STELLA MARY'S COLLEGE OF ENGINEERING

(Accredited by NAAC, Approved by AICTE - New Delhi, Affiliated to Anna University Chennai)

Aruthenganvilai, Azhikal Post, Kanyalumari District, Tamilnadu - 629202.

ME8391 ENGINEERING THERMODYNAMICS

(Anna University: R2017)

Prepared By

Mr. I. P. RAKHESH

Assistant Professor

DEPARTMENT OF MECHANICAL ENGINEERING

2021-2022 (ODD)

STELLA MARY'S COLLEGE OF ENGINEERING

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Aruthenganvilai, Kallukatti Junction Azhikal Post, Kanyakumari District-629202, Tamil Nadu.

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIAL

REGULATION	**2017**
YEAR	**II**
SEMESTER	**03**
COURSE NAME	**ENGINEERING THERMODYNAMICS**
COURSE CODE	**ME8391**
NAME OF THE COURSE INSTRUCTOR	**Mr. I. P. RAKHESH**

SYLLABUS:

UNIT I BASIC CONCEPTS AND FIRST LAW 9 +6

Basic concepts - concept of continuum, comparison of microscopic and macroscopic approach. Path and point functions. Intensive and extensive, total and specific quantities. System and their types. Thermodynamic Equilibrium State, path and process. Quasi-static, reversible and irreversible processes. Heat and work transfer, definition and comparison, sign convention. Displacement work and other modes of work .P-V diagram. Zeroth law of thermodynamics – concept of temperature and thermal equilibrium– relationship between temperature scales –new temperature scales. First law of thermodynamics –application to closed and open systems – steady and unsteady flow processes.

UNIT II SECOND LAW AND AVAILABILITY ANALYSIS 9+6

Heat Reservoir, source and sink. Heat Engine, Refrigerator, Heat pump. Statements of second law and its corollaries. Carnot cycle Reversed Carnot cycle, Performance. Clausius inequality. Concept of entropy, T-s diagram, Tds Equations, entropy change for - pure substance, ideal gases - different processes, principle of increase in entropy. Applications of II Law. High and low grade energy. Available and non-available energy of a source and finite body. Energy and irreversibility. Expressions for the energy of a closed system and open systems. Energy balance and entropy generation. Irreversibility. I and II law Efficiency.

UNIT III PROPERTIES OF PURE SUBSTANCE AND STEAM POWER CYCLE 9 +6

Formation of steam and its thermodynamic properties, p-v, p-T, T-v, T-s, h-s diagrams. p-v-T surface. Use of Steam Table and Mollier Chart. Determination of dryness fraction. Application of I and II law for pure substances.

Ideal and actual Rankine cycles, Cycle Improvement Methods - Reheat and Regenerative cycles, Economiser, preheater, Binary and Combined cycles.

UNIT IV IDEAL AND REAL GASES, THERMODYNAMIC RELATIONS 9+6

Properties of Ideal gas- Ideal and real gas comparison- Equations of state for ideal and real gases- Reduced properties. Compressibility factor-.Principle of Corresponding states. –Generalised Compressibility Chart and its use-. Maxwell relations, Tds Equations, Difference and ratio of heat capacities, Energy equation, Joule-Thomson Coefficient, Clausius Clapeyron equation, Phase Change Processes. Simple Calculations.

UNIT V GAS MIXTURES AND PSYCHROMETRY 9+ 6

Mole and Mass fraction, Dalton's and Amagat's Law. Properties of gas mixture – Molar mass, gas constant, density, change in internal energy, enthalpy, entropy and Gibbs function. Psychrometric properties, Psychrometric charts. Property calculations of air vapour mixtures by using chart and expressions. Psychrometric process – adiabatic saturation, sensible heating and cooling, humidification, dehumidification, evaporative cooling and adiabatic mixing. Simple Applications

TEXT BOOKS :

1. R.K.Rajput, "A Text Book Of Engineering Thermodynamics ",Fifth Edition,2017.
2. Yunus a. Cengel & michael a. Boles, "Thermodynamics", 8th edition 2015.

REFERENCES:

1. Arora C.P, "Thermodynamics", Tata McGraw-Hill, New Delhi, 2003.
2. Borgnakke & Sonnatag, "Fundamental of Thermodynamics", 8th Edition , 2016.
3. Chattopadhyay, P, "Engineering Thermodynamics", Oxford University Press, 2016.
4. Michael J. Moran, Howard N. Shapiro, "Fundamentals of Engineering Thermodynamics", 8th Edition.
5. Nag.P.K., "Engineering Thermodynamics", 5th Edition, Tata McGraw-Hill, New Delhi, 2013..

Course Outcome Articulation Matrix

	Program Outcome												*PSO*		
Course Code / CO No	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***1***	***2***	***3***
ME8391 / C202.1	3	3	3	1	0	1	0	1	1	2	0	3	3	2	1
ME8391 / C202.2	3	3	3	2	1	1	2	1	1	2	1	3	3	2	1
ME8391 / C202.3	3	3	3	2	1	1	2	1	1	2	1	3	3	2	1
ME8391 / C202.4	3	3	3	1	0	1	1	1	1	2	1	3	3	2	1
ME8391 / C202.5	3	3	3	2	1	1	1	1	1	2	2	3	3	2	1
Average	3	3	3	2	1	1	1	1	1	2	1	3	3	2	1

Unit – 1 Question Bank

1. In an isentropic flow through nozzle, air flows at the rate of 600 kg/hr. At inlet to the nozzle, pressure is 2 MPa and temperature is 127°C. The exit pressure is 0.5 MPa. Initial air velocity is 300 m/s determine (i) Exit velocity of air (ii) Inlet and exit area of nozzle.
(16)
(NOV/DEC 2006.)

2. A centrifugal pump delivers 2750 kg of water per minute from initial pressure of 0.8 bar absolute to a final pressure of 2.8 bar absolute. The suction is 2 m below and the delivery is 5 m above the centre of pump. If the suction and delivery pipes are of 15 cm and 1.0 cm diameter respectively, make calculation for power required to run the pump.
(16)
(NOV/DEC 2006.)

3. A reciprocating air compressor takes in 2 m^3/min air at 0.11 MPa, 293 K which it delivers at 1.5 MPa, 384 K to an after cooler where the air is cooled at constant pressure to 298 K. The power absorbed by the compressor is 4.15 kW. Determine the heat transfer in (i) the compressor (ii) the cooler. State your assumptions. **(16)**
Nov / Dec 2009

4. In a turbo machine handling an incompressible fluid with a density of 1000 kg/m3 the conditions of the fluid at the rotor entry and exit are as given below:

	Inlet	Exit
Pressure	1.15 MPa	0.05 MPa
Velocity	30 m/sec	15.5 m/sec
Height above datum	10 m	2 m

If the volume flow rate of the fluid is 40 m^3/s, estimate the net energy transfer from the fluid as work.
(16)
Nov / Dec 2009

5. A rigid tank containing 0.4 m3 of air at 400 kPa and 30°C is connected by a valve to a piston cylinder device with zero clearance. The mass of the piston is such that a pressure of 200 kPa is required to raise the piston. The valve is opened slightly and air is allowed to flow into the cylinder until the pressure of the tank drops to 200 kPa. During this process, heat is exchanged with the surrounding such that the entire air remains at 30°C at all times. Determine the heat transfer for this process. **(16)**
Nov / Dec 2010

6. The electric heating system used in many houses consists of simple duct with resistance wire. Air is heated as it flows over resistance wires. Consider a 15 kW electric heating system. Air enters the heating section at 100 kPa and 17°C with a volume flow rate of 150 m^3/min. If heat is lost from the air in the duct to the surroundings at a rate of 200 W, determine the exit temperature of air. **(16)**
Nov / Dec 2010

7. A gas contained in a cylinder is compressed from 1 MPa and 0.05 m^3 to 2 MPa. Compression is governed by 1.4 *V P* constant. Internal energy of gas is given by; U = 7.5 PV –425, kJ, where *P* is pressure in kPa and V is volume in m3. Determine heat, work and change in internal energy assuming compression process to be quasistatic.

mass flow rate. (iii) If the specific volume at the nozzle exit is 0.498 m^3 / kg. Find the exit area of the nozzle.

