of mixtures and learn in handling them.

COMPOSITION OF A GAS MIXTURE:

① MASS FRACTION

If a gas mixture consists of gases 1, 2, 3 and so on, the mass of the mixture is the sum of masses of the individual component gases

$$m_m = m_1 + m_2 + m_3 + \cdots + m_i = \sum_{i=1}^{K} m_i$$

$$x_i = \frac{m_i}{m_m}$$

② MOLAR FRACTION

It is the ratio of the mole number of a component to the mole number of the mixture. The total number of moles

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f}$$

$$s_{fg} = s_g - s_f$$

$$v_{fg} = v_g - v_f$$

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f}$$

$$\frac{dp}{dT} = \frac{s_{fg}}{v_{fg}}$$

From Second law of Thermodynamics,

$$ds = \frac{dQ}{T}$$

For Constant Pressure Process

$$dQ = dh$$

$$ds = \frac{dh}{T}$$

$$s_{fg} = \frac{h_{fg}}{T}$$

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f} = \frac{s_{fg}}{v_{fg}} = \frac{h_{fg}}{Tv_{fg}}$$

This equation is known as Clapeyron Equation of a mixture is the sum of the number of its components.

$$N_m = N_1 + N_2 + N_3 + \cdots + N_i = \sum_{i=1}^{k} N_i$$

$$y_i = \frac{N_i}{N_m}$$

③ PARTIAL PRESSURE AND PARTIAL VOLUME

The sum of partial pressures of the components of a gas mixture is equal to the mixture pressure.

$$P_i = y_i P_m$$

y_i = mole fraction

P_m = mixture pressure.

DALTON'S LAW OF PARTIAL PRESSURE:

According to Dalton's law of partial pressure the pressure of a gas mixture is equal to the sum of pressure of its each components if each component is exerted alone of the temperature and volume of the mixture. This law is also called as Dalton's law of additive pressure.

AMAGAT'S LAW OF PARTIAL VOLUME:

According to Amagat's law of partial volumes the volume of a gas mixture is equal to the sum of the volumes of each gas if each gas is existed alone at the temperature and pressure of the mixture.

PROPERTIES OF GAS MIXTURES:

① PRESSURE:

Using Dalton's law of partial pressure, the pressure of a mixture is the sum of pressures of each component at the temperature and volume of the mixture.

② VOLUME:

Using Amagat's law of partial volumes the volume of mixture is the sum of volume of each component at the temperature and pressure of the mixture.

③ TEMPERATURE:

At uniform mixture the temperature is the same for each component of the mixture.

$$\omega = 0.622 \frac{p_v}{p_b - p_v}$$

$$= 0.622 \times \frac{0.035986}{1 - 0.035986}$$

$$\omega = 0.0232 \text{ kg/kg of dry air}$$

$$\phi = \frac{p_v}{p_s}$$

$$= \frac{0.035986}{0.07375}$$

$$\phi = 0.488 = 48.8\%$$

$$h = C_p t_d + \omega h_g$$

$$= 1.005 \times 40 + 0.0232 \times 2574.4$$

$$h = 99.93 \text{ kJ/kg}$$

Atmospheric air with barometric pressure of 1.013 bar has 38°c dry bulb temperature and 28°c wet bulb temperature. Without the aid of psychrometric chart determine humidity ratio, relative humidity and dew point temperature.

Given data:

$p_b = 1.013$ bar

$t_d = 38°C$

$t_w = 28°C$

Solution:

$$P_v = P_{sw} - \frac{(P_b - P_{sw})(t_d - t_w)}{1527.4 - 1.3t_w}$$

$$= 0.03778 - \frac{(1 - 0.03778)(38 - 28)}{1527.4 - 1.3 \times 28}$$

$$P_v = 0.031326 \text{ bar}$$

$$\omega = \frac{0.622 \; P_v}{P_b - P_v}$$

$$= 0.622 \times \frac{0.031326}{1 - 0.031326}$$

$$\omega = 0.01985 \text{ kg / kg of dry air}$$

$$\phi = \frac{P_v}{P_s}$$

$$= \frac{0.031326}{0.06624}$$

$$\phi = 0.4729 = 47.29\,\%$$

$$t_{dp} = 25^\circ C$$

$$\Delta S_a = m_a c_{p_a} \ln\left(\frac{T_m}{T_a}\right)$$

$$= 45 \times 1.005 \ln\left(\frac{408.2}{423}\right)$$

$$\Delta S_a = -1.61 \text{ kJ/k}$$

$$\Delta S_m = \Delta S_{Me} + \Delta S_a$$

$$= 1.773 - 1.61$$

$$\Delta S_m = 0.163 \text{ kJ/k}$$

Air contains 21% of oxygen and 79% of nitrogen by volume. Determine the molecular weight of air, R and density at STP.

Given data:

The pressure and temperature at STP are 1 bar and 23°C respectively

Solution:

$$M_O = 16$$

$$O_2 = 16 \times 2 = 32$$

$$M_N = 14$$

$$N_2 = 14 \times 2 = 28$$

$$M_a = \frac{21 \times 32 + 79 \times 28}{21 + 79}$$

$$M_a = 28.84 \text{ kg/kg mole}$$

$$R_a = \frac{R}{M_a}$$

$$= \frac{8.314}{28.84}$$

$$R_a = 0.288 \text{ kJ/kgK}$$

$$\rho_a = \frac{M_a}{\text{Volume}}$$

$$= \frac{28.8}{22.4}$$

$$\rho_a = 1.29 \text{ kg/m}^3$$

PSYCHROMETRY:

The science which deals with the study of behaviour of moist air is known as psychrometry.

PSYCHROMETRIC PROPERTIES:

① DRY AIR:

The dry air is nothing but the air without moisture or water vapour. The pure dry air is a mixture of number of gases such as nitrogen, oxygen, carbon dioxide, hydrogen, etc., among these except nitrogen and oxygen other gases present only in negligible quantity.

② MOIST AIR:

It is a mixture of dry air and water vapour. The amount of water vapour present in the moist air varies with temperature.

③ SATURATION CAPACITY OF AIR:

The maximum quantity of water vapour present in the air at particular air temperature is known as saturation capacity of air

④ MOISTURE:

The water vapour present in the air is known as moisture.

⑤ DRY BULB TEMPERATURE ($DBT - t_d$)

The temperature measured by an ordinary thermometer is known as dry bulb temperature.

⑥ WET BULB TEMPERATURE ($WBT - t_w$)

It is the temperature of air measured by a thermometer when its bulb is covered with wet cloth and is exposed to a current rapidly moving air.

⑦ WET BULB DEPRESSION (WBD)

It is the difference between dry bulb temperature and wet bulb temperature.

$$WBD = DBT - WBT = t_d - t_w$$

⑧ DEW POINT TEMPERATURE ($DPT - t_{dp}$)

It is the temperature at which the water vapour present in air begins to condense when the air is cooled.

For saturated air the dry bulb, wet bulb and dew point temperature are all same

⑨ DEW POINT DEPRESSION (DPD) :

It is the difference between dry bulb temperature and dew point temperature.

$$DPD = DBT - DPT$$

⑩ SPECIFIC HUMIDITY (OR) HUMIDITY RATIO (OR) MOISTURE CONTENT (ω)

It is defined as the mass of water vapour present in one kg of dry air. It is the ratio of the mass of water vapour to the mass of dry air in a given volume of the moisture.

$$\omega = \frac{\text{Mass of water vapour } (m_v)}{\text{Mass of dry air } (m_a)}$$

⑪ DEGREE OF SATURATION (OR) PERCENTAGE SATURATION (μ) (OR) SATURATION RATIO

It is defined as the ratio of specific humidity of the moist air to the specific humidity of saturated air at the same temperature.

$$\mu = \frac{\text{Specific humidity of moist air } (\omega)}{\text{Specific humidity of saturated air } (\omega_s)}$$

(12) RELATIVE HUMIDITY (ϕ)

It is defined as the of the actual mass of water vapour in a given volume to the saturated mass of water in same volume and temperature.

$$\phi = \frac{\text{Mass of water vapour in a given volume } (m_v)}{\text{Saturated mass of water vapour in same volume of temperature } (m_s)}$$

(13) TOTAL ENTHALPY (TOTAL HEAT) OF MOIST AIR (h):

It is the sum of the enthalpy of dry air and the enthalpy of water vapour associated with the dry air

$$H = C_p t_d + \omega h_g$$

C_p - Specific heat at constant pressure = 1·005 kJ/kgK

t_d - Dry Bulb Temperature.

ω - Specific humidity

h_g - Specific enthalpy a air corresponding to dry bulb temperature.

DALTON'S LAW OF PARTIAL PRESSURE:

The total pressure exerted by air and water vapour mixture is equal to the barometric pressure.

$$p_b = p_a + p_v$$

p_b – Barometric pressure

p_a – Partial pressure of dry air

p_v – Partial pressure of water vapour.

Dry bulb and wet temperatures of 1 atmospheric air stream are 40°C and 30°C respectively. Determine ⓐ Humidity ratio ⓑ Relative humidity ⓒ Specific enthalpy.

Given data:

$t_d = 40^\circ C$

$t_w = 30^\circ C$

$p_b = 1$ bar

Solution:

$$p_v = p_{sw} - \frac{(p_b - p_{sw})(t_d - t_w)}{1527.4 - 1.3 t_w}$$

$$p_v = 0.04242 - \frac{(1 - 0.04242)(40-30)}{1527.4 - 1.3 \times 30}$$

$$p_v = 0.035986 \text{ bar}$$

ne moist air is at 45°C dry bulb temperature and 30°C wet bulb temperature. Calculate

- ⓐ Vapour pressure
- ⓑ Dew point temperature
- ⓒ Specific humidity
- ⓓ Relative humidity
- ⓔ Degree of saturation
- ⓕ Vapour density
- ⓖ Enthalpy of mixture.

Given data:

$t_d = 45°C$

$t_w = 30°C$

$p_b = 1$ bar

Solution:

$$p_v = p_{sw} - \frac{(p_b - p_{sw})(t_d - t_w)}{1527.4 - 1.3 t_w}$$

$$= 0.04242 - \frac{(1 - 0.04242)(45 - 30)}{1527.4 - 1.3 \times 30}$$

$$p_v = 0.03277 \text{ bar}$$

$t_{dp} = 25.26°C$

$$\omega = 0.622 \frac{P_v}{P_b - P_v}$$

$$= 0.622 \times \frac{0.03277}{1 - 0.03277}$$

$\omega = 0.02107$ kg/kg of dry air

$$\phi = \frac{P_v}{P_s}$$

$$= \frac{0.03277}{0.09582}$$

$\phi = 0.342 = 34.2\%$

$$\mu = \frac{P_v}{P_s}\left(\frac{P_b - P_s}{P_b - P_v}\right)$$

$$= \frac{0.03277}{0.09582}\left(\frac{1 - 0.09582}{1 - 0.03277}\right)$$

$\mu = 0.3197$

$$\rho_v = \frac{1}{v_g} = \frac{1}{15.276} = 0.06546 \text{ kg/m}^3$$

ρ_v at $34.2\% = 0.06546 \times 34.2 = 0.0224$ kg/m^3

$$h = C_p t_d + \omega h_g$$

$$= 1.005 \times 45 + 0.0210 \times 2583.3$$

$h = 99.65$ kJ/kg

PART - A

① What is meant by Control volume and Control Surface?

A specified large number thermal device has the mass flow in and out of a system is called as control volume. Generally any arbitrary region in space can be selected as a control volume.

Both the mass and energy can cross the boundary of a control volume called as control surface.

② Using knudsen number define continuum.

A continuous homogeneous medium is called as continuum. It is based on the macroscopic approach. The continuum idealization allows us to treat the properties as point functions and assumes the properties varying continually in space with no jump discontinuities. The concept of continuum is valid when the mean path of molecules approaches the magnitude of the vessel dimensions as well as macroscopic approach.

③ Define heat reservoir and source.

The ideal body having large thermal energy capacity which either continuously supplies or absorbs the infinite amount of heat without changing its temperature is called heat reservoir. If the reservoir continuously supplies heat energy to the system it is called sourc

④ What is Helmholtz Free Energy Function?

Helmholtz function is property of a system and it is given by subtracting the product of absolute Temperature (T) and entropy (s) from the internal energy u.

Helmholtz function = u - Ts

⑤ What is critical condition of steam?

It represents the highest pressure and temperature at which the liquid and vapour phases coexist in equilibrium. At the critical point the liquid and vapour phases are indistinguishable i.e., Liquid is directly converted into vapour.

⑥ What do you understand by Heat Rate?

Heat Rate is the ratio between the heat supplied and net work output.

⑦ State the principle of corresponding states.

According to vander Waals, the theorem of corresponding states indicates that all fluids when compared at the same reduced temperature and reduced pressure, have approximately the same compressibility factor and all deviate from ideal gas behaviour to about the same degree.

⑧ Identify the appliation of Clausius-Clapeyron equation

Clapeyron equation which involves the relationship between the saturation pressure, saturation temperature, the enthalpy of evaporation and the specific volume of the two phase involved. This equation provides a basis for calculation of properties in a two phase region.

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f} = \frac{s_{fg}}{v_{fg}} = \frac{h_{fg}}{T v_{fg}}$$

⑨ What is meant by partial volume?

The partial volume of a particular gas in a mixture is the volume of one component of the gas mixture. It is useful in gas mixtures eg air to focus on one particular gas component oxygen.

⑩ Define adiabatic saturation temperature

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

PART - B

⑪ ⓐ ① Derive the expression for the displacement work.

Work is an energy interaction between a system and its surroundings. Usually the energy can cross the boundary of any system in the form of either heat or work. But the energy crossed through the boundary in a closed system is definitely in the form of work.

As with the heat the amount of work done by or on a system depends upon the path and not simply on the initial and final conditions of the system.

Work is defined as the product of force and the distance moved in the direction of the force. Specifically it is the energy transfer associated with force acting through a distance.

Work = Force × Distance moved.

$$W = F \times x$$

The work is expressed in terms of N-m or J

The work done per unit time is called power. The unit of power is kJ/s or kW.

(ii) Determine the work transfer and heat transfer for a system in which a perfect gas having molecular weight of 16 kg/k mol is compressed from 101.3 kPa, 20°C to a pressure of 600 kPa following the law $pV^{1.3}$ = constant. Take specific heat at constant pressure of gas as 1.7 kJ/kgK.

Given data:

$M = 16 \text{ kg / k mol}$

$P_1 = 101.3 \text{ kPa} = 101.3 \times 10^3 \text{ N/m}^2$

$T_1 = 20^\circ C = 293 \text{ K}$

$P_2 = 600 \text{ kPa} = 600 \times 10^3 \text{ N/m}^2$

$pV^{1.3} = C$

$C_p = 1.7 \text{ kJ/kg K}$

To find:

W, Q

Soln:

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

$$R = \frac{R_u}{M} = \frac{8.314}{16} = 0.520 \text{ kJ/kgK}$$

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

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

$$= 293 \times \left(\frac{600 \times 10^3}{101.3 \times 10^3}\right)$$

$$T_2 = 1735.44\ k$$

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

$$= \frac{0.520 \times 10^3 \left(293 - 1735.44\right)}{1.3 - 1}$$

$$W = -2500229.33\ J = -2500.23\ kJ$$

$$Q = \text{Zero.}$$

⑪ ⓑ ⓘ Write the steady flow energy equation and simplify it to be applicable for a gas turbine and a compressor.