(8)

April / May 2010

14. A room of four persons has two fans has two fans, each consuming 0.18 kW power, and three 100 W 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. **(7)**

(Nov / Dec 2007)

15. Three grams of nitrogen gas at 6 atm and 160°C is expanded adiabatically to double its initial volume, then compressed at constant pressure to its initial volume and then compressed again at constant volume to its initial state. Calculate the net work done on the gas. Draw the p – V diagram for the process. Specific heat ratio of nitrogen is 1.4.

(12)

(May / June 2007)

16. Air expands by isentropic process through a nozzle from 784 kPa and 220°C to an exit pressure of 98 kPa. Determine the exit velocity and the mass flow rate, if the exit area is 0.0006 m^2.

(8)

(May / June 2007)

17. A blower handles 1 kg / sec of air at 293 K and consumes a power of 15 kW. The inlet and outlet velocities of air are 100 m / sec and 150 m / sec respectively. Find the exit air temperature, assuming adiabatic conditions. Take Cp of air as 1.005 kJ / kg.K. **(9)**

(Nov / Dec 2007)

18. One litre of hydrogen at 273 K is adiabatically compressed to one half of its initial volume. Find the change in temperature of the gas, if the ratio of two specific heats for hydrogen is 1.4.

(4)

(Nov / Dec 2007)

19. The velocity and enthalpy of fluid at the inlet of a certain nozzle are 50 m / sec and 2800 kJ / kg respectively. The enthalpy at the exit of nozzle is 2600 kJ / kg. The nozzle is horizontal and insulated so that no heat transfer takes place from it. Find

(i) Velocity of the fluid at exit of the nozzle

(ii) Mass flow rate, if the area at inlet of nozzle is 0.09 m^2.

(iii) Exit area of the nozzle, if the specific volume at the exit of the nozzle is 0.495 m^3 / kg.

(12)

(Nov / Dec 2007)

20. A three process cycle operating with nitrogen as the working substance has constant temperature compression at 34°C with initial pressure 100 kPa. Then the gas undergoes a constant volume heating and then polytrophic expansion with 1.35 as index of compression. The isothermal compression requires – 67 kJ / kg of work. Determine

(i) P, v and T around the cycle.

(ii) Heat in and out

(iii) Net work.

For nitrogen gas, Cv = 0.7431 kJ / kg.K.

(16)

May / June 2013

21. A fluid is confined in a cylinder by a spring loaded, frictionless piston so that the pressure in the fluid is a linear function of the volume (p = a + bV). The internal energy of the fluid is given by U = (34 + 3.15 pV) where U is in kJ, p in kPa and V in

Also find out work interaction, if the 180 kJ of heat is transferred to system between same states. Also explain why it is different from above? **(16)**

April / May 2011

8. In a gas turbine installation air is heated inside heat exchanger up to 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.

a. Heat transfer to air in heat exchanger
b. Power output from turbine
c. Velocity at exit of nozzle.

Take up for air as 1.005 kJ / kg. K. **(16)**

April / May 2011, May / June 2014

9. 25 people attended a farewell party *in* a small room *of* size 10 × 8 m *and* have a 5 m ceiling. Each person gives up 350 kJ *of* heat per hour. Assuming that the room is completely sealed off and insulated, calculate *the* air temperature rise occurring *in* 10 minutes. Assume Cv *of* air 0.718 kJ/kg K *and* R = 0.287 kJ/kg K *and* each person occupies a volume of 0.05 m3. Take p = 101.325 kPa an*d* T = 20°C. **(10)**

Nov / Dec 2011

10. Air flows at *the* rate *of* 0.5 kg/s through *an* air compressor, entering at 7 m/s, 100 kPa *and* 0.95 m^3/ kg and leaving at 5 m/s, 700 kPa, a*nd* 0.19 m3/kg. The internal energy of air leaving is 90 kJ/kg greater than that *of the* air entering. Cooling water *in the* compressor jackets absorbs heat from *the* air at the rate *of* 58 kW. (1) Compute the rate *of* shaft work input to *the* air *in* kW (2) Find *the* ratio *of* the inlet pipe diameter to outer pipe diameter. **(8)**

Nov / Dec 2011

11. A gas of mass 1.5 kg undergoes a quasi-static expansion which follows a relationship p = a + bV, where a and b are constants. The initial and final pressures are 100 kpa and 200 kpa respectively and the corresponding volumes are 0.20 m^3 and 1.20 m^3. The specific internal energy of the gas is given by the relation U=1.5pv – 85 kJ / kg. Where p is in kpa and v is in m^3/kg. Calculate the net heat transfer and the maximum internal energy of the gas attained during expansion. **(10)**

Nov / Dec 2012, May / June 2009

12. A gas flows steadily through compressor. The gas enters the compressor at a temperature of 16°C, a pressure of 100 kpa, and an enthalpy of 391.2 kJ / kg. The gas leaves the compressor at a temperature of 245°C, a pressure of 0.6 MPa, and an enthalpy of 535.5 kJ /kg. There is no heat transfer to (or) from the gas as it flows through the compressor. Evaluate the external work done per unit mass of gas when the velocity at entry 80 m /s and that at exit is 160 m/s.

13. A nozzle is a device for increasing the velocity of a steady flowing steam. At the inlet to a certain nozzle, the enthalpy of the fluid passing is 3000 kJ / kg and the velocity is 60 m / s. At the discharge end, the enthalpy is 2762 kJ / Kg. The nozzle is horizontal and there is negligible heat loss from it. (i) Find the velocity at exit from the nozzle. (ii) If the inlet area is 0.1 m^2 and the specific volume at inlet is 0.187 m^3 / kg. Find the cubic meter. If the fluid changes from an initial state of 170 kPa, 0.03 m^3 to final state of 400 kPa, 0.06 m^3, with no work other than that done on the piston, find the direction and magnitude of the work and heat transfer. **(12)**

Nov / Dec 2012

22. Determine the heat transfer and its direction for a system in which a perfect gas having molecular weight of 6 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 / kg. K. **(16)**

May / June 2014

23. Air at a temperature of 15°C passes through a heat exchanger at a velocity of 30 m/s where its temperature is raised to 800°C. It then enters a turbine with the same velocity of 30 m/s and expands until the temperature falls to 650°C. On leaving the turbine, the air is taken at a velocity of 60 m/s to a nozzle where it expands until the temperature has fallen to 500°C. If the air flow rate is 2 kg /s. Calculate (a) the rate of heat transfer to the air in the heat exchanger (b) the power output from the turbine assuming no heat loss, and (c) the velocity at exit from the nozzle, assuming no heat loss. Take the enthalpy of air as h = Cp.t, where Cp is the specific heat equal to 1.005 kJ / kg.K and t is the temperature.

Theory questions

1. Considering a system which changes its state, prove that the internal energy is a point function. **(8)**

Nov / Dec 2011

2. Define the following terms
(1) Thermodynamics
(2) Macroscopic approach
(3) Continuum. **(6)**

Nov / Dec 2012, Nov / Dec 2011

3. Deduce the expression for the displacement work in an isothermal process. **(4)**

(May / June 2007)

4. Describe steady flow energy equation and deduce suitable expression for the expansion of gas in a gas turbine with suitable assumptions. **(8)**

(May / June 2007)

5. **(i)**Derive the steady flow energy equation, stating the assumptions made. **(6)**
(ii) Prove that energy is a property of a system. **(5)**
(iii) Enumerate and explain the limitations of first law of thermodynamics. **(5)**

May / June 2013

6. Define enthalpy. How is it related to internal energy? **(4)**

Nov / Dec 2012

7. Derive steady flow energy equation and reduce it for turbine, pump, nozzle and a heat exchanger. **(16)**

Nov / Dec 2013

8. Briefly explain the following:
(i) Point function and path function. **(4)**
(ii) Property, state, process and path **(8)**
(iii) Quasi- static process. **(4)**

Nov / Dec 2013

Two mark questions and answers

UNIT I

BASIC CONCEPT AND FIRST LAW

1. What do you understand by pure substance?

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

2. Define thermodynamic system.

A thermodynamic system is defined as a quantity of matter or a region in space, on which the analysis of the problem is concentrated.

3. Name the different types of system.

1. Closed system (only energy transfer and no mass transfer)
2. Open system (Both energy and mass transfer)
3. Isolated system (No mass and energy transfer)

4. What is meant by closed system? Give an example

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

Example: Piston and cylinder arrangement.

5. Define a open system, Give an example.

When a system has both mass and energy transfer it is called as open system.

Example: Air Compressor.

6. Define an isolated system

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

Example: Entire Universe

7. Define: Specific heat capacity at constant pressure.

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

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

8. Define: Specific heat capacity at constant volume.

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

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

9. What is meant by surroundings?

Any other matter outside the system boundary is called as surroundings.

10. What is boundary?

System and surroundings are separated by an imaginary line is called boundary.

11. What is meant by thermodynamic property?

Thermodynamic property is any characteristic of a substance which is used to identify the state of the system and can be measured, when the system remains in an equilibrium state.

12. Name and explain the two types of properties. **Nov / Dec 2013**

The two types of properties are intensive property and extensive property.

Intensive Property: It is independent of the mass of the system.

Example: pressure, temperature, specific volume, specific energy, density.

Extensive Property: It is dependent on the mass of the system.

Example: Volume, energy. If the mass is increased the values of the extensive properties also Increase.

13. What is meant by thermodynamic equilibrium? **May / June 2014**

When a system is in thermodynamic equilibrium, it should satisfy the following three conditions.

(a) Mechanical Equilibrium :- Pressure remains constant

(b) Thermal equilibrium :- Temperature remains constant

(c) Chemical equilibrium: There is no chemical reaction.

14. Explain Mechanical equilibrium.

If the forces are balanced between the system and surroundings are called Mechanical equilibrium

15. Explain Chemical equilibrium.

If there is no chemical reaction or transfer of matter form one part of the system to another is called Chemical equilibrium

16. Explain Thermal equilibrium.

If the temperature difference between the system and surroundings is zero then it is in Thermal equilibrium.

17. What is Quasi – Static process? **Nov/Dec 2012**

26. Define the term Cycle **Nov/Dec 2011**

It is defined as a series of state changes such that the final state is identical with the initial state.

27. Define Zeroth law of Thermodynamics. **Nov/Dec 2009**

When a body A is in thermal equilibrium with body B and also separately with a body C, then B and C will be in thermal equilibrium with each other.

28. What are the limitations of first law of thermodynamics? **Nov/Dec 2012**

1. According to first law of thermodynamics heat and work are mutually convertible during any cycle of a closed system. But this law does not specify the possible conditions under which the heat is converted into work.

2. According to the first law of thermodynamics it is impossible to transfer heat from lower temperature to higher temperature.

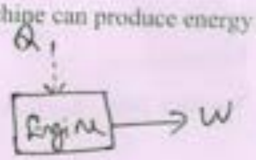
3. It does not give any information regarding change of state or whether the process is possible or not.

4. The law does not specify the direction of heat and work.

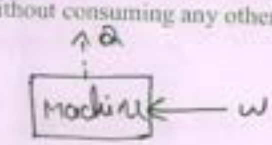
29. What is perpetual motion machine of first kind or PMMI?

Nov/Dec 2007, May/June 2010

It is defined as a machine, which would continuously supply mechanical work without some other form of energy disappearing simultaneously. It is impossible to obtain in actual practice, because no machine can produce energy of its own without consuming any other form of energy.



A PMMI



Converse of PMMI

30. Define the term enthalpy?

The Combination of internal energy and flow energy is known as enthalpy of the system. It may also be defined as the total heat of the substance.

Mathematically, enthalpy **(H) = U + PV** KJ)

The process is said to be quasi – static, it should proceed infinitesimally slow and follows continuous series of equilibrium states at all times. Therefore, the quasi static process may be a reversible process.

18. Define Path function. **May / June 2014, Nov/Dec 2010**

The work done by a process does not depend upon the end of the process. It depends on the path of the system follows from state 1 to state 2. Hence work is called a path function.

19. Define point function. **May / June 2014, Nov/Dec 2010**

Thermodynamic properties are point functions. The change in a thermodynamic property of a system is a change of state is independent of the path and depends only on the initial and final states of the system.

20. Explain homogeneous and heterogeneous system.

The system consist of single phase is called homogeneous system and the system consist of more than one phase is called heterogeneous system.

21. What is a steady flow process?

Steady flow means that the rates of flow of mass and energy across the control surface are constant.

22. Prove that for an isolated system, there is no change in internal energy. **Nov/Dec 2011**

In isolated system there is no interaction between the system and the surroundings. There is no mass transfer and energy transfer. According to first law of thermodynamics as

$dQ = dU + dW$; $dU = dQ - dW$; $dQ = 0$, $dW = 0$,

Therefore $dU = 0$ by integrating the above equation U = constant, therefore the internal energy is constant for isolated system.

23. Indicate the practical application of steady flow energy equation.

1. Turbine 2.Nozzle 3.Condenser, 4.Compressor.

24. Define state. **Nov/Dec 2011, April /May 2012**

The condition of the system at particular time.

25. Define the term process and path **Nov/Dec 2011, April /May 2012**

Process

Any change that a system undergoes from one equilibrium state to another is called a *process*.

Path

Series of states through which a system passes during a process is called the *path*.

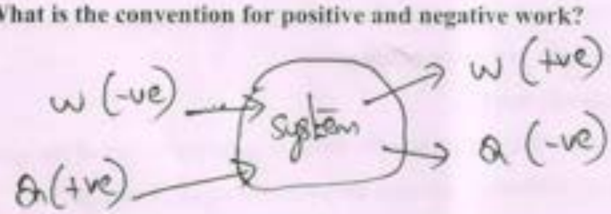
36. What do you understand by flow work? Is it different from displacement work?

May/June 2013, April /May 2010, 2009.

Flow work is the energy transferred across the system boundary as a result of energy imparted to the fluid by a pump, blower to make the fluid flow across the control volume.

Flow work is analogous to displacement work.

37. What is the convention for positive and negative work? Nov/Dec 2006



38. What are the corollaries to the first law of thermodynamics? **Nov / Dec 2006**

Corollary I

There exists a property of a closed system such that a change in its value is equal to the difference between the heat supplied and the work done during any change of state.

Corollary II

The internal energy of a closed system remains unchanged if the system is isolated from its surroundings.

Corollary III

A perpetual motion machine of first kind (PMM-1) is impossible.

39. Is it correct to say 'total heat' or 'heat content' of a closed system? Nov / Dec 2007

Yes. The total heat or heat content of a closed system is also called as enthalpy.

Where, U – internal energy

p – Pressure

v – Volume

In terms of Cp & T → **H = mCp (t_2-t_1)** KJ

31. Define the term internal energy **Nov/Dec 2011**

Internal energy of a gas is the energy stored in a gas due to its molecular interactions. It is also defined as the energy possessed by a gas at a given temperature.

32. What is meant by thermodynamic work?

It is the work done by the system when the energy transferred across the boundary of the system. It is mainly due to intensive property difference between the system and surroundings.

33. Distinguish between 'macroscopic energy' or classical thermodynamics and 'microscopic energy' or statistical thermodynamics.

Nov / Dec 2013, Nov/Dec 2012, Nov/Dec 2009

Macroscopic energy or classical thermodynamics

A certain quantity of matter is considered, without the events occurring at the molecular level being taken into account. It is concerned with the effects of the action of many molecules, and these effects can be perceived by human senses

Pressure is the average rate of change of momentum due to all the molecular collisions made on a unit area.

Microscopic energy or statistical thermodynamics

Each molecule at a given instant has a certain position, velocity and energy and each molecule these change very frequently as a result of collisions. The behavior of the gas is described by the summing up the behavior of each molecule

34. What is meant by 'hyperbolic processes? **April/May 2011**

Super heated steam acts like gas. The isothermal process in the superheated region is called hyperbolic process. A process in which the gas is heated or expanded in such a way that the product of its pressure and volume remains constant is called hyperbolic process. The curve in such an expansion process is a rectangular hyperbola and hence this is known as hyperbolic expansion.