Consider an open system through in which the working substance flows as a steady rate.

By first law of thermodynamics

Total energy entering the system = Total energy leaving the system

$$gz_1 + \frac{c_1^2}{2} + u_1 + p_1v_1 + Q = gz_2 + \frac{c_2^2}{2} + u_2 + p_2v_2 + W$$

$$gz_1 + \frac{c_1^2}{2} + h_1 + Q = gz_2 + \frac{c_2^2}{2} + h_2 + W$$

Gas Turbine:

It is a device which converts the potential energy of working fluid into mechanical work. The turbine is fully insulated. There is no heat transfer. $Q = 0$. In the turbine the expansion of working fluid is treated as reversible adiabatic or isentropic. The change in potential and kinetic energy is negligible. $z_1 = z_2$ and $c_1 = c_2$

Applying SFEE to the above system,

$$h_1 = h_2 + W$$

$$W = h_1 - h_2$$

Air Compressor:

It is a device which is used to compress air from low pressure to high pressure. The input for this compressor is atmospheric pressure.

Rotary Compressor:

i, $Q = 0$

ii, $Z_1 = Z_2$

iii, $C_1 = C_2$

Then the SFEE can be written as

$$h_1 = h_2 - W$$

$$W = h_2 - h_1$$

Reciprocating Compressor:

i, $Z_1 = Z_2$

ii, $C_1 = C_2$

Then the SFEE can be written as

$$h_1 - Q = h_2 - W$$

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

(ii) In a gas turbine installation air is heated inside heat exchanger upto 750°c from ambient temperature of 27°C. Hot air then enters into gas turbine with the velocity of 50 m/s and leaves at 600 °c. Air leaving turbine enters a nozzle at 60 m/s velocity and leaves nozzle at temperature of 500°C. For unit mass flow rate of air determine the following assuming adiabatic expansion in turbine and nozzle.

① heat transfer to air in heat exchanger

② power output from turbine

③ velocity at exit of nozzle

Take C_p for air as 1.005 kJ/kg k.

Given data:

$T_1 = 27°c = 300 k$

$C_1 = 50\ m/s$

$T_2 = 750°c = 1023\ k$

$C_2 = 50\ m/s$

$T_3 = 600°c = 873\ k$

$C_3 = 60\ m/s$

$T_4 = 500°C = 773\ k$

$= 1 kg/s$

To find:

$$Q_{1-2}\,,\; W_{2-3}\,,\; C_4$$

Solution:

SFEE between 1-2

$$m\left[gz_1 + \frac{C_1^2}{2} + h_1\right] + Q_{1-2} = m\left[gz_2 + \frac{C_2^2}{2} + h_2\right] + W_{1-2}$$

$$W_{1-2} = 0\,,\quad z_1 = z_2$$

$$m\left[h_1 + \frac{C_1^2}{2}\right] + Q_{1-2} = m\left[h_2 + \frac{C_2^2}{2}\right]$$

$$C_1 = C_2$$

$$Q_{1-2} = m\left(h_2 - h_1\right) = mC_p\left(T_2 - T_1\right)$$

$$= 1 \times 1.005 \times \left(1023 - 300\right)$$

$$Q_{1-2} = 726.615 \text{ kW}$$

SFEE between 2-3

$$m\left[gz_2 + \frac{C_2^2}{2} + h_2\right] + Q_{2-3} = m\left[gz_3 + \frac{C_3^2}{2} + h_3\right] + W_{2-3}$$

$$Q_{2-3} = 0\,,\quad z_2 = z_3$$

$$m\left[h_2 + \frac{C_2^2}{2} + gZ_2\right] = m\left[h_3 + \frac{C_3^2}{2}\right] + W_{2-3}$$

$$\left[1.005 \times 1023 + \frac{50^2}{2}\right] = \left[1.005 \times 873 + \frac{60^2}{2}\right] + W_{2-3}$$

$$W_{2-3} = 150.2 \text{ kW}$$

Applying SFEE between 3-4

$$m\left[h_3 + \frac{C_3^2}{2} + gZ_3\right] + Q_{3-4} = m\left[h_4 + \frac{C_4^2}{2} + gZ_4\right] + W_{3-4}$$

$$Z_3 = Z_4 , \quad Q_{3-4} = 0 , \quad W_{3-4} = 0$$

$$m\left[h_3 + \frac{C_3^2}{2}\right] \pm m\left[h_4 + \frac{C_4^2}{2}\right]$$

$$1.005 \times 873 + \frac{60^2}{2} = 1.005 \times 773 + \frac{C_4^2}{2}$$

$$C_4 = 452.33 \text{ m/s}$$

⑫ ⓐ ⓘ Show that the efficiency of the reversible heat engine depends only on the maximum and minimum absolute temperature in the cycle.

Heat engine is a device which operates a thermodynamic cycle and produces work by supplying heat from hot reservoir. Example : IC engine, Boiler etc.

The performance of any engine is measured by the term efficiency. It is defined as the ratio of network output produced by an engine to the amount of heat supplied to the engine.

$$\eta = \frac{\text{Net work output}}{\text{Total heat input}} = \frac{W}{Q_S}$$

$$W = Q_S - Q_R$$

$$\eta = \frac{Q_S - Q_R}{Q_S} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

(ii) A fluid undergoes a reversible adiabatic compression from 4 bar, 0.3 m^3 to 0.08 m^3 according to the law $pV^{1.25} = C$. Determine the change in enthalpy, the change in internal energy and change in entropy

Given data:

$P_1 = 4 \text{ bar} = 4 \times 10^5 \; N/m^2$

$V_1 = 0.3 \; m^3$

$V_2 = 0.08 \; m^3$

$pV^{1.25} = C.$

To find:

$\Delta H, \; \Delta U, \; \Delta S$

Soln:

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

$$P_2 = 4 \times 10^5 \left(\frac{0.3}{0.08}\right)^{1.25}$$

$$P_2 = 20.87 \times 10^5 \; N/m^2$$

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

$$= \frac{4 \times 10^5 \times 0.3 - 20.87 \times 10^5 \times 0.08}{1.25 - 1}$$

$$\Delta U = -187840 \text{ J} = -187.84 \text{ kJ}$$

ΔH = Zero.

ΔS = Zero.

(12) (b) (i) State and prove Carnot theorem

Carnot theorem states that No heat engine operating in a cyclic process between two fixed temperatures can be more efficient than a reversible engine which is operating between the same temperature limit.

(ii) Air flows through an adiabatic compressor at 2 kg/s. The inlet condition are 100 kPa and 310 k and the exit conditions are 700 kPa and 560 k. Consider T_0 to be 298 k Determine the change of availability and the irreversibility

Given data:

$m = 2\ \text{kg/s}$

$P_1 = 100\ \text{kPa} = 100 \times 10^3\ \text{N/m}^2$

$T_1 = 310\ \text{K}$

$P_2 = 700\ \text{kPa} = 700 \times 10^3\ \text{N/m}^2$

$T_2 = 560\ \text{K}$

$T_0 = 298\ \text{K}$

To find:

Change of availability and irreversibility

Solution:

$$\Delta S = S_2 - S_1$$

$$= m\left[C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)\right]$$

$$= 2\left[1.005 \ln\left(\frac{560}{310}\right) - 0.287 \ln\left(\frac{700\times10^3}{100\times10^3}\right)\right]$$

$$= 0.07169\ \text{kJ/kg K}$$

Change in availability

$$\psi_1 - \psi_2 = m(h_1 - h_2) - T_0(s_1 - s_2)$$

$$= 2 \times 1.005(310 - 560) - 298(-0.07169)$$

$$= -481.14 \text{ kJ/kg}$$

⑬ ⓐ ⓘ Explain the process of formation of steam with T-s diagram

It is also called as Mollier chart. In T-s diagram the vertical ordinate represents the Temperature while the base represents the entropy. In this diagram the dry steam line divides the chart into two regions. The region which is below the dry steam line represents the wet condition of steam. The dryness fraction lines are shown parallel to dry steam line. During isentropic expansion in turbine entropy remains constant.

(ii) 3 kg of steam at 18 bar occupy a volume of 0.2550 m³. During a constant volume process the heat rejected is 1320 kJ. Determine final internal energy also find initial dryness and work done.

Given data:

$m = 3\ kg$

$P_1 = 18\ bar$

$V_1 = V_2 = 0.2550\ m^3$

$Q_R = 1320\ kJ$

To find:

$U_2,\ x_1,\ W$

Solution:

From steam table at 18 bar

$$T_S = 207.1^\circ C$$

$$h_{f_1} = 884.5 \ kJ/kg$$

$$h_{fg_1} = 1910.3 \ kJ/kg$$

$$v_{g_1} = 0.11033 \ m^3/kg$$

$$V_1 = x_1 \ v_{g_1}$$

$$0.2550 = x_1 \times 0.11033$$

$$x_1 = 2.3112 \ kg$$

Question Bank

ME 6301

Engineering Thermodynamics

Unit I

Unit I – University Question

1.) April/May 2017

A gas occupies $0.028 m^3$ at 1.4 bar. It executes a cycle consists of processes.

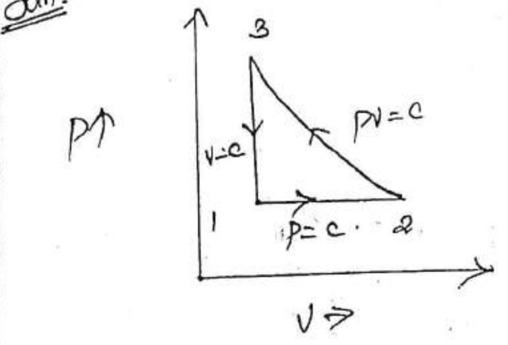
(i) 1 – 2, Constant pressure with work interaction of ~~15 kJ~~ 10.5 kJ

(ii) 2 - 3, Compression process which follows the law $PV = C$ and $U_3 = U_2$ and

(iii) 3-1, Constant Volume process, and reduction in internal energy is 40 kJ.

Neglecting the changes in kinetic energy and potential energy. Draw PV Diagram for the process and determine the Net work transfer for the cycle. Also show that 1st law is obeyed by the cycle.

Soln:-



① - ② ⇒ Constant Pressure process

$$W_{1-2} = P_1(V_2 - V_1).$$

$V_2 = 0.103 m^3$

② - ③ ⇒ Constant Temp. process:

$W_{2-3} = P_2V_2 \ln V_3/V_2$

$W = -18.8 kJ$

$\Delta U = 0$

$Q_{2-3} = W = -18.78 kJ$

③ - ① ⇒ Constant Volume process.

$V_1 = V_3 = 0.103 m^3$

$W_{3-1} = 0, \quad Q_{3-1} = -26.4 kJ$

$W_{Net} = -8.28 kJ$

$U_{1-2} = 20.4 kJ$

$Q_{1-2} = W_{1-2} + U_{1-2} = 36.9 kJ$

$Q_{Net} = -8.28 kJ$

$\Sigma Q_{cycle} = \Sigma W_{cycle}.$

Gn data

$P_1 = P_2 = 1.4 bar = 140 kN/m^2$

$V_1 = 0.028 m^3$

1-2 Constant Pressure Process

$W_{1-2} = 10.5 kJ$

①-② ⇒ Constant Pressure process

$W_{1-2} = P_1 (V_2 - V_1)$

$10.5 = 140 \times (V_2 - 0.028)$

$V_2 = 0.103 m^3$

②-③ ⇒ Constant temp process

$W_{2-3} = P_2 V_2 \ln (V_3/V_2)$

$= 140 \times 0.103 \times \ln\left(\frac{0.028}{0.103}\right)$

$= -18.78 kJ$

$\Delta U = U_3 - U_2 = 0$

$Q_{2-3} = W = -18.78 kJ$

③-① ⇒ Constant Volume process

$V_1 = V_3 = 0.103 m^3$

$W_{3-1} = 0$

$Q_{3-1} = U_1 - U_3 = -26.4 kJ$

$W_{Net} = W_{1-2} + W_{2-3} + W_{3-1}$

$= 10.5 - 18.78 + 0$

$= -8.28 kJ$

$U_{1-2} = U_2 - U_1$

$= (U_2 - U_3) + (U_3 - U_1)$

$= 0 + -(-26.4)$

$= 26.4 \text{ kJ}$

$Q_{1-2} = W_{1-2} + U_{1-2}$

$= 10.5 + 26.4$

$= 36.9 \text{ kJ}$

Net heat transfer of the cycle $Q_{Net} = Q_{1-2} + Q_{2-3} + Q_{3-1}$

$= 36.9 - 18.78 - 26.4$

$= -8.28 \text{ kJ}$

$\Sigma Q_{cycle} = \Sigma Q_{cycle} = \Sigma W_{cycle}$.

Hence. proved

Q) In a gas turbine, the gases enter the turbine at the rate of 5 kg/s with a velocity of 50m/s and enthalpy of 900 kJ/kg and leaves the turbine with 150m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surroundings is 25kJ/kg. Assume R = 0.285 kJ/kgk, 5

C_p = 1.004 KJ/kgk and inlet Conditions to be at 100 kpa and 27°c. Det The N.D and diameter of The inlet pipe. (April/May 2017)

Soln:

Gn data

$m = 5$ kg/s

$C_1 = 50$ m/s

$h_1 = 900$ KJ/kg

$h_2 = 400$ KJ/kg

$C_2 = 150$ m/s

$Q = -25$ KJ/kg

$R = 0.285$ KJ/kgk

$C_p = 1.004$ KJ/kgk

$P_1 = 100$ kPa

$T_1 = 27°c$.