35. Distinguish between stored energies and interaction energies. **Nov/Dec 2010**

First law for a closed system

① A piston and cylinder machine contains a fluid system which passes through a complete cycle of four processes. During a cycle, the sum of all heat transfers is −170 kJ. The system completes 100 cycles per min. Complete the following table showing the method for each item, and compute the net rate of work output in kW.

Process	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
a-b	0	2,170	—
b-c	21,000	0	—
c-d	− 2,100	0	—
d-a	—	—	—

Answer : −283·3 kW

② A fluid is confined in a cylinder by a spring-loaded, frictionless piston so that the pressure in the fluid is a linear function of the volume ($p = a + bv$). The internal energy of the fluid is given by the following equation.

$$U = 34 + 3.15\,PV$$

Where, U – internal energy

p – Pressure

v – Volume

In terms of Cp & T → **H = mCp (t_2-t_1)** KJ

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Nov / Dec 2013, Nov/Dec 2012, Nov/Dec 2009

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35. Distinguish between stored energies and interaction energies. **Nov/Dec 2010**

where U is in kJ, P in kPa, and V in cubic metre. If the fluid changes from an initial state of 170 kPa, 0.03 m^3 to a final state of 400 kPa, 0.06 m^3. with no work other than that done on the piston. find the direction and magnitude of the work and heat transfer.

Ans: $W_{1-2} = 8.55 kJ$,

Nov/Dec 2012

$Q_{1-2} = 68.05 kJ$

③ A gas of mass 1.5 kg undergoes a quasi-static expansion which follows a relationship $P = a + bV$, where a and b are constants. The initial and final pressures are 1000 kPa and 200 kPa respectively and the corresponding volumes are 0.20 m^3 and 1.20 m^3. The specific internal energy of the gas is given by the relation

$$u = 1.5\,PV - 85\ kJ/kg$$

where P is the kPa and v is in m^3/kg. Calculate the net heat transfer and the maximum internal energy of the gas attained during expansion

Ans: $Q_{1-2} = 660 kJ$

Nov/Dec 2012

May / June 2009 K

$U = 503.3 kJ$

First law of thermodynamics for an open system

① Air flows steadily at the rate of 0.5 kg/s through an air compressor, entering at 7 m/s velocity, 100 kPa pressure, and 0.95 m^3/kg volume, and leaving at 5 m/s, 700 kPa and 0.19 m^3/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in the compressor jacket absorbs heat from the air at the rate of 58 kW. (a) Compute the rate of shaft work input to the air in kW. (b) Find the ratio of the inlet pipe diameter to outlet pipe diameter.

④

Ans : $W = 122$ kW (or) kJ/s

$d_1/d_2 = 1.89$

NOV / DEC 2011

② A reciprocating air compressor takes in $2 m^3/min$ air at 0.11 MPa, 293 K which it delivers at 1.5 MPa, 384 K to an after cooler where the air is cooled at constant pressure to 298 K. The power absorbed by the compressor is 4.15 kW.

③

Determine the heat transfer in (i) the compressor (ii) cooler. state your assumption.

Answer: $Q_{compressor} = -1.275$ kJ/s

$Q_{cooler} = -3.8$ kJ/s

Nov/Dec 2009

③ A gas flows steadily through compressor. The gas enters the compressor at a temperature of 16°c, a pressure of 100kpa, and an enthalpy of 391.2 kJ/kg. The gas leaves the compressor at a temperature of 245°c, a pressure of 0.6mpa, and an enthalpy of 535.5kJ/kg. There is no heat transfer to (or) from the gas as it flows through the compressor. Evaluate the external work done per unit mass of gas when the velocity at entry 80m/s and that at exit is 160m/s.

H.W

Ans: $W = -152.9$ kJ/kg

④ A gas contained in a cylinder is compressed from 1MPa and $0.05 m^3$ to 2MPa. Compression is governed by $PV^{1.4}$ constant. Internal energy of gas is given by $U = 7.5PV$, kJ. where P is pressure in kPa and V is volume in m^3. Determine heat, work and change in internal energy assuming compression process to be quasistatic. Also find out work interaction, if the 180kJ of heat is transferred to system between same states. Also explain why it is different from above?

April/May - 2011

Ans: (a) $W = 85kJ$

$Q = 100kJ$

(b) $Q = 180kJ$

$W = 105kJ$

5. In a steam power station, steam flows steadily through a 0.2m diameter pipeline from the boiler to the turbine. At the boiler end, the steam conditions are found to be: $P = 4\ MPa$, $t = 400°c$, $h = 3213.6\ kJ/kg$, and $v = 0.073\ m^3/kg$. At the turbine end, the conditions are found to be; $P = 3.5MPa$, $t = 392°c$, $h = 3202.6\ kJ/kg$ and $v = 0.084\ m^3/kg$. There is a heat loss of 8.5 kJ/kg from the pipeline. Calculate the steam flow rate.

Ans: 53.8 kg/s

6. In a gas turbine the gas enters at the rate

of 5kg/s with a velocity of 50m/s and enthalpy of 900 kJ/kg and leaves the turbine with a velocity of 150m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surroundings is 25 kJ/kg. Assume for gas R = 0.285 kJ/kgk and cp = 1.004 kJ/kgk and the inlet conditions to be at 100kpa and 27°C. Determine the power output of the turbine and the diameter of the inlet pipe.

Ans: W = 2325 kw
D_1 = 0.33m

(7) 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 50m/s and leaves at 600°c. Air leaving turbine enters a nozzle at 60m/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.

H.W

(i) Heat transfer to air in heat exchanger
(ii) Power output from turbine
(iii) velocity at exit of nozzle

April/May-2011

Take cp for air as 1.005 kJ/kg k.

Ans: Q_{1-2} = 726.615 kJ/kg ; W = 150.2 kJ/kg ; V_4 = 452.33m/s

(8) Air at a temperature of 15°c passes through a heat exchanger at a velocity of 30m/s where its temperature is raised to 800°c. It then enters a turbine with the same velocity of 30m/s and expands until the temperature falls to 650°c. On leaving the turbine, the air is taken at a velocity of 60m/s to a nozzle where it expands until the temperature has fallen to 500°c. If the air flow rate is 2kg/s, calculate (a) the rate of heat transfer to the air in the heat exchanger, (b) the power output from the turbine
(4) assuming no heat loss, and (c) the velocity at exit from the nozzle, assuming no heat loss. Take the enthalpy of air as $h = c_p t$, where c_p is the specific heat equal to 1.005 kJ/kg K and t is the temperature.

Ans: $Q_{1-2} = 1580$ kJ/s ; $W_T = 298.8$ kW

$V_4 = 554$ m/s

(9) A nozzle ~~velocity~~ is a device for increasing the velocity of a steadily flowing steam. At the inlet to a certain nozzle, the enthalpy of the

fluid passing is 3000 kJ/kg and the velocity is 60m/s. At the discharge end, the enthalpy is 2762 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it. (i) Find the velocity at exit from the nozzle. (ii) If the inlet area is 0.1m² and the specific volume at inlet is 0.187 m³/kg. Find the mass flow rate. (iii) If the specific volume at the nozzle exit is 0.498 m³/kg. Find the exit area of the nozzle.

Ans: (i) = 692.5m/s (ii) $\dot{m}$ = 32.08kg/s (iii) A_2 = 0.023m²

May/June - 2009

10. The air speed of a turbojet engine in flight is 270 m/s. Ambient air temperature is −15°c. Gas temperature of outlet of nozzle is 600°c. Corresponding enthalpy values for air and gas are respectively 260 and 912 kJ/kg. Fuel-air ratio is 0.0190. chemical energy of the fuel is 44.5MJ/kg. Owing to incomplete combustion 5% of the chemical energy is not released in the reaction. Heat loss from the engine is 21 kJ/kg of air. calculate the velocity of the exhaust jet.

Ans: V_g = 560m/s

Q In a turbo machine handling an incompressible fluid with a density of $1000 kg/m^3$ the conditions of the fluid at the rotor entry and exit are as given below

	Inlet	outlet
Pressure	1.15 MPa	0.05 MPa
velocity	30 m/sec	15.5 m/sec
Height above datum	10 m	2 m

If the volume flow rate of the fluid is $40 m^3/s$. Estimate the net energy transfer from the fluid as work. NOV/DEC - 2009

Ans: Energy transfer = 176×10^6 mw

12. In a steady flow apparatus, 135 kJ of work is done by each kg of fluid. The specific volume of the fluid, pressure, and velocity at the inlet are $0.37 m^3/kg$, 600 kpa, and 16 m/s. The inlet is 32 m above the floor, and the discharge pipe is at floor level. The discharge conditions are $0.62 m^3/kg$, 100 kpa, and 270 m/s. The total heat loss between the inlet and discharge is 9 kJ/kg of fluid. In flowing through this apparatus

does the specific internal energy increase (or) decrease, and by how much?

Ans: $U = 20.136\,kJ$

13. A turbine operates under steady flow conditions, receiving steam at the following state: Pressure 1.2 MPa, temperature 188°c, enthalpy 2785 kJ/kg, velocity 33.3 m/s and elevation 3m. The steam leaves the turbine at the following state: Pressure 20 kPa, enthalpy 2512 kJ/kg, velocity 100 m/s, and elevation 0m. Heat is lost to the surroundings at the rate of 0.29 kJ/s. If the rate of steam flow through the turbine is 0.42 kg/s. what is the power output of the turbine in kW.

H.W

(2)

Ans: 112.51 kW (or) kJ/s

14. A room for four persons has two fans, each consuming 0.18 kW power, and three 100W lamps. Ventilation air at the rate of 80 kg/h 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/h. Determine the rate at which heat is to be removed by a room cooler, so that a steady state is maintained in the room.

(6)

(4)

Ans: 1.92 kW

15\. 5 kg of air at 40°c and 1 bar is heated in a reversible non-flow constant pressure until the volume is doubled. Find (a) change in volume (b) work done (c) change in internal energy and (d) change in enthalpy.

Ans: $V_2 - V_1 = 4.49 m^3$; $W = 449 kJ$; $\Delta u = 1117.41 kJ$

$\Delta H = 1572.825 kJ$.

16\. 10 kg of fluid per minute goes through a reversible steady flow process. The properties of fluid at the inlet are $P_1 = 1.5 bar$, $\rho_1 = 26 kg/m^3$, $V_1 = 110 m/s$ and $u_1 = 910 kJ/kg$ and at the exit are

(8) $P_2 = 5.5$ bar $\rho_2 = 5.5 kg/m^3$, $V_2 = 190 m/s$ and $u_2 = 710 kJ/kg$.

(3) During the passage, the fluid rejects 55 kJ/s and rise through 55m. Determine: (i) the change in enthalpy (h) (ii) work done during the process (w)

Ans: $h_2 - h_1 = -105.7 kJ/kg$; $w = -39.42 kW$ Nov/Dec -2011

17\. A system contains $0.2 m^3$ of a gas at a pressure of 4 bar and 150°c. It is expanded adiabatically

(6) till the pressure falls to 1 bar. The gas is then heated at a constant pressure till its enthalpy increases by 100 kJ. Determine the total work done. Take $C_p = 1 kJ/kg k$ and $C_v = 0.714 kJ/kg k$.

Ans: $T_2 = 284.66 k$; $T_3 = 436.175 k$; workdone = 94.01 kJ

Nov/Dec - 2011

Engineering Thermodynamics

Thermo → Heat

Dynamics → Power

Applications
① I.C. Engines
② Power plants
③ solar cooker
④ pressure cooker
⑤ water heater

conservation of energy principle

Thermodynamics is the science of energy transfer and its effect on the physical properties of substances.

Macroscopic Approach: (classical thermodynamics)

*A certain quantity of matter is considered, without the events occuring at the molecular level being taken into account.

*It is only concerned with the effects of the action of many molecules, and these effects can be perceived by human senses.

(e.g) Pressure is the average rate of change of momentum due to all the molecular collisions made on a unit area

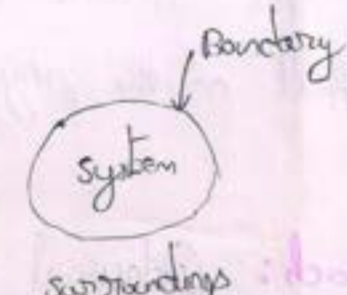
Microscopic approach: (statistical thermodynamics)

matter is composed of (group) myriads of molecules.

(e.g) Gas, each molecule ~~these change~~ at a given instant has a certain position, velocity, and energy and each molecule these change very frequently as a result of collisions. The behaviour of the gas is described by the summing up the behaviour of each molecule.

Thermodynamics system:

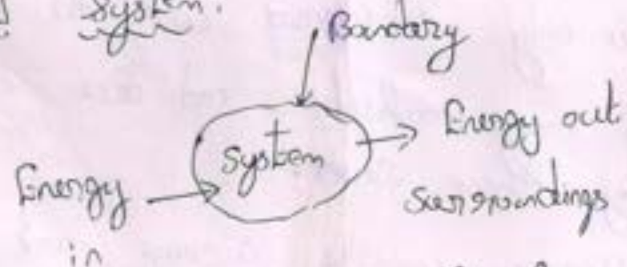
It is defined as a quantity of matter (or) a region in space upon which attention is concentrated in the analysis of a problem.



Thermodynamic system

Types of system

① closed system:



No mass transfer

→ Energy ~~and mass~~ cross the boundary

→ No mass transfer (e.g) Piston & cylinder device

② open system

→ eg Nozzle, compressor, turbine

→ Energy and mass cross the bandary of the system.

③ Isolated system:

No mass (or) energy transfer across the system bandary.

Property:

Every system has certain characteristics by which its physical condition may be described.

Intensive property:

Independent of mass of the system.

(e.g) Pressure, Temperature.

Extensive property:

→ Dependent of mass of the system

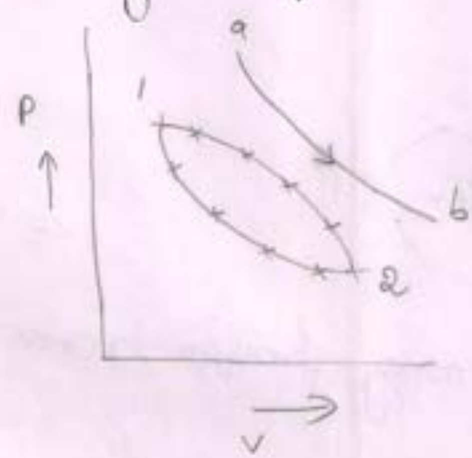
(e.g) Density, volume, Energy.

State:

condition of the system at particular time. Each and every condition of the system is called state.

Path:

series of states through which a system passes during a process is called the path.



a-b – A process
1-2-1 – A cycle

Process:

Any change that a system undergoes from one equilibrium state to another is called a process.

Cycle:

It is defined as a series of state changes such that the final state is identical with the initial state.

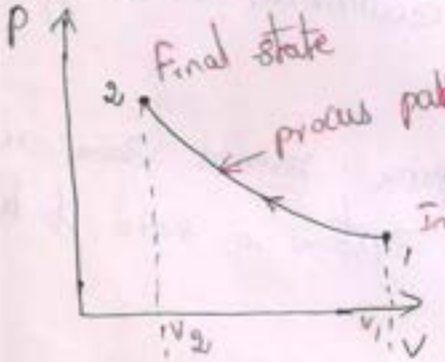
Quasi - static process:

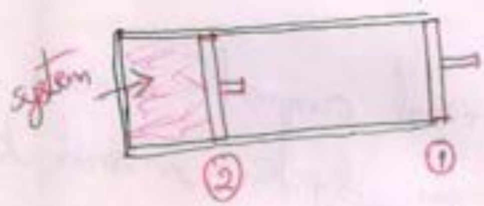
slow compression (Quasi - static process)

very fast compression (Non quasic - static process)

To describe a process completely, one should specify the initial and final states of the process, as well as path it follows ~~when a proceeds~~ and interactions with surroundings.

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a quasi - static (or) quasi - equilibrium, process.





When a gas in a piston-cylinder device is compressed suddenly, the molecules near the face of piston will not have enough time to escape and they will have to pile up in a small region in front of the piston, thus creating a high - pressure region there. Because of this pressure difference, the system can no longer be said to be in equilibrium, and makes the entire process non quasi - equilibrium. If the piston moved slowly, the molecules will have sufficient time to redistribute and there will not be a molecular pileup in front of the ~~system~~ piston.