SFEE

$$m(h_1 + C_1^2/2 + z_1 g) + Q = m(h_2 + C_2^2/2 + z_2 g) + W$$

$$5\left(900 + \frac{150^2}{2000}\right) - 25 = 5\left(400 + \frac{150^2}{2000}\right) + W$$

$$W = 2425 \text{ kW}$$

From ideal Gas Eqn

$$P_1V_1 = m R T_1$$

$$V_1 = \frac{5 \times 0.285 \times 300}{100000}$$

$$V_1 = 4.275 \text{ m}^3/\text{s}$$

$$\dot{m} = \frac{A_1 C_1}{\vartheta_1}$$

$$= \frac{\pi/4 \times d_1^2 \times 50}{4.275}$$

$$\dot{m} = 738 \text{mm}$$

Nov/Dec 2016:

2) A piston - cylinder device containing 0.15 kg of air initially at 2 MPa and 350°C. The air is 1st expanded isothermally to 500 kPa, Then Compressed polytropically with a polytropic exponent of 1.2 to the initial pressure, and finally Compressed at the Constant pressure to the initial state. Determine the boundary work for each process and the network of the cycle.

$$V_1 = \frac{mRT_1}{P_1}$$

$$= \frac{0.15 \times 0.287 \times (350+273)}{2000}$$

$$= 0.01341\, m^2$$

$$V_2 = \frac{mRT}{P_2}$$

$$= \frac{0.15 \times 0.287 \times (350+273)}{500}$$

$$= 0.05365$$

$$W_{1-2} = P_1 V_1 \ln(V_2/V_1)$$

$$= 37.2\, kJ$$

Polytropic Compression

$$P_2 V_2^n = P_3 V_3^n$$

$$\Rightarrow \quad = 500 \times (0.05365)^{1.2}$$

$$= 2000 \times V_3^{1.2}$$

$$= 0.0169\, m^3$$

$$W_{2-3} = \frac{P_3V_3 - P_2V_2}{1-n}$$

$$= \frac{(2000 \times 0.0169) - (500 \times 0.05364)}{1-1.2}$$

$$= -34.9 \text{ kJ}$$

Constant pressure Compression

$$W_{3-1} = P_3(V_1 - V_3)$$

$$= 2000 \times (0.01341 - 0.0169)$$

$$= -6.98 \text{ kJ}$$

Net Work

$$W_{net} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$= 37.2 + -34.9 - 6.98$$

$$= -4.68 \text{ kJ}$$

(b)(ii) Air enter the Compressor of a Gas turbine plant at ambient Conditions of 100 kPa and 25°C with a low Velocity and exits at 1 MPa and 347°C with a Velocity of 90 m/s. The Compressor is Cooled at a rate of 1500 kJ/min and the power input to the Compressor is 250 kW. Det the Mass flow rate of air through the Compressor. Assume $C_p = 1.005$ kJ/kgk. (Nov/Dec 2016)

Soln:

Gn data

$T_1 = 298k$

$h_1 = 298.2$ kJ/kg

$T_2 = 620k$

$\Rightarrow h_2 = 628.07$ kJ/kg

$m_1 = m_2 = m$

By SFEE

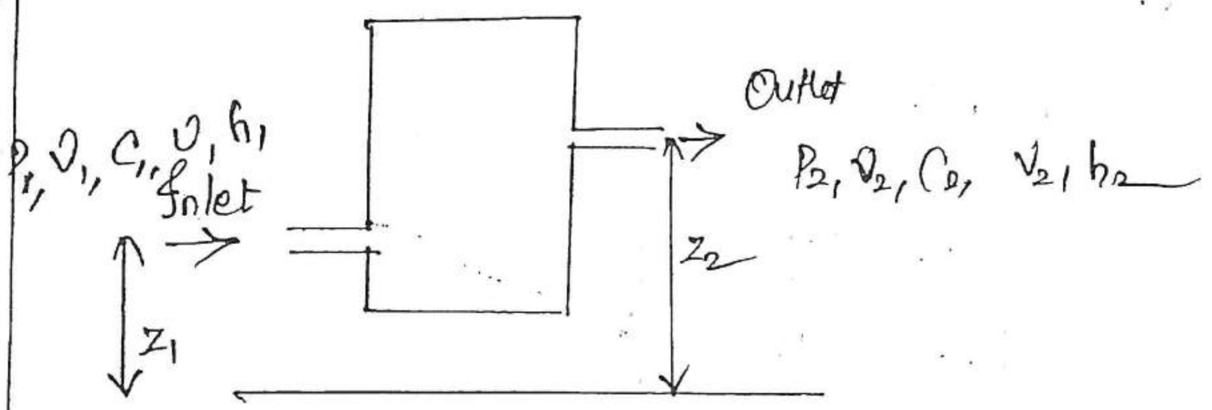
$$Q - W = m\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

$= -1500/60 + 250$

$= m\left[628.07 - 298.2 + \frac{90^2 - 0}{2}\right]$

$\Rightarrow \dot{m} = 0.674$ kg/s

(ii) Derive Steady State Energy Equation



Total Energy Entering the System $= P.E + K.E + I.E + F.E$ + Heat Energy

$$= gz_1 + \frac{C_1^2}{2} + u_1 + P_1v_1 + Q$$

Total Energy leaving the System $= gz_2 + \frac{C_2^2}{2} + u_2 + P_2v_2 + W$

Energy in = E out

$$gz_1 + \frac{C_1^2}{2} + u_1 + P_1v_1 + Q = gz_2 + \frac{C_2^2}{2} + u_2 + P_2v_2 + W$$

$$\Rightarrow m\left(\frac{gz_1}{1000} + \frac{C_1^2}{2000} + h_1\right) + Q = m\left(\frac{gz_2}{1000} \frac{+C_2^2}{2000} + h_2\right) + W.$$

May/ June 2016

5) 12) a) A Mass of air is initially at 260° and 700kPa and occupies 0.028m³. The air is expanded at Constant pr of 0.084 m³. A polytropic process with n = 1.5 is then carried out, followed by a Constant Temp. process. All the processes are reversible.

1) Sketch the cycle in PV and TS plane
2) Find the heat received and heat rejected in the cycle
3) Find the efficiency of the cycle.

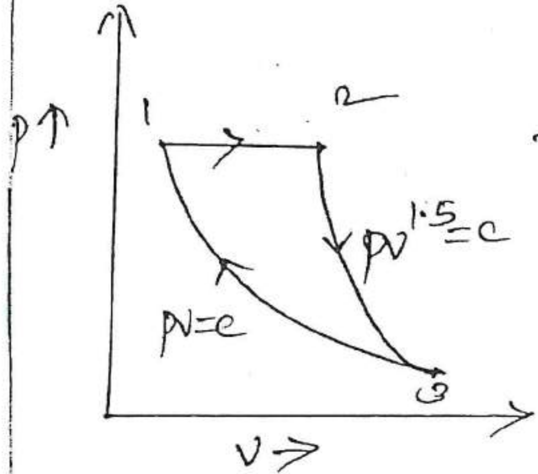
Gin data

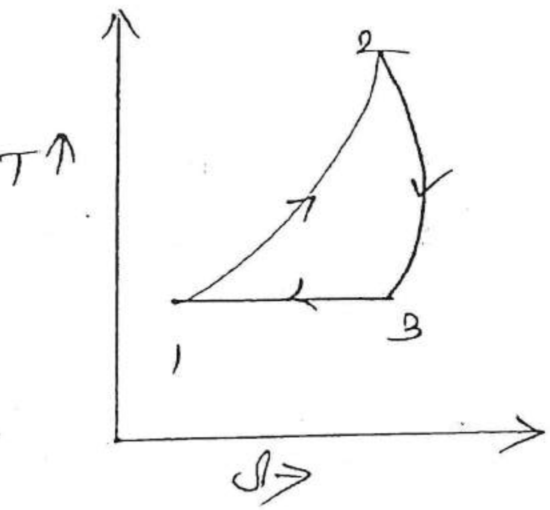
$T_1 = 533 k$

$P_1 = 700$ kPa

$V_1 = 0.028 m^3$

$V_2 = 0.084 m^3$





process ①-② ⇒

$V_1/T_1 = V_2/T_2$

$T_2 = 1599 K.$

$$\dot{m} = \frac{PV}{RT} = \frac{700 \times 0.028}{0.287 \times 533}$$

$= 0.128$ kg.

$\dot{W} = P(V_2 - V_1)$

$= 39.2$ kJ

$Q_{1-2} = mC_p(T_2 - T_1)$

$= 137.13$ kJ

process ②-③ ⇒

$T_3/T_2 = (P_3/P_2)^{n-1/n}$

$P_3 = 25.93$ kPa

$P_3V_3 = mRT_3$

$V_3 = 0.755\ m^3$

$$W_{2-3} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{700 \times 0.084 - 25.93 \times 0.755}{1.5-1}$$

$= 78.446$ kJ

$$Q = \frac{\gamma - n}{\gamma - 1} . W_{2-3}$$

$$= \frac{1.4 - 1.5}{1.4 - 1} \times 78.446$$

$= -19.612$ kJ

process ③-① ⇒

$T_1 = T_3 = 260^\circ C = 533 K$

$W_{3-1} = -P_3 V_3 \ln(P_1/P_3)$

$= -64.5 \text{ KJ}$

$Q_S = 137.1 \text{ KJ}$

$Q_R = 19.612 + 64.52$

$= 84.132 \text{ KJ}$

$\eta = W.D / Q_S$

$$= \frac{39.2 + 78.446 - 64.52}{137.13}$$

$= 38.74\%$

$\eta = 1 - Q_R / Q_S$

$$= 1 - \frac{84.132}{137.13}$$

$= 38.74\%$

3) A room for four persons has two fans, each consuming 0·18 KW power and 3 100W lamps. Ventilation air at the rate of 80 kg/hr enters with an enthalpy of 84 KJ/kg and leaves with an enthalpy of 59 KJ/kg. If each person puts out heat at the rate of 630 KJ/hr, determine the rate at which heat is to be removed by a room cooler so that a steady state is maintained in the room. (May/June 2016)

Soln:-

Gn data $n_p = 4$, $n_f = 2$

$$W_F = 0{\cdot}18 \text{ kW}$$

$W_l = 100 \text{W}$

$\dot{m} = \frac{80}{3600}$ kg/s

$h_1 = 84$ kJ/kg

$h_2 = 59$ kJ/kg

$Q_p = 630$ kJ/hr

$Q = F - mC(h_1 - h_2) - W$

$F = -\eta_p Q_p$

$= -4 \times \frac{360}{3600}$

$= -0.7\,kW$

$mC(h_1 - h_2) = \frac{80}{3600}(84 - 59)$

$= 0.55\,kJ/s = 0.55\,kW$

W= electrical Energy input

$= 2 \times 0.18 + \frac{3 \times 100}{1000}$

$= 0.66\,kW$

$Q = -0.7 - 0.556 - 0.66$

$= -1.916\,kW$.

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UNIT - I

1) 7) Three grams of N_2 @ 6 atm and 160°c in a frictionless Piston cylinder device is expanded adiabatically to double its Initial volume, then Compressed at Const. pressure to its initial Volume and then Compressed again at cont. volume to its initial State. Calculate the net work done on the gas. Draw P-V diagram for the Processes. [NOV/DEC 14]

Given

$m = 3g = 0.003kg$

$P_1 = 6atm = 6\times1.0132 = 6.0792 bar$

$= 607.92 kPa.$

$T_1 = 160°c = 433k.$

Process 1-2 ⇒ adiabatic expansion. $(V_2 = 2V_1)$

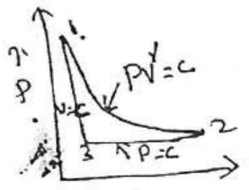
Process 2-3 ⇒ Const. Pr. Compression $(P_2 = P_3)$

Process 3-4 ⇒ Cont. Vol. compression $V_3 = V_1$

To find - Net work done & PV diagram

$\hookrightarrow W_{1-2} + W_{2-3} + W_{3-1}$

Soln



Step i,

$$* \; W_{1-2} = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

* From adiabatic process

$P_1V_1^\gamma = P_2V_2^\gamma$ [To find P_2].

$$* \; P_2 = P_1\left(\frac{V_1}{V_2}\right)^\gamma \Rightarrow \begin{array}{l} V_2 = 2V_1 \\ \gamma = 1.4 \text{ for adiabatic process} \end{array}$$

* $P_2 = 2.304 bar$ (or) $230.4 kPa$.

* To find V_2

$P_1V_1 = MRT_1$ $\boxed{V_1 = \frac{V_2}{2} \text{ [from given data]}}$

$\boxed{R = \frac{R_u}{M}}$ R_u ← universal gas const; M ← molecular wt. of N_2.

Molecular wt. of $N_2 = 2\times14 = 28$

$R_u = 8.314.$

$$\boxed{R = 0.297 kJ/kg\cdot k}$$

$V_2 = 0.000635 m^3$ ∴ $\boxed{W_{1-2} = 0.319 kJ}$

Step (ii)

$W_{2-3} = P_2 (V_3 - V_2)$ [∵ Isobaric Process (or) Const. Pr. Process]

$V_3 = V_1$

$\therefore W_{2-3} = -0.146$ kJ.

Step (iii)

$W_{3-1} = 0$ [Isochoric (or) Const. Vol. Process]

Step (iv) $W_{net} = W_{1-2} + W_{2-3} + W_{3-1} = 0.173$ kJ

Q) 90 kJ of heat is supplied to a system at a Const. Vol. The system rejects 95 kJ of heat at Const. Pressure and 18 kJ of work is done on it. The system is brought to original state by adiabatic process. Determine : (i) The adiabatic work.
(ii) The values of Internal energy at all states if initial value is 105 kJ

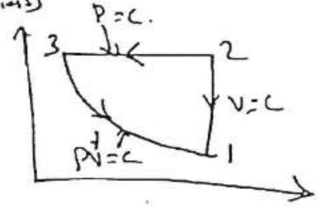
NOV/DEC '14

Given

$Q_{1-2} = 90$ kJ $\quad Q_{2-3} = -95$ kJ, $\quad W_{2-3} = -18$ kJ

$Q_{3-1} = 0$ [adiabatic Process]. $\quad U_1 = 105$ kJ

Soln



* Adiabatic Work.

From I law of thermodynamics $\oint dQ = \oint dW$

i.e: $Q_{1-2} + Q_{2-3} + Q_{3-1} = W_{1-2} + W_{2-3} + W_{3-1}. \Rightarrow \boxed{13\text{ kJ} = W_{3-1}}$

* $Q_{1-2} = W_{1-2} + \Delta U$ [from I law]

$W_{1-2} = 0$ for Isochoric process

$U_2 - U_1 = \Delta U = 90$ kJ.

$\boxed{U_2 = 195\text{ kJ}}$

* $Q_{2-3} = W_{2-3} + \Delta U \Rightarrow -95 = -18 + U_3 - U_2 \Rightarrow \boxed{U_3 = 118\text{ kJ}}$

UNIT - I

9) A gas undergoes a thermodynamic Cycle consisting of the following process. (i) Process 1-2 ⇒ Const. Pre. $(P_1) = 1.4$ bar, $V_1 = 0.028 m^3$, $W_{1-2} = 10.5$ kJ

(ii) Process 2-3 ⇒ Compression with $PV = $ Const, $U_3 = U_2$.

(iii) Process 3-1 ⇒ Const. Volume, $U_1 - U_3 = -26.4$ kJ

There are no significant Changes in KE & PE.

(1) Sketch the cycle on PV diagram

(2) Calculate the network for the cycle in kJ

(3) Calculate the heat transfer for Process 1-2

(4) Show that $\sum Q_{cycle} = \sum W_{cycle}$. [∵ April/may 2015]

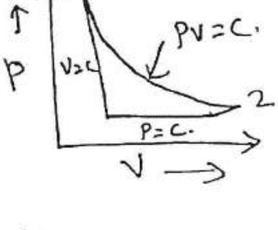
Given:

$P_1 = P_2 = 1.4$ bar $= 140$ kN/m², $V_1 = 0.028 m^3$, $W_{1-2} = 10.5$ kJ

$U_1 - U_3 = -26.4$ kJ, $U_3 = U_2$.

Soln

1)



2)

* Network of the cycle $= W_{net} = W_{1-2} + W_{2-3} + W_{3-1}$

* $W_{2-3} = P_2 V_2 \ln\left(\frac{V_3}{V_2}\right)$ [∵ find V_2 from Process 1-2.]

  * $W_{1-2} = P_1 [V_2 - V_1]$ ⇒ $\boxed{V_2 = 0.103 m^3}$

  $\boxed{V_3 = V_1}$ ← from given data

* $\boxed{W_{2-3} = -18.78 \text{ kJ}}$

* $W_{3-1} = 0$ [∵ Const. vol. Process Work done = 0]

* $W_{net} = 10.5 - 18.78 + 0 = \boxed{-8.28 \text{ kJ} = W_{net}}$

3) $U_{1-2} = U_2 - U_1 = (U_2 - U_3) + (U_3 - U_1)$ [∵ add and substract U_3]

$= (U_2 - U_3) - (U_1 - U_3)$

[∵ For Iso thermal Process ⇒ $U_3 - U_2 = 0$]
~~for~~ $\Delta U = 0$

$= 0 - (-26.4)$ ⇒ $\boxed{U_2 - U_1 = 26.4 \text{ kJ}}$

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3) $Q_{1-2} = W_{1-2} + U_{1-2}$

$= 10.5 + 26.4 = 36.9$ kJ

4) Net heat transfer of the cycle $Q_{net} = Q_{1-2} + Q_{2-3} + Q_{3-1}$

$Q_{2-3} = W_{2-3}$ [∵ In Const. tempt (or) Isothermal process $Q = W$]

$Q_{3-1} = W_{3-1} + U_{3-1}$

$\downarrow$

$W_{3-1} = 0$. For const vol. process

$Q_{3-1} = U_1 - U_3 = -26.4$ kJ.

$$\boxed{Q_{net} = -8.28 \text{ kJ} = W_{net}}$$

10) A turbine operating under steady flow conditions receives steam at the following state. Pressure = 13.8 bar, Sp. vol. 0.143 m³/kg ; Internal energy 2590 kJ/kg ; Velocity 30 m/s. The state of steam leaving the turbine is Pressure = 0.35 bar ; Sp. vol = 4.37 m³/kg ; Internal energy = 2360 kJ/kg, Velocity 90 m/s. Heat is lost to surroundings at the rate of 0.25 kJ/s. If the rate of steam flow is 0.38 kg/s, What is the Power developed.

{April/May '15}

Given

$P_1 = 13.8$ bar $= 1380$ kN/m² $\quad v_1 = 0.143$ m³/kg $\quad u_1 = 2590$ kJ/kg $\quad V_1 = 30$ m/s

$P_2 = 0.35$ bar $= 35$ kN/m² $\quad v_2 = 4.37$ m³/kg $\quad u_2 = 2360$ kJ/kg $\quad V_2 = 90$ m/s

$Q = -0.25$ kJ/s. $\quad m = 0.38$ kg/s $\quad , Z_1 = Z_2$.

Soln SFEE $\Rightarrow Q + m\left[h_1 + \frac{V_1^2}{2} + Z_1 g\right] = W + m\left[h_2 + \frac{V_2^2}{2} + Z_2 g\right]$

$\because h_1 = u_1 + P_1 v_1$ & $h_2 = u_2 + P_2 v_2$

$\Rightarrow Q + m\left[u_1 + P_1 v_1 + \frac{V_1^2}{2} + Z_1 g\right] = W + m\left[u_2 + P_2 v_2 + \frac{V_2^2}{2} + Z_2 g\right]$

$\Rightarrow -0.25 + 0.38\left[2590 + (1380 \times 0.143) + \frac{30^2}{2000}\right] = W + 0.38\left[2360 + (35 \times 4.37) + \frac{90^2}{2000}\right]$

$$\boxed{W = 102.65 \text{ kW}}$$

Question Bank
ME 6301
Engineering Thermodynamics
Unit II

Unit - II – University Questions ME6301 I

1) A heat pump working on a Carnot cycle takes in heat from a reservoir at 5°C and delivers heat to a reservoir at 60°C. A heat engine is driven by a source at 840°C and reject heat to a reservoir at 60°C. The reversible heat engine, in addition to driving the heat pump, also drives a machine that absorbs 30 kW. If the heat pump extracts 17 kJ/s from 5° reservoir.

Det

(i) the rate of heat supply from the 840°C source and

(ii) the rate of heat rejection to the 60° sink (April/May 2017)

Soln:

$T_1 = 1113\,K$

$T_2 = 333\,K$

$T_3 = 278\,K$

$T_4 = 333\,K$

$Q_3 = 17\,kJ/s$

$W_3 = 30$ kW

Carnot COP $= \frac{333}{333 - 278}$

$= 6.055$

$COP_{HP} = \frac{Q_4}{Q_4 - 17}$

$Q_4 = 20.36$ kJ/s

$W_2 = Q_4 - Q_3$

$= 20.36 - 17$

$= 3.36$ kJ/s

$W_1 = W_2 + W_3$

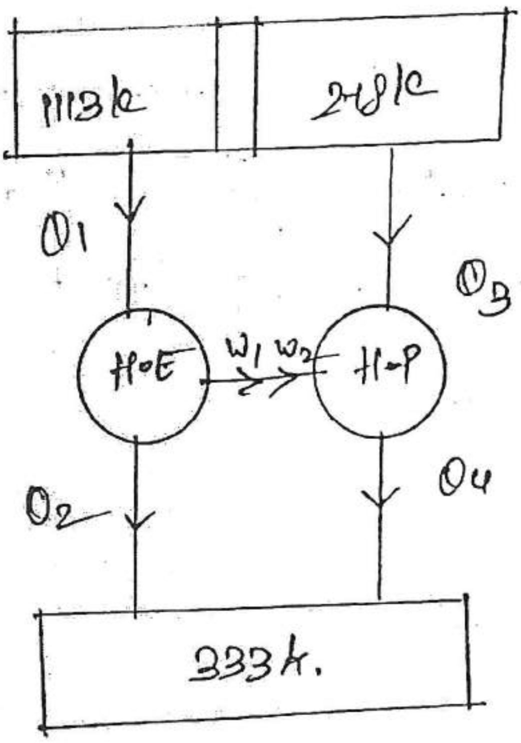
$= 3.36 + 30$

$= 33.36$ kW

$\eta_{mor} = \frac{T_1 - T_2}{T_1}$

$= \frac{1113 - 333}{1113}$

$= 0.7$



Q) A heat engine operating between two reservoirs at 1000k and 300k is used to drive heat pump which extracts heat from the reservoir at a rate twice that at which engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the coefficient of the performance of the heat pump is 50% of the maximum possible, make calculations for the temperature of the reservoirs to which the heat pump rejects heat. Also work out the rate of heat rejection from the heat pump if the rate of heat to the engine is 50 kW. (May/June 2016)

Given data:

$T_1 = 1000\,k$

$T_2 = 300\,k$

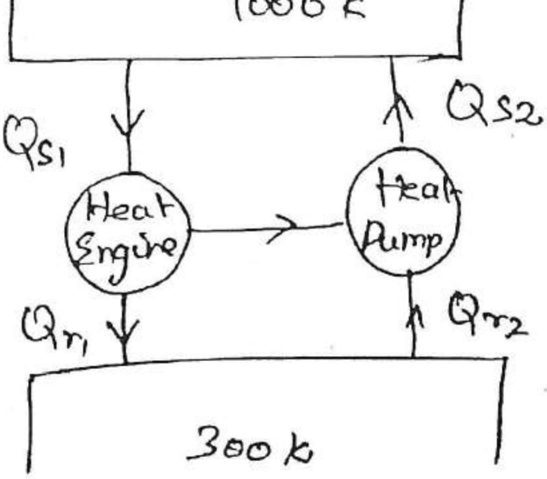
Efficiency of heat engine = 40% of max. possible efficiency

COP of heat pump = 50% of max. possible COP

Rate of supply of heat engine Q_{s_1} = 50 kW

Soln:

$$\eta = \frac{T_1 - T_2}{T_1} = \frac{1000-300}{1000} = 0.7$$



Actual efficiency = 40 % of carnot efficiency

$= 0.4 \times 0.7 = 0.28$

w.k.T $\eta_{H.E} = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{Q_{s_1} - Q_{r_1}}{Q_{s_1}}$

$0.28 = \frac{50 - Q_r}{50}$

$\Rightarrow Q_{r_1} = 36$ KW

$Q_{s_2} = 2 Q_{r_1} = 2 \times 36 = 72$ KW

Work output of heat engine = $50 - 36 = 14$ KW

$Q_{r_2} = Q_{s_2} +$ work output of HE

$= 72 + 14 = \underline{\underline{86 \text{ KW}}}$

$COP_{H.P} = \frac{\text{Heat Supplied}}{\text{Work done}} = \frac{86}{86 - 72} = 6.14$

Actual COP of heat pump = 50 % of Carnot COP

$6.14 = 0.5 \times \frac{T_4}{T_4 - T_3}$

w.k.T $T_3 = 300$

$\Rightarrow T_4 = \underline{\underline{326.6 \text{K}}}$

3) An inventor claims to have developed a refrigenting unit which maintains the refrigenerated space at $-6^\circ C$ while operating in a room where temperature is $27^\circ C$ and has COP 8.5. Find out whether his claim is correct or not. (Nov/Dec 2016)

Given data :

Inventor's refrigerating unit

$T_H = 27^\circ C$

$T_L = -6^\circ C$

$COP = 8.5$

To find : Decision

Soln : $\text{COP of carnot} = \frac{T_L}{T_H - T_L} = \frac{-6+273}{27-(-6)}$

$= 8.09$

$COP_{inventor} > COP_{Carnot}$

$\therefore$ His claim is not correct.

4) A 5 kg metal block, C = 0.4 KJ/kg K at 40°C is kept in a room at 20°C. It is cooled in the following two ways: (1) Using a Carnot Engine (executing integral number of cycles) with the room itself as the cold reservoir. (2) Naturally. In each case, calculate the changes in entropy of the block, of the air of the room and of the universe. ~~Assume~~ that the metal block has constant specific heat.

Given data:

$m = 5$ kg

$C_m = 0.4$ KJ/kg K

$T_1 = 40°C = 273+40 = 313$ K

$T_2 = 20°C = 293$ K

Soln:

i) cooling naturally

Heat absorbed by air, $\delta Q = mC(T_1 - T_2)$

$= 5 \times 0.4 (40-20)$

$= 40$ KJ

$$\delta Q_{block} = \int_{313}^{293} mC \frac{dT}{T}$$

$$= 5 \times 0.4 \ln\left(\frac{293}{313}\right)$$

$$= \underline{\underline{-0.132 \text{ kJ/K}}}$$

$$\delta Q_{air} = \frac{\delta Q}{T} = \frac{40}{293} = \underline{\underline{0.1365 \text{ kJ/k}}}$$

∴ Entropy of universe,

$$\delta Q_{univ} = \delta Q_{block} + \delta Q_{air}$$

$$= -0.132 + 0.1365$$

$$= \underline{\underline{0.0045}} \text{ kJ/k}$$

(ii) Cooling using Carnot Engine

$$\delta Q = 40 \text{ kJ}$$

$$\Delta S_{block} = 0.132 \text{ kJ/k}$$

$$\Delta S_{carnot} = 0.$$

~~For~~ carnot engine,

$$\eta_{carnot} = \frac{T_1 - T_2}{T_1}$$

$$= \frac{313 - 293}{313} = 6.39\%$$

$$\eta_{carnot} = \frac{\text{Work output}}{\text{Heat Supplied}} = \frac{W}{\delta Q}$$

$$0.0639 = \frac{W}{40} \Rightarrow W = 2.556 \text{ KJ}$$

$$\Delta S_{air} = \frac{\delta Q + W}{T_{air}} = \frac{40+2.556}{293}$$

$$= 0.1452 \text{ KJ/K}$$

$$\Delta S_{univ} = \Delta S_{block} + \Delta S_{carnot\ engine} + \Delta S_{air}$$

$$= 0.132 + 0 + 0.1452$$

$$= 0.2772 \text{ kJ/K}$$

5) Air flows through an adiabatic Compressor at 2 kg/s. The inlet Conditions are 1 bar and 310 K, and the exit temperature are 7 bar and 560 K. Compute the Net rate of energy transfer and the irreversibility. Take $T_0 = 298$ K. (April/May 2017)

Soln:

$$\psi = (h_2 - h_1) - T_0 (s_2 - s_1)$$

$$= C_p(T_2 - T_1) - T_0 \left(C_p \ln \frac{T_2}{T_1} - R \ln P_2/P_1\right)$$

$$= 1.005 (560 - 310)$$

$$- 298\left(1.005 \ln \frac{560}{310} - 0.287 \ln 7/1\right)$$

$$= 240.58 \text{ kJ/kg}$$

$$\Psi = \dot{m}\psi$$

$$= 2 \times 240.58$$

$$= 481.16 \text{ kW}$$

The actual work required is

$$W_{act} = \dot{m} (h_2 - h_1)$$

$$= \dot{m} C_p (T_2 - T_1)$$

$$= 2 \times 1.005 \times (560 - 310)$$

$$= 502.5 \text{ kW}$$

Therefore Irreversibility

$I = W_{act} - \text{Energy}$

$= 502.5 - 481.2$

$= 21.3\ kW.$

6) A 50 kg iron block and 20 kg Copper block at 80°C are dropped into a large lake at 15°C. They exchange heat with the lake water until they reach thermal equilibrium. (Nov/Dec 2016)

Soln:-

C_p Copper = 0.386 kJ/kgK

C_p Iron = 0.45 kJ/kgK

$\Delta S_{net} = \Delta S_{system} + \Delta S_{surroundings}$

$Q = \left[(50 \times 0.45) + (20 \times 0.386)\right] 80 - 15$

$= 1964.3\ kJ$

$\Delta S_{surr} = Q/T_0 = 1964.3/288 = 6.82\ kJ/K$

$$\Delta S_{sys} = m C_p \ln (T_2/T_1)$$

$$\Delta S_{Copper} = 20(0.386) \ln\left(\frac{288}{353}\right)$$

$$= -1.571 \text{ kJ/kg K}$$

$$\Delta S_{Iron} = 50(0.45) \ln 288/353$$

$$= -4.579 \text{ kJ/K}$$

$$\Delta S_{net} = 6.82 - 1.571 - 4.579$$

$$= 0.670 \text{ kJ/K}$$

7) How much of 100 kJ of thermal Energy at 650 K can be converted to useful work. Assume the environment to be at 25°C (Nov/Dec 2016)

Solns:

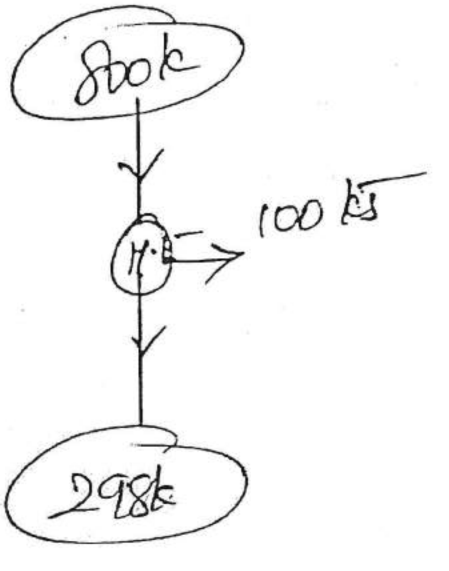
$$W_{max} = W_{rev} = \eta_{th} \times \dot{Q}_{in}$$

$$\eta_{th} = 1 - 298/800$$

$$= 0.6275$$

Thus, $W_{max} = 0.6275 \times 100$

$= 62.75$ kJ



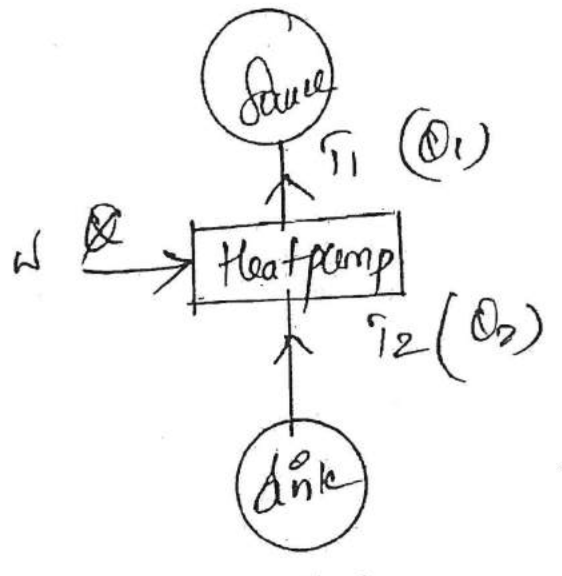
8) A heat pump operates on a Carnot heat pump with a COP of 8.7. It keeps a space at 24°c by consuming 2.15 kW of power. Det the temp of the reservoir from which the heat is absorbed and the heating load provided by the heat pump. (Nov/Dec 2015)

Soln

$COP = 8.7$

$T_1 = 24°C = 297 K$

$W = 2.15 kW$



$$COP = Q_1/W$$

$$= Q_1/W$$

$$= \frac{Q_1}{Q_1 - Q_2}$$

$$COP_{H.P} = \frac{T_1}{T_1 - T_2}$$

$$8.7 = \frac{Q_1}{2.15}$$

$$Q_1 = 18.7 kW$$

$$8.7 = \frac{297}{297 - T_2} \qquad T_2 = 262.8K.$$

9) 50 kg of water is at 313k and enough ice is at $-5^\circ C$ is mixed with water in an adiabatic vessel, S.T, at the end of the process, all the ice melts and water at $0^\circ C$ is obtained. Find the mass of ice required and the entropy change of water and ice. Given C_p of water is 4.2 kJ/kgk C_p of ice is 2.1 kJ/kg k and latent heat of ice is 333.3 kJ/kg. (May/June 2016)

Gn data

$M = 50$ kg

$T_{w1} = 313$ k

$T_{ice,1} = -5^\circ C$

$T_{w2} = 273$ k

$\Delta H = 333.3 \times 10^3$ kJ/kg

* Energy of water before mixing

$= 50 \times 4200 \times 313$

$= 65730000$ J

* Energy of ice before mixing $= m_{ice} \times 2100 \times 268$

$= 562800\ m_{ice}\ J$

* Energy of Mixture $= (m_w + m_{ice})\ C_{pw}\ T_{w2}$

$= (50 + m_{ice})\ 4200 \times 373$

$E_{before\ mixing} = E_{after\ mixing}$

$657300000 + 562800\ m_{ice}$

$= (50 + m_{ice})\ (4200)\ (273)$

$m_{ice} = 14.4$ kg.

* Entropy change of Water =

$= 50 \times 4200 \times \ln 313/273$

$= 28713.6$ J/k

* Entropy change of ice $(\Delta S)_{ice} = (\Delta S)_{I} + (\Delta S)_{II}$

$= 558.5$ J/k

$(\Delta S)_{II} = dQ/T$

$= 17566 \, J/k$

$(\Delta S)_{\overset{o}{iv}} = -(558\cdot5) + 17566$

$= 17007\cdot5 \, J/k$

UNIT-2

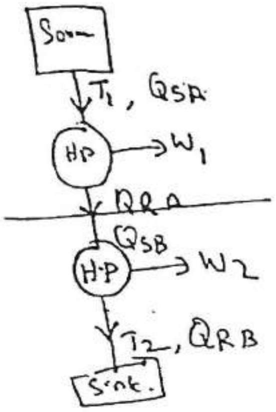
(6) Two heat Engines operating in Series are giving out equal amount of work. The total work is 50kJ/cycle. If the reservoirs are at 1000k & 250k, Find the Intermediate tempt. and the efficiency of each Engine. Also, find the heat extracted from the source.

NOV/DEC 14

Given: $T_1 = 1000\,k$. $T_2 = 250\,k$. $W_1 = W_2 = 50\,kJ$

To find. $T_{intermediate}$, η_{ea} of each engine., Q_{SA}

Soln



$Q_{SA} \rightarrow$ heat suppliead at 'A'

$Q_{RA} \rightarrow$ heat rejectea at 'A'

$$\boxed{Q_{RA} = Q_{SB}}$$

→ Intermediate heat transfer

$$W_1 = Q_{SA} - Q_{RA} \qquad W_2 = Q_{SB} - Q_{RB}$$

$$W_1 = W_2 \implies Q_{SA} - Q_{RA} = Q_{SB} - Q_{RB}$$

$$\implies 2Q_{RA} = Q_{SA} + Q_{RB}$$

$$2T = T_1 + T_2 = 1250$$

$$\boxed{T = 625\,k.}$$ Intermediate temp.

$\eta_{A} = \dfrac{W_1}{Q_{SA}}$; Carnot efficiency of engine 'A' $\Rightarrow \eta_A = 1 - \dfrac{T}{T_1}$

For reversible heat engine, actual engine efficiency = Carnot efficiency.

$$\therefore \eta_A = 1 - \frac{625}{1000} = 37.5\,\%$$

|||ly for engine B. $\eta_B = 1 - \dfrac{T_2}{T}$

$$\eta_B = 1 - \frac{250}{625} = 60\%.$$

Based on reversible heat engine Condition.

Actual efficiency = Carnot efficiency.

$$\frac{W_1}{Q_{SA}} = 1 - \frac{T}{T_1} \Longrightarrow \boxed{Q_{SA} = 133.33\ kJ}$$

For total Work ~~out~~ output from series of reversible engines equal to work output from engine operates b/w the same tempt limits

$$\frac{W_A}{Q_{SA}} = 1 - \frac{T_2}{T_1} \Longrightarrow \boxed{Q_{SA} = 6667\ kJ}$$

11) 5 kg of air at 550 k and 4 bar is enclosed in a closed vessel
(i) Determine the availability of the system, if the surrounding pr. & tempt are 1 bar and 290 k. (Nov/Dec '14)
(ii) If the air is cooled at const. pr. to atm tempt, determine the availability and effectiveness

Soln

Given $m = 5\ kg$, $P_1 = 4$ bar. $P_0 = 1$ bar. $T_1 = 550k$, $T_0 = 290k$

$C_p = 1.005\ kJ/kg.k$, $R = 0.287\ kJ/kg.k$ — assume.

(i) availability of the system

$$\psi = m\left\{C_p T_1 - T_0\left[C_p \ln\left(\frac{T_1}{T_0}\right) - R \ln\left(\frac{P_1}{P_0}\right)\right]\right\}$$

$$\psi = 576.7\ kJ.$$

(ii) Availability of energy of air during cooling

$$AE = Q - m T_0\left[C_p \ln\left(\frac{T_1}{T_0}\right) - R \ln\left(\frac{P_1}{P_0}\right)\right] \quad \boxed{\because P_1 = P_0}$$

$$Q = mC_p(T_1 - T_2) = 5 \times 1.005(550 - 290) = 1306.5\ kJ$$

$$AE = 1306.5 - 5 \times 290\left[1.005 \ln\left(\frac{550}{290}\right) - 0.287 \ln\left(\frac{P_1}{P_1}\right)\right] = 373.86\ kJ$$

$$\text{Effectiveness}(\varepsilon) = \frac{\text{Availability of energy of air}}{\text{availability of the system}} = \frac{373.86}{576.7} = 64.8\%.$$

UNIT-2

12b A reversible heat engine operates b/w two reservoirs at templ. of 600°c and 40°c. The engine drives a reversible refridgerator which operates b/w reservoirs at templ. of 40°c & −20°c. The heat transfer to the heat engine is 2000 kJ and the net work o/p for the combined engine refridgerator is 360 kJ. Calculate the heat transfer to the refridgerant & the net heat transfer to the reservoir at 40°c

(April/may '15)

273
40
313

Soln

$T_2 = 313k.$ $\qquad T_3 = 253k.$

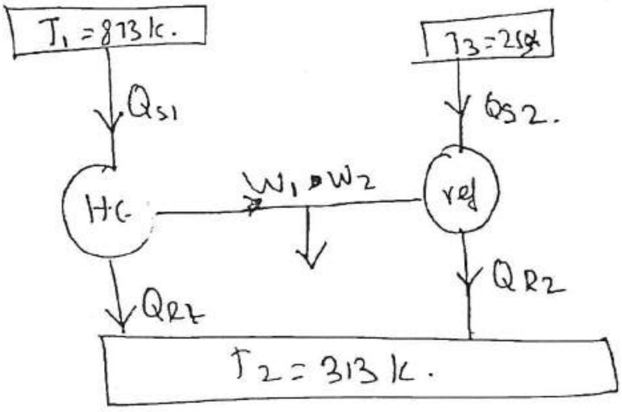
$T_1 = 873k.$ $\qquad Q_{S1} = 2000\,kJ$

$W_{net} = 360kJ.$

To find

Q_{S2} , $Q_{R1} + Q_{R2}.$

Soln



WKT.

$$W_2 = Q_{S2} \mp Q_{R2}$$

$$COP_{ref} = \frac{Q_{R2}}{W_2.}$$

$$COP_{ref} = \frac{T_3}{T_2 - T_3} = \frac{253}{313-253} = 4.23$$

$W_1 - W_2 = 360\,kJ.$

$W_2 = W_1 - 360$

$W_1 = Q_{S1} - Q_{R1}$

$$\eta_{max} = \frac{W_1}{Q_{S1}}$$

$$\eta_{max} = \frac{T_1 - T_2}{T_1} = 0.64 = 64\%.$$

$W_1 = 2000 \times .64 = 1280.\,kJ$

$W_2 = 1280 - 360 = 920$

$\boxed{W_2 = Q_{S2} - Q_{R2}.}$ $\therefore$ $\boxed{Q_{S2} = W_2 + Q_{R2}}$

$$\frac{Q_{R2}}{W_2} = COP_{ref} \quad \therefore$$

$\boxed{Q_{R2} = COP \times W_2}$

$\boxed{Q_{R1} = Q_{S1} - W_1}$

Net heat trasfered to reservoir $\Longrightarrow Q_{R1} + Q_{S2}$

UNIT-2

13) Two kg of air at 500 kpa, 80°c expands adiabaticaly in a closed system until its volume is doubled and its temp becomes equal to that of the surroundings which is at 100 kpa, 5°c. For this process determine: (i) W_{max} (ii) Change in availability. (iii) Irreversibility.

April/may 2015

Soln:

$$W_{max} = \psi_1 - \psi_2$$

$$* \ \psi_1 = m\left\{C_pT_1 - T_0\left[C_p \ln\left(T_1/T_0\right) - R \ln\left(P_1/P_0\right)\right]\right\}$$

$m = 2kg.$ $C_p = 1.005$, $T_1 = 353\ k.$, $T_0 = 278k.$, $R = 0.287$

$P_1 = 500kpa.$ $P_2 = P_1 \times (V_1/V_2)^{\gamma} = 500 \times \left(\frac{V_1}{2V_1}\right)^{1.4} = 189.47\ kPa.$

$P_0 = 100\ kPa.$

$$* \ \psi_2 = m\left\{C_pT_2 - T_0\left[C_p \ln\left(\frac{T_2}{T_0}\right) - R \ln\left(\frac{P_2}{P_0}\right)\right]\right\}$$

* Irreversibility $I = T_0\ \Delta S.$

$$= T_0 \times m\left[C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)\right]$$

Unit 4 - University Question

1) A Vessel of Volume $0.3 m^3$ Contains 15 kg of air at 303 K. Determine the pressure created by the air using (April/May 2016)

1) Perfect gas Equation
2) Vander Waal Equation
3) Generalized Compressibility chart

Take Critical temperature of air is 132.8 K and Critical pr. of air is 37.7 bar.

Soln: Given data

$V = 0.3 m^3$

$m = 15 kg$

$T = 303 K$

$T_c = 132.8 K$

$P_c = 37.7 bar$

1) Perfect Gas Equation

$PV = mRT$

$P = mRT/V$

Question Bank

ME6301

Engineering thermodynamics

Unit III

Unit - 3 - University Question

1) A vessel of volume 0.04 m^3 contains a mixture of saturated water and steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, mass, specific volume, enthalpy, entropy and internal energy. (April/May 2017)

Given data:

$V = 0.04\ m^3$

$T = 250°C$

$m_1 = 9\ kg$

To find:

p, m, v, h, S and U.