As a result pressure inside the cylinder will always be nearly uniform and will rise at the same rate at all locations. Since equilibrium is maintained at all times, this is a quasi- equilibrium process.

Thermodynamic Equilibrium:

when mechanical Equilibrium, chemical Equilibrium and thermal Equilibrium are satisfied, then the system is said to be in thermodynamic equilibrium.

When any property remains same with respect to time it is called equilibrium (or) steady state.

mechanical Equilibrium:

If the system's pressure remains same with respect to time, then the system is said to be in mechanical Equilibrium.

chemical Equilibrium:

if the system's chemical composition remains same with respect to time, then the system is said to be in chemical Equilibrium.

Thermal Equilibrium:

if the system's temperature remains same with respect to time, then the system is said to be in thermal Equilibrium.

Work transfer:

work is an energy interaction between system and surroundings.

work can be defined as the energy interaction which is not caused by the temperature difference between system and surroundings.

work = force × Distance moved

$$w = f \times x$$

work done per unit time is called power.

Modes of work transfer:

* Mechanical work
* Non - mechanical work

mechanical work is again categorized into following forms:

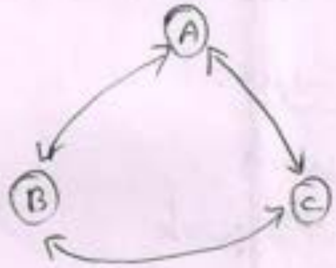
1. moving boundary work
2. Gravitational work
3. Acceleration work
4. Spring work

Non - mechanical work

1. Electrical work
2. Magnetic work
3. Electrical polarization work

Zeroth Law of thermodynamics:

when a body A is in thermal Equilibrium with a body B, and also seperately with a body C, then B and C will be in thermal equilibrium with each other.



concept of continuum:

The atomic nature of a substance and view it as a continuous, homogenous matter with no holes, that is a continuum.

Consider a container filled with oxygen at atmospheric conditions. The diameter of the oxygen molecule is about $3\times10^{-10}m$ and its mass is $5.3\times10^{-26}kg$. The mean free path of oxygen at 1 atm pressure and 20°c is $6.3\times10^{-8}m$.

i.e oxygen travels on average a distance of $6.3\times10^{-8}m$ before it collides with another molecule.

)

3×10^{16} molecules of oxygen in the tiny volume of $1 mm^3$ at 1 atm pressure and 80°c.

The continuum model is applicable as long as the characteristic length of the system is much larger than the mean free path of the molecules.

Therefore a substance can be treated as continuum because of the very large number of molecules even in an extremely small volume.

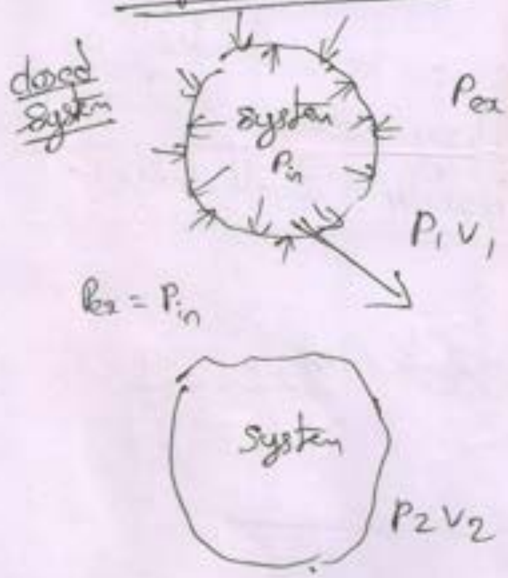
Thermodynamic concept of Energy

- Energy in storage (internal energy) point function (state variable)
- Energy in transit path function
  - work transfer (all other forms of transfer)
  - heat transfer (temperature difference alone)

Different types of work transfer

* Displacement (or) pdv work
* paddle wheel work
* flow work
* shaft work

Displacement work (control mass)



Expand (or) collapse slowly — ie ~~qual~~ quasi static

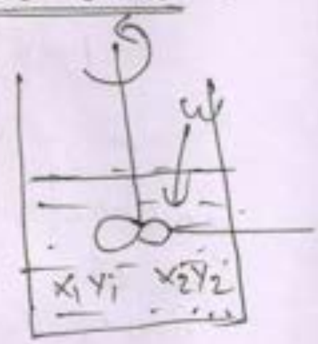
Displacement work

$$w = \int_1^2 P\,dv$$

It takes place by the displacement of a system boundary in a quasi equilibrium

Paddle work (or) stirring work (control mass)

[Friction is important)



~~Shimmery~~ Stirring ∴ paddle work

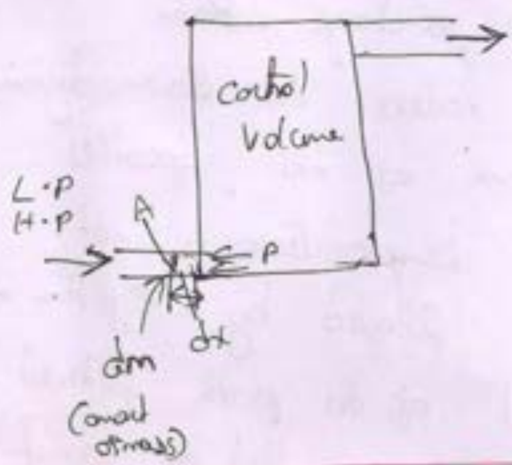
viscosity is more external work is required to rotate

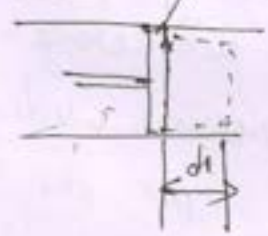
It is accomplished by the rotation of paddle wheel against the friction between wheel and the system fluid.

control volume

Flow work

It is the work done by a fluid to move against pressure. This form of work appears in an open system due to flow of mass into or out of the system.





$F = P \cdot A$

$W = P \cdot A \cdot dx$

$W/\text{mass} = \dfrac{P \cdot A \cdot dx}{\rho \cdot \underbrace{A dx}_{\text{volume}}}$

work that is required to push certain amount of fluid across the section in a flow process

$W/\text{mass} = \dfrac{P}{\rho} = \underbrace{Pv}_{\text{flow work}}$

control volume

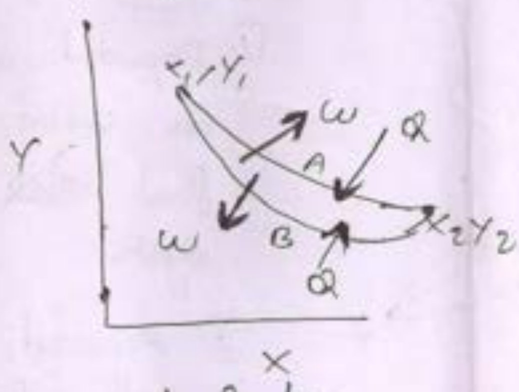
Shaft work

It is accomplished by the rotation of a shaft attached to a system against an external torque

$$w = \int_1^2 T\, d\theta$$

where $T \rightarrow$ torque

$d\theta \rightarrow$ angular displacement



$W_{1-A-2} \neq W_1 - W_2$

$Q_{1-A-2} \neq Q_1 - Q_2$

$W_{1-B-2} \neq W_{1-A-2}$

$Q_{1-B-2} \neq Q_{1-A-2}$

path & point function

property is a point (temp., pressure, volume)

work & heat transfer are path function

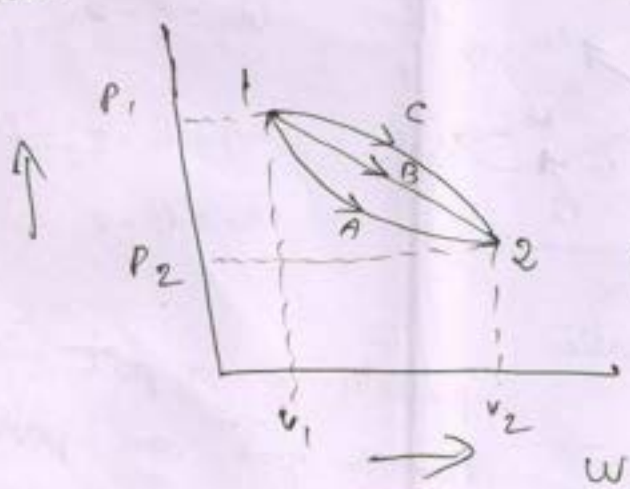
Point function:

when a gas undergoes a change from initial value to final value, the thermodynamic properties will change. Some of the properties like pressure, volume and temperature are not dependent upon the path followed by a system. It is purely independent of the path followed by a process. These properties are called as point function (or) state function.

E.g: Pressure, volume, Temperature.

Path function:

Properties like work transfer, heat transfer etc are dependent upon the path followed by a gas. These properties are called as path function.



point

① Dependent only on the initial and final state of the system

② Dependent on the path followed by the system during a process.

$$W_{1-C-2} \neq W_{1-B-2} \neq W_{1-A-2}$$

Specific heat:

It is defined as the amount of heat required to raise a ~~the temperature of~~ unit mass of substance through a unit rise in temperature.

$$C = \frac{Q}{m \cdot \Delta t} = J/kg \cdot k$$

Thermal capacity:

Quantity of heat required to raise the temperature of a whole body by one degree.

Thermal capacity = mass × Specific heat

Latent heat:

It is the amount of heat transfer required to cause a phase change in a unit mass of substance at constant pressure and constant ~~temp~~ volume.

Latent heat of fusion:

It is the amount of heat transfer to melt unit mass of solid into liquid (or) freeze unit mass liquid into solid.

Latent heat of vaporization: (l_{vap})

It is the quantity of heat required to vaporize unit mass of substance liquid into vapour (or) condense unit mass of vapour into liquid.

Latent of sublimation: (l_{sub})

amount of heat required to convert unit mass of solid into vapour (or) viceversa.

First law

The algebraic sum of net heat ~~transfer~~ and work interaction between a system and its surroundings in a thermodynamic cycle is zero

$\boxed{\delta Q - \text{infinite small process}}$

$$\sum_{cycle} Q = \sum_{cycle} W$$

$$\boxed{\oint (Q - W) = 0}$$

$\oint dx = 0$
cyclic integral of any point function = 0

$$\oint (\delta Q - \delta W) = 0$$

$\boxed{Q \rightarrow \text{finite process}}$

infinite process $\delta Q - \delta W = dx$

finite process · $Q - W = \Delta x$
change in a point function

$\boxed{x \rightarrow \text{Internal energy}}$

Heat and work transfers are path function but there difference is point function

$$\delta Q - \delta W = dE$$

$$\Rightarrow \boxed{\delta Q = \delta W + dE}$$

$$Q - W = \Delta E \implies \boxed{Q = W + \Delta E}$$

$$Q_{1-2} - W_{1-2} = E_2 - E_1 \; ; \quad Q_{1-2} = W_{1-2} + E_2 - E_1$$

$U \rightarrow$ intermolecular energy

$\boxed{E = U + K.E + P.E + \text{Any other kind of energy}}$

$$dE = dU + d(K.E) + dPE + d(\cdots\cdots)$$

Internal energy:

A property of a system whose change in a process executed by the system equals to the difference between the heat and work interaction by the system with its surroundings.

First law of thermodynamics for closed system

$$Q_{1-2} = E_2 - E_1 + W_{1-2}$$

$$\delta Q = dE + \delta W$$

$$\oint \delta Q = \oint \cancel{dE}^{\,0} + \oint \delta W$$

stationary closed system when it is at equilibrium state

$$E = U + \cancel{K.E}_0 + P.E$$

(stationary) when compared to dU, $d(PE)$ is negligible

$$dE = dU + d(K.E + P.E)$$

$$dE = dU$$

$$Q_{1-2} = U_2 - U_1 + W_{1-2}$$

$$\delta Q = dU + \delta W$$

closed system when it interact with surroundings in the form of pdv work

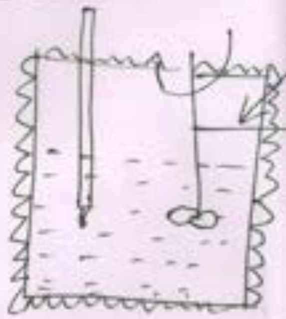
$$Q_{1-2} = U_2 - U_1 + \int_1^2 p\,dv$$

$$\delta Q = dU + p\,dv$$

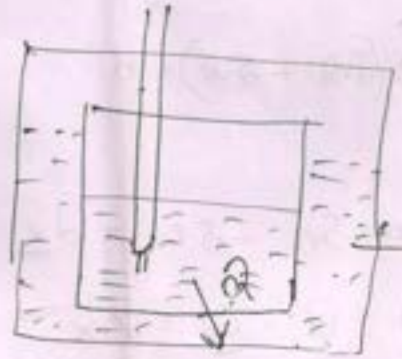
First law of thermodynamics:

It is conservation of energy.

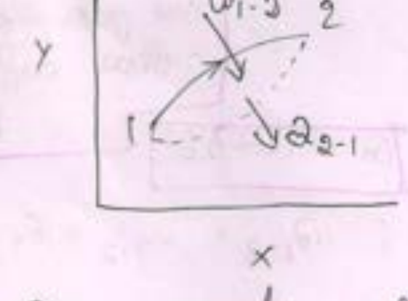
Joule's Experiment



* work & heat transfers are produce same effect on the system
* They are not different
*

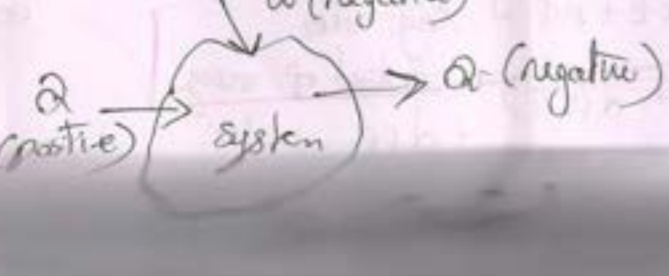


Q =



$$\boxed{W_{1-2} = Q_{2-1}}$$

Sign convention of work and Heat flow



closed system per unit mass

$$\frac{Q_{1-2}}{m} = u_2 - u_1 + \int_1^2 P\,dv$$

$$\frac{\delta Q}{\delta m} = du + P\,dv$$

Enthalpy:

It is a property of a system

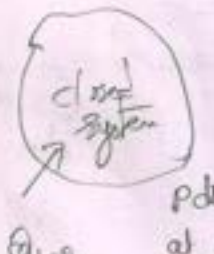
$$\boxed{\underline{H} = \underline{U} + P\underline{V}}$$

= Extensive property

mass = Intensive property

$U \rightarrow$ internal energy
$P \rightarrow$ pressure
$V \rightarrow$ volume

$$h = u + P v$$



pdv work at constant pressure

$$Q_{1-2} = U_2 - U_1 + \int_1^2 p\,dv$$

$$= U_2 - U_1 + P(V_2 - V_1)$$

$$= (U_2 + P_2 V_2) - (U_1 + P_1 V_1)$$

$$= H_2 - H_1$$

$$\delta Q = du + P\,dv$$

$$= d(u + Pv) = dH$$

$H_2 > H_1$ — Heat added

$H_2 < H_1$ — Heat rejected

$$Q_{1-2} = H_2 - H_1$$

During Expansion, the pressure will reduced, heat is added to system, the pressure is balanced.

During collapse, the pressure is increased, heat is rejected from the system, thus pressure is balanced.