Soln:

From Steam Tables corresponding to 250°C,

$v_f = v_1 = 0.001251\ m^3/kg$

$v_g = v_s = 0.050037\ m^3/kg$

$p = \underline{\underline{39.776}}$ bar

Total volume occupied by the liquid,

$V_l = m_1 v_1 = 9 \times 0.001251 = 0.0113\ m^3$

Total volume of the vessel,

V = Volume of liquid + Volume of steam

$= V_l + V_s$

$0.04 = 0.0113 + V_s$

$V_s = 0.0287\ m^3$

Mass of steam, $m_s = \frac{V_s}{v_s} = \frac{0.0287}{0.050037} = 0.574$ kg

Mass of mixture of liquid and steam,

$m = m_1 + m_s = 9 + 0.574 = \underline{\underline{9.574 \text{ kg}}}$

Total specific volume of the mixture,

$v = \frac{V}{m} = \frac{0.04}{9.574} = \underline{\underline{0.00418}}\ m^3/kg$

w.k.T $\quad v = v_f + x v_{fg}$

$x = 0.06$

From Steam Tables corresponding to 250°C,

$h_f = 1085.8$ KJ/kg ; $h_{fg} = 1714.6$ KJ/kg

$s_f = 2.794$ KJ/kg K ; $s_{fg} = 3.277$ KJ/kg K

Enthalpy of mixture,

$h = h_f + x h_{fg} = \underline{\underline{1188.67}}$ KJ/kg

Entropy of mixture,

$s = s_f + x s_{fg} = \underline{\underline{2.99}}$ KJ/kg K

Internal energy,

$u = h - pv$

$= 1188.67 - 39.776 \times 10^2 \times 0.00418$

$= \underline{\underline{1172}}$ KJ/kg

2) A reheat Rankine cycle receives steam at 30 bar and 0.075 bar. Steam enters the first stage steam turbine 350°C. If reheating is done at 5 bar to 350°C, calculate the specific steam consumption and reheat Rankine cycle efficiency. (April/May 2017)

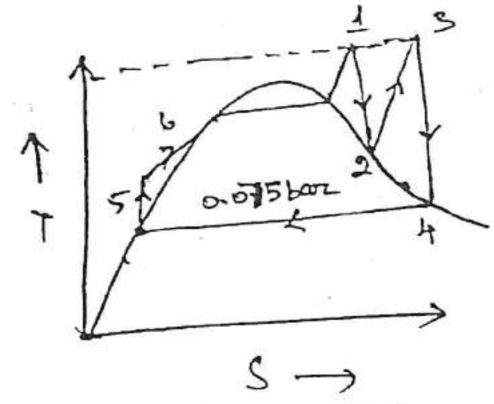
Given data:

$P_1 = 30$ bar and $T_1 = 350°C$
$P_2 = 5$ bar
$P_3 = 0.075$ bar

To find:

η_{reheat}, x_4

Soln:



From super heated Steam Table

At $P_1 = 30$ bar and $350°C$
$h_1 = 3115.3$ kJ/kg ; $S_1 = 6.7428$ kJ/kg K

From saturated Steam Table

At 5 bar $S_{g_2} = 6.8213$ kJ/kg K; $S_{f_2} = 1.8607$ kJ/kg K

$s_{fg_2} = 4.9606$ kJ/kg K ;

$h_{f2} = 640.23$ kJ/kg ; $h_{fg_2} = 2108.5$ kJ/kg

$\because$ $s_{g_2} > s_1$, the steam is in wet condition

$s_1 = s_2 = s_{f2} + x \times s_{fg_2}$

$6.7428 = 1.8607 + x_2 \times 4.9606$

$x_2 = 0.98$

$h_2 = h_{f2} + x_2 \times h_{fg_2}$

$= 640.23 + 0.98 \times 2108.5 = 2706.56$ kJ/kg

From superheated steam table at 5 bar and 350°C

$h_3 = 3167.7$ kJ/kg $s_3 = 7.6329$ kJ/kg K

From saturated Steam Table at 0.075 bar

$h_{f4} = 168.79$ kJ/kg ; $h_{fg4} = 2406$ kJ/kg

$s_{f4} = 0.5764$ kJ/kg K ; $s_{fg4} = 7.675$ kJ/kg K

$v_{f4} = 0.001008$ m³/kg

W.K.T

$s_3 = s_4 = s_{f4} + x_4 \, s_{fg4}$

$\Rightarrow x_4 = \underline{\underline{0.919}}$

$h_4 = h_{f4} + x_4 \times h_{fg_4}$

$= 168.79 + 0.919 \times 2406$

$= 2380.89$ kJ/kg

Pump work,

$$W_p = v_{f4}(P_1 - P_4)$$

$$= 0.001008\ (3000 - 7.5)$$

$$= 3.0164\ kJ/kg$$

Efficiency of reheat Rankine cycle,

$$\eta_{reheat} = \frac{(h_1-h_2) + (h_3 - h_4) - W_P}{h_1 - (h_5 + W_P) + (h_3 - h_2)}$$

$$= \frac{(3115.3-2706.56)+(3167.7-2380.89) - 3.0164}{3115.3 - (168.79+3.0164)+(3167.70-2706.56)}$$

$$= 0.35 = \underline{\underline{35\ \%}}$$

3) A steam boiler initially contains 5 m^3 of steam and 5 m^3 of water at 1 MPa. Steam is taken out at constant pressure until 4 m^3 of water is left. What is the heat transferred during the process? (Nov/Dec 2016)

Soln: At 1 MPa,

$v_f = 0.001127$, $v_g = 0.1944\ m^3/kg$

$h_g = 2778.1\ kJ/kg$

$u_f = 761.68$, $u_g = 2583.6\ kJ/kg$

$u_{fg} = 1822\ kJ/kg$.

$\frac{V_f}{v_f} + \frac{V_g}{v_g} = \frac{5}{0.001127} + \frac{5}{0.1944}$

$= (4.45 \times 10^3 + 25.7)$ kg

Final mass of saturated water and steam

$= \frac{4}{0.001127} + \frac{6}{0.1944} = (3.55 \times 10^3 + 30.8)$ kg

∴ Mass of steam taken out of the boiler

$m_s = 0.90 \times 10^3 - 5.1 = 894.9$ kg

We have $U_1 + Q = U_f + m_s h_g$

Assume $x = 1$

$\rightarrow Q = 894.9 \times 2778.1 - (0.9 \times 10^3) \times 761.68 + 5.1 \times 2583.6$

$= 1752676$ kJ

f) A steam power plant operates on an ideal regenerative Rankine cycle. Steam enters the turbine at 40 bar and 450°C and condensed in the condenser at 30 kpascal. Steam is extracted from the turbine at 3 bar to heat the feed water in an open feed water heater. Water leaves the feedwater heater as a saturated liquid. To show the cycle on TS diagram & determine the (1) network output / kg of steam flowing through the boiler (2) thermal efficiency of boiler. (Nov/Dec 2016)

Gn : $p_1 = 40$ bar

$T_1 = 450°C$

$p_2 = 3$ bar

$p_3 = 0.03$ bar

To find : $\eta_{regenerative}$

Soln:

At $p_1 = 40$ bar & $450°C$

$h_1 = 3330.3$ kJ/kg

$s_1 = 6.9363$ kJ/kg k

At $p_2 = 3$ bar

$h_{f2} = 561.47$ kJ/kg ; $h_{fg2} = 2163.8$ kJ/kg

$s_{f2} = 1.6718$ kJ/kg k ; $s_{fg2} = 5.3201$ kJ/kg k

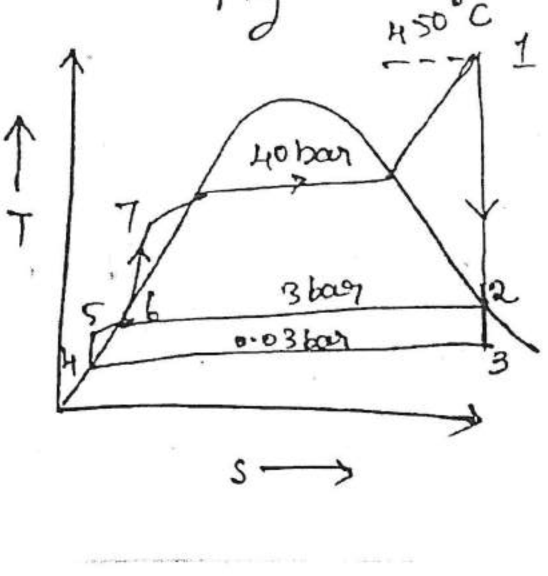
$v_{f2} = 0.001073$ m³/kg

At $p_3 = 0.03$ bar

$h_{f3} = 101.05$ kJ/kg ; $h_{fg3} = 2444.5$ kJ/kg

$s_{f3} = 0.3545$ kJ/kg k ; $s_{fg3} = 8.2231$ kJ/kg k

$v_{f3} = 0.001063$ m³/kg



W.K.T $s_1 = s_2 = s_{f2} + x_2 \times s_{fg2}$

$6.9363 = 1.6718 + x_2 \times 5.321$

$x_2 = 0.9895$

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

$= 2702.65$ kJ/kg

III^{ly}

$\Rightarrow s_1 = s_3 = s_{f3} + x_3 \times s_{fg3}$

$\Rightarrow x_3 = 0.8$

$\Rightarrow h_3 = h_{f3} + x_3 \times h_{fg3}$

$= 2057.63$ kJ/kg

$\Rightarrow h_4 = h_{f3} = 101.05$ kJ/kg

$W_{P_{4-5}} = (1-m)(h_5 - h_4)$

$\Rightarrow h_5 - h_4 = v_{f3}(P_2 - P_3) = 0.001003\,(300-3)$

$= 0.2989$ kJ/kg

$h_5 = 101.35$ kJ/kg

$$m = \frac{h_{f2} - h_5}{h_2 - h_5} = \frac{561.47 - 101.35}{2702.65 - 101.35} = 0.117\text{ kg}$$

$W_{P_{6-7}} = h_7 - h_6 = v_{f2}(P_1 - P_2)$

$h_7 - 561.47 = 0.001073\,(4000-300)$

$h_7 = 565.44$ kJ/kg

$$\eta_{regenerative} = \frac{(h_1 - h_7) - (1-m)(h_3 - h_{f3})}{(h_1 - h_7)}$$

$$= \frac{(3330.3 - 5654.4) - (1 - 0.177)(2057.63 - 101.05)}{(3330.3 - 5654.4)}$$

$$= 41.75\ \%$$

5) In a steam power plant the condition of steam at inlet to the steam generator is 20 bar. and 500°C and the condenser pressure is 0.1 bar. Two feed water heaters operate at optimum temperatures. Determine (a) the quality of steam at turbine exhaust (b) network per kg of steam (c) cycle efficiency and (d) ~~the~~ steam rate. Neglect pump work.

(May / June 2016)

Soln:

$h_1 = 3023.5$ kJ/kg

$s_1 = 6.7664$ kJ/kg K $= s_2 = s_3 = s_4$

t_{sat} at 20 bar $\simeq$ 212 °C

t_{sat} at 0.1 bar $\cong$ 46 °C

$\Delta t_{on} = 212 - 46 = 166$ °C

$\therefore$ Temperature rise per heater $= \frac{166}{3} = 55$ °C.

∴ Temperature at which 1st heater operates

$= 212 - 55$

$\simeq 150\ °C$ (assumed)

Temperature at which 2nd heater operates

$= 157 - 55$

$\simeq 100\ °C$ (assumed)

At 0.1 bar,

$h_f = 191.83$, $h_{fg} = 2392.8$

$s_f = 0.6493$, $s_g = 8.1502$

At 100°C,

$h_f = 419.04$, $h_{fg} = 2257.$

$s_f = 1.3069$, $s_g = 7.3549$

At 150°C,

$h_f = 632.20$, $h_{fg} = 2114.3$

$s_f = 1.8418$, $s_g = 6.8379$

$6.7664 = 1.8418 + x_2 \times 4.996$,

$\Rightarrow x_2 = 0.986$

$h_2 = 632.2 + 0.986 \times 2114.3$
$= 2716.9$ kJ/kg

$6.7664 = 1.3069 + x_3 \times 6.0480$

$\Rightarrow x_3 = 0.903$

$h_3 = 419.04 + 0.903 \times 2257.$

$= 2457.1$ kJ/kg

$h_4 = 191.83 + 0.816 \times 2392.8$

$= 2144.3$ kJ/kg

∵ Work pump is neglected,

$h_{10} = h_9$, $h_8 = h_7$, $h_6 = h_5$

For hp heater,

$(1-m_1)(h_9 - h_8) = m_1(h_2 - h_9)$

$$\Rightarrow m_1 = \frac{h_9 - h_7}{h_2 - h_7} = \frac{213.16}{2297.86} = 0.093 \text{ kg}$$

For lp heater,

$(1-m_1-m_2)(h_7 - h_6) = m_2(h_3 - h_7)$

$\Rightarrow m_2 = 0.091$ kg

$W_T = 1(h_1 - h_2) + (1-m_1)(h_2 - h_3) + (1-m_1-m_2)(h_3 - h_4)$

$= 797.48$ kJ/kg

$Q_1 = h_1 - h_9 = 3023.5 - 632.5 = 2391.3$ kJ/kg

$$\therefore \eta_{cycle} = \frac{W_T - W_P}{Q_1} = \frac{797.48}{2391.3} = 0.3334 = \underline{\underline{33.34\%}}$$

$$\text{Steam rate} = \frac{3600}{W_{net}} = \frac{3600}{797.48}$$

$= 4.51$ kJ/kWh

UNIT-3

In a Rankine cycle, the steam at inlet to turbine is saturated at a pr. of 35 bar and the exhaust pr. is 0.2 bar. Determine: (i) Pump work. (ii) Turbine work. (iii) Rankine efficiency (iv) Condenser heat flow (v) Dryness at the end of expansion. Assume flow rate of 9.5 kg/s Nov / Dec '14, Nov/ Dec 11.

Soln:

$P_1 = 35$ bar $P_2 = 0.2$ bar. $m = 9.5$ kg/s

* From steam table at 35 bar $h_1 = h_g = 2802$ kJ/kg
$S_1 = S_g = 6.123$ kJ/kg.

* From Steam table at 0.2 bar.

$h_{f2} = 251.5$ kJ/kg. $h_{fg2} = 2358.4$ kJ/kg.
$S_{f2} = 0.832$ kJ/kg $S_{fg2} = 7.077$ kJ/kg.K.
$v_f = 0.001017$ m³/kg $v_g = 7.6498$ m³/kg

For Isentropic
$S_1 = S_2 = S_{f2} + x_2 S_{fg2}$

$x_2 = 0.75$

$h_2 = h_{f2} + x_2 h_{fg2} = \boxed{2020.3 \text{ kJ/kg} = h_2}$

$\boxed{h_3 = h_f = 251.5 \text{ kJ/kg}}$ → @ 0.2 bar.

$h_4 - h_3 = W_p = v_f(P_1 - P_2)$.

$h_4 - h_3 = 3.54 \Rightarrow \boxed{h_4 = 255.04 \text{ kJ/kg}}$

(i) Pump Work, $(W_P) = v_f(P_1 - P_2) = 3.54$ kJ/kg.

(ii) Turbine work $(W_T) = h_1 - h_2 = 781.7$ kJ/kg

(iii) Rankine efficiency $\eta_{rankine} = \frac{W_{net}}{h_1 - h_3}$

$W_{net} = W_T - W_P = 778.16$ kJ/kg.

$\eta_{rankine} = 30.6$ %.

(iv) Condenser heat flow $\underset{Q_r}{} = h_2 - h_3 = 1768.8$ kJ/kg

(v) Dryness fraction of steam after expansion $= 0.86$

A Vessel of volume $0.04 m^3$ contains a mixture of saturated water and saturated steam at a tempr. of 250°C. The mass of the liquid present is 9 kg. Find the pressure, mass, the specific volume, enthalpy, entropy, Internal energy of the mixture. (May/ June '15) Apr '03, Nov '12

Given. $V = 0.04 m^3$, $T = 250°C$, $m_1 = 9 kg$.

Soln:

From Steam tables corresponding to 250°C.

$v_f = v_1 = 0.001251 m^3/kg$. $V_g = v_s = 0.050037 m^3/kg$

$$\boxed{P = 39.776 \text{ bar}}$$

UNIT-3

* Mass of Steam, $(m_s) = \dfrac{V_s}{v_s}$

Total volum of vessel.

Total vol. occupied by liquid.

$V =$ Vol. of liquid + Vol. of Steam $\qquad V_1 = m_1 v_1 = 9 \times 0.00125$

$= V_1 + V_s$.

$0.04 = 0.0113 + V_s \implies v_s = 0.0287.$

$\boxed{m_s = 0.574 \text{ kg}}$, $m_1 = 9$.

Mass of mixture of liquid & steam $(m) = m_1 + m_s = \boxed{9.574 = m}$

* Specific volume of mixture (v)

$$v = V/m = \frac{0.04}{9.574} = 0.00418 \text{ m}^3/\text{kg}$$

* Enthalpy of mixture $\quad h = h_f + x \, h_{fg}$

from steam table corresponds to 250°C.

$h_f = 1085.8$ kJ/kg $\qquad h_{fg} = 1714.6$ kJ/kg

$S_f = 2.794$ kJ/kg $\qquad S_{fg} = 3.277$ kJ/kg

To find x $\quad v = v_f + x v_{fg}$

$v_{fg} = v_g - v_f$.

$0.00418 = 0.001251 + x(0.050037 - 0.001251)$

$x = 0.06$.

$h = 1188.67$ kJ/kg.

* Entropy of mixture (S)

$$S = S_f + x S_{fg} = 2.99 \text{ kJ/kg·K}.$$

* Internal energy (u)

$$u = h - Pv = 1188.67 - 39.776 \times 10^2 \times 0.00418 = 1172 \text{ kJ/kg}$$

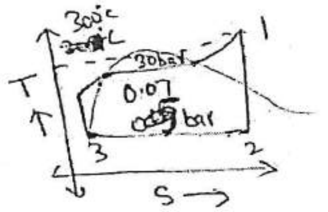
A steam Power Plant operates in a simple ideal. Rankine cycle b/w the Pressure limits of 2MPa and 0.07bar 50kPa. The temperature of the steam at the turbine inlet is 300°c and the mass rate of steam through the cycle is 35 kg/s. Show the Cycle on Ts diagram wrt saturation lines and determine.

(i) thermal eff. of the Cycle

(ii) Net Power output of the Power plant.

APR/May '15

Soln



10^3 k.pa

find h_1, h_2, h_3, h_4

$h_1 = 3025$ kJ/kg

$h_2 = 2090.76$ kJ/kg.

$h_3 = 163.4$

Thermal efficiency $\eta = \frac{W}{Q_S}$

$Q_S = h_1 - (h_{f2} + W_p)$

$W_p = h_4 - h_3 = v_3 (P_4 - P_3)$

$= v_{f2}(P_1 - P_3) = 2.0069$ kJ/kg.

$Q_S = 3025 - (163.4 + 2.0069) = 2859.79$ kJ/kg

$\boxed{Q_S = 2859.79 \text{ kJ/kg}}$

$W = Q_S - Q_R.$

$Q_R = h_2 - h_3 = h_2 - h_{f2} = 1927.36$ kJ/kg

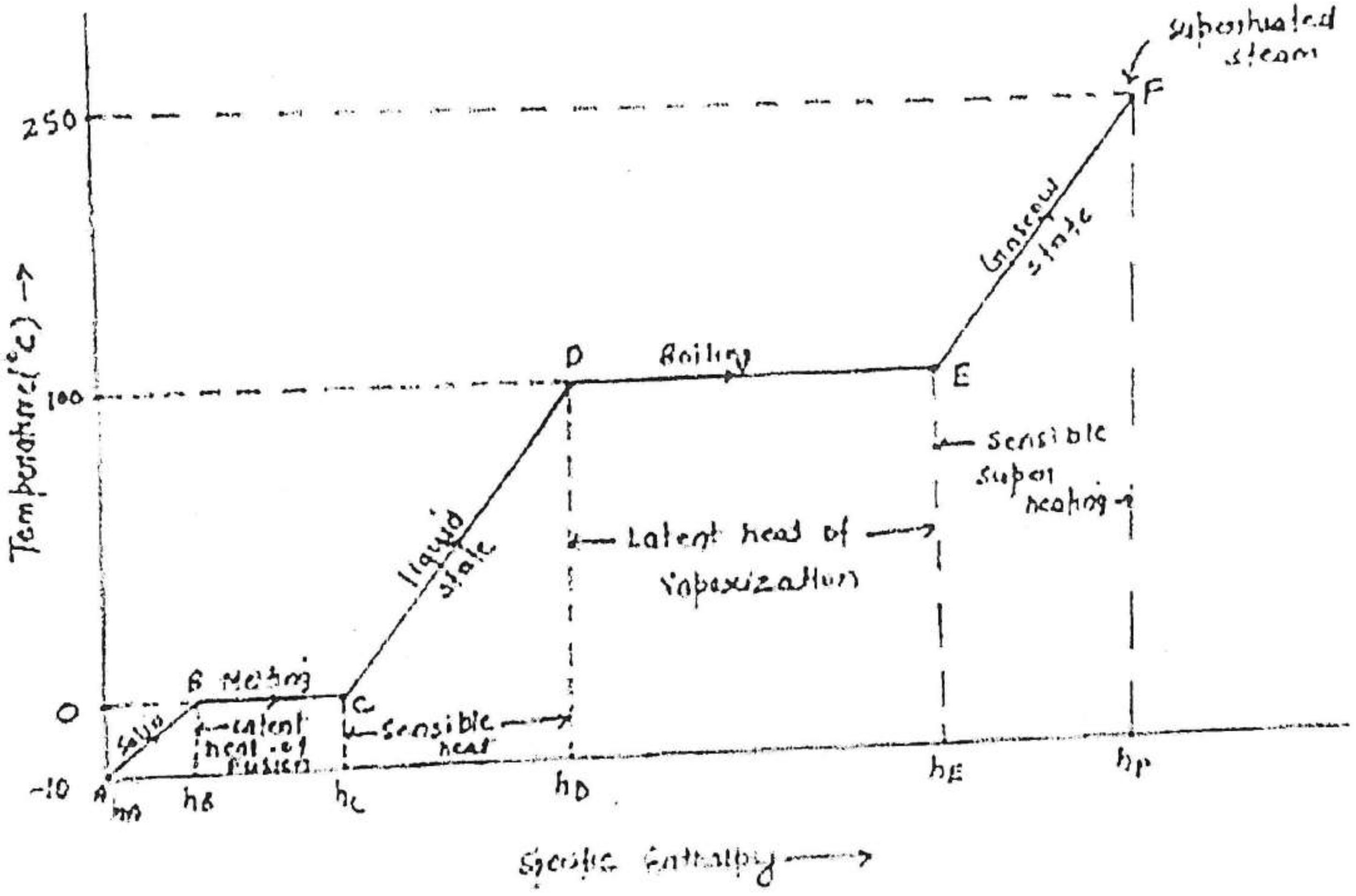
$W = 932.34$ kJ

$\eta = W/Q_S = \frac{932.34}{2859.79} = 0.326 = 32.6\%$

UNIT -3

Explain the Steam formation with relevant Sketch and label all Salient Points

Nov | Dec 14



A → starting point

B → Melting point (0°C)

C → Saturated liquid (0°C)

D → Boiling point (100°C)

E → Saturated steam (100°C)

F → Superheated steam (250°C)

graph/map not to scale

Question Book

ME6301

Engineering Thermodynamics

Unit IV

Unit 4 - University Questions

1) A Vessel of Volume $0.3 m^3$ Contain 15 kg of air at 303 K. Determine the pressure created by the air using (April/May 2016)

1) Perfect gas Equation
2) Vander Waals Equation
3) Generalized Compressibility chart

Take Critical temperature of air is 132.8 k and Critical pr. of air is 37.7 bar.

Soln: Given data

$V = 0.3 m^3$

$m = 15 kg$

$T = 303 K$

$T_c = 132.8 k$

$P_c = 37.7 bar$

1) Perfect Gas Equation

$pV = mRT$

$p = mRT/V$

$$p = \frac{15 \times 0.287 \times 303}{0.3}$$

$$p = 4358.05 \text{ kPa}$$

2. Vander waals Equation

$$\left(p + a/v^2\right)(v - b) = RT$$

$$a = \frac{27 \times (0.287)^2 \times (132.8)^2}{64 \times 37.7 \times 100}$$

$$= 0.162$$

$$b = \frac{RT_c}{8P_c}$$

$$= \frac{0.287 \times 132.8}{8 \times 37.7 \times 100}$$

$$= 1.26 \times 10^{-3}$$

$$v = \frac{\text{Volume}}{\text{Mass}}$$

$$= 0.3/15 = 0.02 \text{ m}^3/\text{kg}$$

$$\left(P + \frac{0.162}{(0.02)^2}\right)\left(0.02 - 1.26\times10^{-3}\right)$$

$$= 0.287 \times 303$$

$$P = 4235.4 \text{ kN/m}^2$$

3) Generalized Compressibility Chart

$$T_r = T/T_c$$

$$= 303/1328 = 2.28$$

$$v_r = v/v_c$$

$$= \frac{0.02 \times 37.7 \times 100}{0.287 \times 132.8}$$

$$= 1.98 \text{ m}^3/\text{kg}$$

$$Z = Pv/RT$$

$$0.99 = \frac{P \times 0.02}{0.287 \times 303}$$

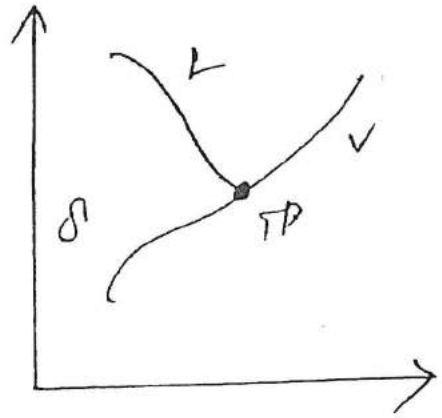
$$P = 4304.6 \text{ kN/m}^2$$

Q) Derive clausius clapeyron Equation for a phase change (May/June 2016)

Let the entropy (S) is a function of Temperature (T) and Volume (V)

$$S = f(T, V)$$

$$dS = \left(\frac{\partial S}{\partial T}\right)_V dT + \left(\frac{\partial S}{\partial V}\right)_T dV$$



$$dS = \left(\frac{\partial S}{\partial V}\right)_T dV$$

From Maxwell Relation

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

$$dS = \left(\frac{\partial P}{\partial T}\right)_V dV$$

$$\int_{s_f}^{s_g} ds = \frac{dp}{dT}\int_{v_f}^{v_g} dv$$

$$(s_g - s_f) = dp/dT \; (v_g - v_f)$$

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f}$$

$$\frac{dp}{dT} = \frac{s_{fg}}{v_{fg}}.$$

$$ds = dQ/T$$

$$dQ = dh$$

$$ds = dh/T$$

$$s_{fg} = \frac{h_{fg}}{T}$$

So, $$dP/dT = \frac{s_g - s_f}{v_g - v_f}$$

$$= \frac{s_{fg}}{v_{fg}} \cdot = \frac{h_{fg}}{T\,v_{fg}}.$$

3) One kg of Co_2 has a Volume of $1m^3$ at 100°c.
Compute the pressure by
(i) Van der Waals Equation
(ii) Perfect Gas Equation (Nov/Dec 2016)

Soln:

(i) Vander Waals Equation

$$\bar{v} = 1 \times 44 = 44 \, m^3/kg \, mol$$

$$T = 373k$$

$$a = 362850 \, Nm^4/(kg \, mol)^2$$

$$b = 0.0423 \, m^3/kg\text{-}mol$$

$$R_0 = 8314 \, Nm/kg\text{-}mol \, k$$

$$(p + a/v^2)(v - b) = R_0 T$$

$$p = \frac{R_0 T}{v - b} - a/v^2$$

$$p = \frac{8314 \times 373}{44 - 0.0423} - \frac{362850}{44^2}$$

$= 70548 - 187$

$= 70361\ N/m^2$

(ii) Using Perfect Gas Eqn

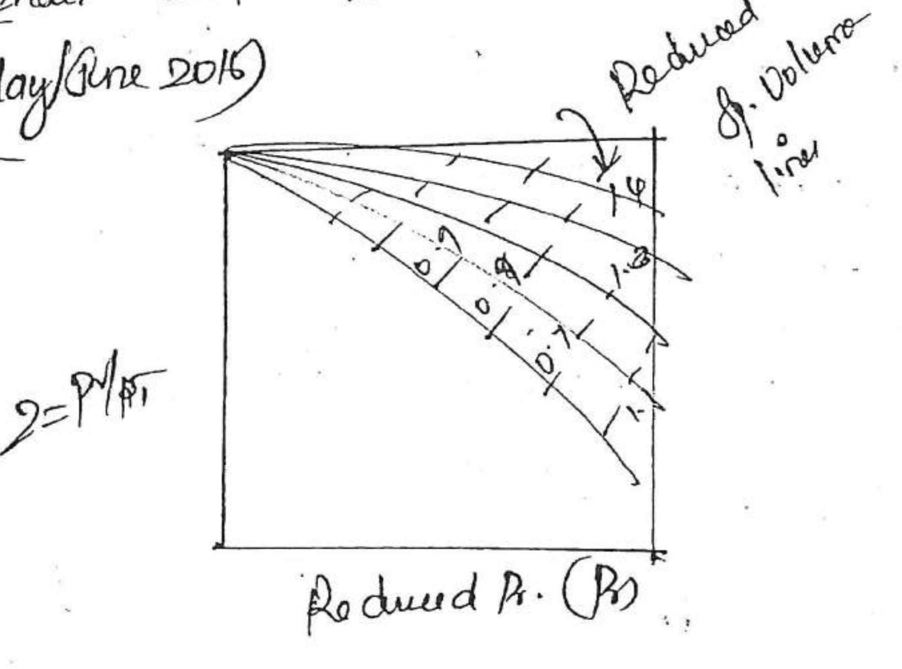
$p = R_0T/v$

$= \dfrac{8314 \times 373}{44}$

$= 0.7048$ bar.

4) Draw a neat Schematic of a Compressibility chart and indicate its Salient features

(May/June 2016)



* The General Compressibility Chart is plotted with Compressibility factor (Z) versus reduced pressure (P_r) for various values of reduced temperature (T_r). This is constructed by plotting the known data of one or more gases and it can be used for any gas as shown in figo.

The following observations can be made from the generalised compressibility chart

1) At very low pressure ($P_r < 1$), the gases behave as an ideal gas.

2) At high temperature, ideal gas behaviour is assumed with good accuracy of pressures.

3) The deviation of the gas from ideal gas behaviour is the greatest in the vicinity of critical point

Use of Compressibility Chart

* The reduced properties in the chart indicates the status of the substance from critical point.

6) Derive Maxwell's Equation. (June 2012)

Maxwell's Equation relates entropy to the three directly measurable properties P, V & T for pure compressible substance.

The Generalized form

$$dz = M dx + N dy$$

$$\left(\partial M/\partial y\right)_{x=C} = \left(\partial N/\partial x\right)_{y=C}$$

Maxwell's 1st Equation

From 1st law of thermodynamics

$$Q = W + \Delta U$$

$dQ = dw + du$

$dQ = Tds$

$dw = pdv$

$Tds = pdv + vdp$

$du = Tds - pdv$

from ①

$dz = Mdx + Ndy$

On Comparing

$z = u, \quad M = T, \quad x = s, \quad N = -P, \quad y = v$

$$\left(\partial M / \partial y\right)_{x=c} = \left(\partial N / \partial x\right)_{y=c}$$

$$\Rightarrow \left(\partial T / \partial v\right)_{s=c} = -\left(\partial P / \partial s\right)_{v=c}$$

② Maxwell's Second Eqn

$h = u + pv$

$dh = du + pdv + vdp$

$$dQ = dw + du$$

$$dQ = Tds$$

$$dw = pdV$$

$$Tds = pdv + vdp$$

$$du = Tds - pdv$$

from ①

$$dz = Mdx + Ndy$$

On Comparing

$$z = u, \quad M = T, \quad x = s, \quad N = -P, \quad y = u.$$

$$\left(\partial M/\partial y\right)_{x=c} = \left(\partial N/\partial x\right)_{y=c}$$

$$\Rightarrow \left(\partial T/\partial v\right)_{s=c} = \left(\partial P/\partial s\right)_{v=c}$$

2) Maxwell's Second Equation

$$h = u + pv$$

$$dh = du + pdv + vdp$$

$dh = Tds - pdv + pdv + vdp$

$dh = Tds + Vdp$

$Z = h, \quad M = T, \quad x = s, \quad N = V, \quad y = p$

$\left(\partial M / \partial y\right)_{x=c} = \left(\partial N / \partial x\right)_{y=c}$

$\Rightarrow \left(\partial T / \partial p\right)_{s=c} = \left(\partial V / \partial s\right)_{p=c}$

3) Maxwell's third Equation

$a = u - Ts$

$da = du - Tds - sdT$

$da = -pdv - sdT$

On Comparing

$\left(\partial P / \partial T\right)_{v=c} = \left(\partial s / \partial v\right)_{T=c}.$

4) Maxwell's Fourth Equation

$G = h - Ts$

$dG = dh - Tds - sdT$

$$= Vdp - SdT$$

$$dG = Vdp - SdT$$

So final eqn is

$$\left(\partial V/\partial T\right)_{p=c} = -\left(\partial S/\partial p\right)_{T=c}.$$

UNIT - 4

6) State the conditions under which the eqn of state will hold good for a gas Nov / Dec '14

The eqn of state for real gases $\Rightarrow \left(P+\frac{a}{V^2}\right)V-b=RT$

- For Ideal gas the constants a & b are zero
- The values of a & b are dependent on the type of fluid (or) gases used.
- Experimentally $\frac{P_c V_c}{RT_c}$ chages from 0.2 to 0.3

State the main reasons for the deviation behaviour of real gasg from Ideal gases. Nov / Dec '14

- At low pressures and high temperatures, the density of gas decreases.
- At high pressure, the gas starts to deviate from Ideal gas behaviar to real gas.
- To account this deviation, a factor called Compressibility is Introduced. ~~For~~ to

$$PV = \underset{\substack{\downarrow \\ \text{Compressibility.}}}{Z}RT$$

$$Z = \frac{V_{actual}}{V_{ideal.}} = \frac{\text{sp. vol. of real gases}}{\text{sp. vol. of Ideal gases}}$$

Z:1 for Ideal gases.

Z is greater than or less than 1 for real gasg

7) Explain Irreversibility With respect to flow & non flow Processes
Nov/Dec '14

Defined as the diff. b/w max work to actual work Obtained in a process

$$I = W_{max} - W_{act} = T_0 \Delta S$$

$$W_{max} = (h_1 - h_2) - T_0(S_1 - S_2)$$

$$W_{act} = m(h_1 - h_2) - T_0(S_1 - S_2)$$

$$\Delta S = S_1 - S_2$$

for air. $h_1 - h_2 = C_p(T_1 - T_2)$

Explain the effectiveness of a system : Nov/Dec '14.

Second law of efficiency is known as the effectiveness of a system

It is defined as the ratio b/w the change in the available energy of the system and source.

$$\eta_{II} = \frac{\text{Change in available energy of system}}{\text{Change in available energy of the source}} = \frac{A_{out}}{A_{in}}$$

UNIT-4

Nov / Dec '14.

8 Maxwell relation : April / May 2015 .

Maxwell equation relates entrophy to the three directly measurable propesties pressure volume and temperature for pure simple compressible substances.

From Ist law of thermodynamics,

$$Q = \Delta u + w \rightarrow ①$$

From IInd law of thermodynamics,

$$ds = \frac{Q}{T}$$

$$Tds = Q .$$

w.k.t, $w = Pdv$.

from ① law,

$$Tds = du + Pdv .$$

$$du = Tds - Pdv \quad — ① .$$

Enthalpy, $h = u + Pv$.

$$dh = du + Pdv + vdp .$$

$dh = Tds - Pdv + Pdv + vdp$.

$dh = Tds + vdp$ — ②.

By Helmoltz function;

$a = u - TS$

differentiating on both sides. $da = du - Tds - sdT$.

$da = Tds - Pdv - Tds - sdT$.

$da = -Pdv - sdT$ — ③.

By Gibb's function,

$G = h - TS$

differentiating on both sides,

$dG = dh - Tds - sdT$.

$d\theta = Tds + vdp - Tds - sdT$.

$d\theta = vdp - sdT$.

By inverse exact differential equation,

eqn ①, ②, ③, ④ Rewrite as

$du = Tds - Pdv$.

$$\left[\frac{\partial T}{\partial v}\right]_s = -\left[\frac{\partial P}{\partial s}\right]_v.$$

$dh = Tds + vdp.$

$$\left[\frac{\partial T}{\partial P}\right]_s = \left[\frac{\partial v}{\partial s}\right]_p.$$

$$\left[\frac{\partial P}{\partial T}\right]_v = \left[\frac{\partial s}{\partial v}\right]_T.$$

$$\left[\frac{\partial v}{\partial T}\right]_p = -\left[\frac{\partial s}{\partial P}\right]_T$$

9) Determine the pressure of N_2 at $T = 175\,k$ an $\nu = 0.00375\ m^3/kg$ on the basis of. (i) The Ideal gas eqn of state.
(ii) The Van der waals eqn of state.

The Van der waals constants for Nitrogen are $a = 0.175\,m^6 \cdot kPa/kg^2$. $b = 0.00138\ m^3/kg$.

Soln

The eqn. of state for Ideal gas.

$\boxed{P\nu = mRT}$

$N_2 = 2 \times 14 = 28 = M$

$\boxed{R = 0.287}$

The eqn. of State for real gases i.e. Vander waals eqn.

$$\left(P+\frac{a}{v^2}\right)(v-b) = RT.$$

$$a = \frac{27R^2(T_c)^2}{64P_c}$$ ~~- find P_c~~

$$b = \frac{RT_c}{8P_c}$$

Question Bank

ME6301

Engineering Thermodynamics

Unit V

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Unit 5 – University Question

1) Air at 20°C and 40% RH is mixed adiabatically with air air at 40°C, 40% RH in the ratio of 1kg of the former with 2kg of the latter. Find the specific humidity & the enthalpy of the mixed stream. (April/May 2017)

Soln:

$$t_{d_1} = 20°C$$

$$\phi_1 = 40\%$$

$$t_{d_2} = 40°C$$

$$\phi_2 = 40\%$$

$$\frac{m_1}{m_2} = 1/2$$

$$m_1 + m_2 = m$$

$$m_1\omega_1 + m_2\omega_2 = m_3\omega_3$$

By energy balance

$$m_1h_1 + m_2h_2 = m_3h_3$$

$$\Rightarrow \frac{m_1}{m_2} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_2}$$

From psychometric chart

$\omega_1 = 0.0058$ kg/kg of dry air

$\omega_2 = 0.0184$ " "

$$\frac{1}{2} = \frac{\omega_3 - 0.0184}{0.0058 - \omega_3}$$

$\omega_3 = 0.0144$ kg/kg of air

$$\Rightarrow m_1h_1 + m_2h_2 = (m_1+m_2)\,h_3$$

$$\therefore \frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}$$

From psychometric chart

$h_1 = 35$ kJ/kg

$h_2 = 90$ kJ/kg

$$\frac{1}{2} = \frac{h_3 - 90}{35 - h_3}$$

$h_3 = 71.67$ kJ/kg

2) Atmosphere air at 101.325 kPa and 288.15 k Contain 21% O_2 and 79% N_2 by volume Calculate the

(i) Moles of N_2 per mole of oxygen

(ii) The partial pr of O_2 and N_2 if the total pr is atmosphere

(iii) The kg of Nitrogen per kg of mixture

Take molar mass of O_2 and N_2 as 32 and ~~28~~ kg/kmol. (April/May 2017)

Soln:

$n_{O_2} = 1.0$ and

$V_{O_2} = 0.21V, \quad V_{N_2} = 0.79V$

Let V contain $n = n_{O_2} + n_{N_2}$

(i) Moles of N_2/mole of O_2

$$pV_{O_2} = n_{O_2} R_0 T$$

$$pV_{N_2} = n_{N_2} R_0 T$$

$$\frac{V_{O_2}}{V_{O_2}} = \frac{n_{O_2}}{n_{N_2}}$$

$$n_{N_2} = (1 \times 0.79V)/0.21V = 3.76 \text{ moles}$$

(ii) P_{O_2} & P_{N_2}

$$x_{O_2} = \frac{n_{O_2}}{4}$$

$$= \frac{P_{O_2}}{P}$$

$$P_{O_2} = \frac{n_{O_2}}{n} \times P$$

$$= \frac{1}{1+3.76} \times 1$$

$$= 0.21 \text{ atm}$$

Again $x_{N_2} = \frac{n_{N_2}}{n} = \frac{P_{N_2}}{P}$

$$P_{N_2} = \frac{n_{N_2}}{n} \times P$$

$$= \frac{3.76}{1+3.76} \times 1$$

$$= 0.79 \text{ atm}.$$

(iii) The kg of N_2/kg of Mixture

$$\frac{m_{N_2}}{m_{N_2}+m_{O_2}} = \frac{n_{N_2}\ M_{N_2}}{n_{N_2}M_{N_2}+n_{O_2}\ M_{O_2}}$$

$$= \frac{3.76\times 28}{3.76\times 28+1\times 32}$$

$= 0.77$ kg N_2/kg Mix.

3) An air conditioning system is designed under the following conditions.

- Outdoor Condition 15°C DBT & 10°C WBT
- Required Condition 20°C DBT & 50% RH
- Amount of free air circulation of 0.25 m³/min
- Seating Capacity – 50 persons

The required condition is achieved 1st by heating and then by adiabatic humidifying. Determine the following

1) Capacity of heating coil in kW
2) Capacity of humidifier (Nov/Dec 2016)

From psychometric chart

$h_1 = 30$ kJ/kg

$h_2 = h_3 = 40$ kJ/kg

$\omega_1 = \omega_3 = 0.0055$ kg/kg of dry air

$\omega_2 = 0.0075$ kg/kg of dry air

Specific Volume passing through point 1

is 0.835 m^3/kg

$v_1 = 0.835\ m^3/kg$

$$m_a = \frac{V_1}{v}$$

$$= \frac{0.21}{0.835}$$

$= 0.25$ kg/s

* Heating Coil Capacity

$= m_a (h_3 - h_1)$

$= 0.25 (40 - 30)$

$= 2.5$ kW

Capacity of the humidifier

$= m_a(\omega_2 - \omega_1)$

$= 0.25(0.0075 - 0.0055)$

$= 5 \times 10^{-4}$ kg/s.

4) A rigid tank that contains 4 kg of N_2 at 20°C and 150 kPa is connected to another rigid tank that contains 7 kg of O_2 at 40°C and 100 kPa. The valve connecting the two tanks is opened and the two gases are allowed ~~to~~ mix. ~~If the~~ final mixture temp is 30°C, determine the volume of each tank and the final mixture pressure (Nov/Dec 2016)

Soln: Gn data

$m_{O_2} = 7$ kg

$T_{O_2} = 313$ K

$P_{N_2} = 100$ kPa

$m_{N_2} = 4$ kg

$T_{N_2} = 293K$

$P_{N_2} = 150 kPa$

$M_{O_2} = 2 \times 16 = 32$ kg/kmol

$$N_{O_2} = \frac{m_{O_2}}{M_{O_2}} = 7/32 = 0.219 \text{ kmol}$$

$$N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = 4/28 = 0.142 \text{ kmol}$$

Mole of Mixture

$$N_m = N_{O_2} + N_{N_2}$$

$$= 0.219 + 0.142$$

$$= 0.362 \text{ kmol.}$$

$$V_{O_2} = \frac{0.219 \times 8.314 \times 313}{100}$$

$$= 5.7 m^3$$

$$V_{N_2} = \frac{0.142 \times 8.314 \times 293}{150}$$

$$= 2.32 m^3$$

Volume of mixture

$$V_m = V_{O_2} + V_{N_2}$$

$$= 5.7 + 2.32$$

$$= 8.02 m^3$$

$$P_m = \frac{N_m R_u T_m}{V_m}$$

$$= \frac{0.362 \times 8.314 \times 305.2}{8.02}$$

$$= 114.5 kPa$$

5) A room 7m × 4m × 4m is occupied by an air water vapour mixture at 38°C. The atmosphere pressure is 1 bar and the RH is 70%. Determine the humidity ratio, dew point temperature mass of dry air and mass of water vapour. If the mixture of air-water vapour is further cooled at constant pressure until the temp is 10°C. Find the amount of water vapour condensed. (May/June 2016)

Solnr

Given data

$V = 7 \times 4 \times 4 = 112\, m^3$

$P_b = 1\, bar$

$t_d = 38^\circ C$

$\phi = 0.07$

$\phi = P_v / P_s$

$P_s = 6.681\, kPa$

$$\phi = \frac{P_v}{P_s}$$

$$0.7 = \frac{P_v}{6.6816}$$

$P_v = 0.7 \times 6.6816$

$= 4.677\, kPa$

$$W = \frac{0.622\, P_v}{P_b - P_v}$$

$$= \frac{0.622 \times 4.677}{100 - 4.677} = 0.0305\, kg/kg \text{ of dry air}$$

From steam Tables, for vapour pressure

$P_v = 4.677$ kPa, $t_{dp} = 36.5°c$

$P_b = P_v + P_a$

$P_a = P_b - P_b$

$= 100 - 4.677$

$= 95.3$ kPa

$P_a v = \dot{m}_a R_a T$

$$v_a = \frac{0.287 \times 311}{95.3}$$

$= 0.936\ m^3/kg$

$$0.027 = \frac{m_v}{758.55}$$

$$m_a = \frac{7 \times 4 \times 4}{0.936}$$

$= 119.6$ kg

$m_a = 20.48g.$

$\omega = \frac{m_v}{m_a}$

$m_v = 0.0305 \times 20.48$

$= 0.6246$ kg

From Steam tables, for 10°C the Corresponding pr is 0.01227 bar

$P_v = P_s = 0.01227$ bar

$$\omega = \frac{0.622 \; P_v}{P_b - P_v}$$

$$\frac{0.622 \times 0.01227}{1 - 0.01227}$$

$= 7.726 \times 10^{-3}$ kg/kg of dry air