Specific heat:

C_v & C_p

Specific heat at constant volume

$$C_v = \lim_{\delta T \to 0} \left[\frac{\delta Q / \delta m}{\delta T} \right]_{v = \text{constant}}$$

control volume

$$\boxed{\begin{aligned} \delta Q &= du + p\,dv \\ \frac{\delta Q}{\delta m} &= du + p\,\cancel{dv}^{\;0} \\ \left(\frac{\delta Q}{\delta m}\right)_{v=c} &= (du)_{v = \text{constant}} \end{aligned}}$$

$$C_v = \lim_{\delta T \to 0} \frac{(du)_{v=c}}{\delta T}$$

$u = u(T, v)$

$$\boxed{C_v = \left(\frac{\partial u}{\partial T}\right)_v}$$

$U(T, v)$

Specific heat at constant pressure

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$$C_p = \lim_{\delta T \to 0} \left(\frac{\delta Q / \delta m}{\delta T} \right)_{p=c}$$

$$\delta Q = du + p\,dv$$

$$\frac{\delta Q}{\delta m} = du + p\,dv = d(u + pv)$$

$$\left(\frac{\delta Q}{\delta m}\right)_{p=c} = d(h)_{p=c}$$

$$= \lim_{\delta T \to 0} \frac{(dh)_{p=c}}{\delta T}$$

$Q - W = \Delta E$

for sum $= \Delta E$

$-W = \Delta E - Q$

$$\boxed{c_p = \left(\frac{\partial h}{\partial T}\right)_p}$$

First Law applied to an open system (or) control volume

Problem ①

A piston and cylinder machine contains a fluid system which passes through a complete cycle of four processes. During a cycle, the sum of all heat transfers is −170kJ. The system completes 100 cycles per min. Complete the following table showing the method for each item and compute the net rate of work output in kW.

Process	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
a-b	0	2,170	—
b-c	21,000	0	—
c-d	−2,100	—	−36,600
d-a	—	—	—

$$-2170 + 21{,}000 - 36{,}600 + \Delta E_{d-a} = 0$$

$$\boxed{\Delta E_{d-a} = 17{,}770\ kJ/min}$$

$$W_{d-a} = Q_{d-a} - \Delta_{d-a}$$

$$= -35{,}900 - 17{,}770 = -53{,}670\ kJ/min$$

$$\boxed{W_{d-a} = -53{,}670\ kJ/min}$$

Since

$$\sum_{cycle} Q = \sum_{cycle} W$$

Rate of work output

$$= -17000\ kJ/min = -283.3\ kW$$

(2) A fluid is confined in a cylinder by a spring-loaded, frictionless piston so that the pressure in the fluid is a linear function of the volume $(P = a + bV)$. The internal energy of the fluid is given by the following equation

$$U = 34 + 3.15PV$$

where U is in KJ, P in KPa, and V in cubic metre. If the fluid changes from an initial state of 170kPa, $0.03\,m^3$ to a final state of 400kPa, $0.06\,m^3$,

Solution:

Process a-b:

$Q = \Delta E + W$

$0 = \Delta E + 2170$

$\boxed{\Delta E = -2170\ kJ/min}$

Process b-c

$Q = \Delta E + W$

$21000 = \Delta E + 0$

$\boxed{\Delta E = 21,000\ kJ/min}$

~~process d-a~~

Process c-d:

$Q = \Delta E + W$

$-2100 = -36,600 + W$

$\boxed{W = 34,500\ kJ/min}$

Process d-a:

$\sum_{cycle} Q = -170\ kJ$

The system completes 100 cycles/min

$Q_{ab} + Q_{bc} + Q_{cd} + Q_{da} = -17000\ kJ/min$

$0 + 21,000 - 2100 + Q_{da} = -17,000$

$\boxed{Q_{da} = -35,900\ kJ/min}$

Now $\oint dE = 0$, since cyclic integral of any property is zero

$\Delta E_{a-b} + \Delta E_{b-c} + \Delta_{c-d} + \Delta E_{d-a} = 0$

From pressure equation:

$$P = a + bV$$

$$P_1 = a + bV_1 \longrightarrow ①$$

$$P_2 = a + bV_2 \longrightarrow ②$$

At initial state

$1pa = 1N/m^2$

$1000kpa = 1000 \; kN/m^2$

$$170 = a + b(0.03)$$

$$170 = a + 0.03b \longrightarrow ③$$

final state $\quad 400 = a + 0.06b \longrightarrow ④$

For ④ - ③

$$230 = 0.03b \Rightarrow \boxed{b = 7666.67}$$

$KPa/m^3 = kN/m^5$

Substituting the value of b in ③

$$170 = a + 0.03(7666.67)$$

$$\boxed{a = -60.0} \; kpa = kN/m^2$$

∴ pressure equation

$$P = -60 + 7666.67V$$

$$\text{work done } W = \int_{V_1}^{V_2} P \cdot dV = \int_{V_1}^{V_2} (-60 + 7666.67V)\,dV$$

$$= \left[-60 + 7666.67\frac{V^2}{2}\right]_{0.03}^{0.06}$$

with no work other than that done on the piston. Find the direction and magnitude of the work and heat transfer.

Given Data:

$P = a + bv$

$U = 34 + 3.15\,PV$

$P_1 = 170\,kPa \qquad P_2 = 400\,kPa$

$V_1 = 0.03\,m^3 \qquad V_2 = 0.06\,m^3$

N·m

To find:

work transfer $w = ?$

Heat transfer $Q = ?$

1 kpa = 1000 pa

1 MPa = 10^6 Pa

$\boxed{1\,Pa = N/m^2}$

1 bar = 10^5 Pa

= 100 kpa

= 0.1 MPa

Solution:

change in internal energy $U_2 - U_1$

$= (34 + 3.15\,P_2V_2) - (34 + 3.15\,P_1V_1)$

$= 3.15\,(P_2V_2 - P_1V_1)$

$= 3.15\,(400 \times .06 - 170 \times .03)$

$\boxed{U_2 - U_1 = 59.535\,kJ}$

$$= \int_{v_1}^{v_2} (a+bv)\,dv \qquad = \left[av + \frac{bv^2}{2}\right]_{v_1}^{v_2} = a(v_2 - v_1) + b\,\frac{v_2^2 - v_1^2}{2}$$

$$= (v_2 - v_1)\left[a + \frac{b}{2}(v_2 - v_1)\right]$$

$$= 0.03\left[-60 + \frac{7666.6}{2}\times(0.06)\right]$$

$$= -1.8 + 6.89$$

$$= \int_{v_1}^{v_2} (-60 + 7666.67v)\,dv$$

$$= \left[-60v + 7666.67\frac{v^2}{2}\right]_{0.03}^{0.06}$$

$$w = -60(0.06 - 0.03) + \frac{7666.67}{2}(0.06^2 - 0.03^2)$$

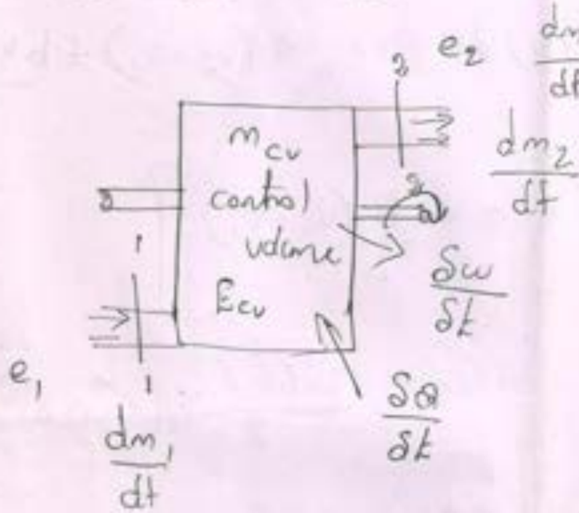
$$\boxed{w = 8.55\,kJ}$$

$$Q = w + \Delta u$$

$$Q = 8.55 + 59.35$$

$$= 68.085\,kJ$$

First Law applied to an open system (control volume)



conservation of mass

$$\frac{dm_1}{dt} - \frac{dm_2}{dt} = \cancel{\frac{dm_{cv}}{dt}}^{\,0}$$

mass flow rate   mass flow rate

conservation of energy

$\frac{dm_1}{dt} \cdot e_1$

e (stored energy in a stream of fluid)

$$e = u + pv + \frac{v^2}{2} + gz$$

$$\boxed{\frac{dm_1}{dt} \cdot e_1 + \frac{\delta Q}{\delta t} - \left[\frac{dm_2}{dt} e_2 + \frac{\delta W}{\delta t}\right] = \cancel{\frac{dE_{cv}}{dt}}^{\,0}}$$

$$\frac{dm_1}{dt}\left(u_1 + p_1v_1 + \frac{v_1^2}{2} + gz_1\right) + \frac{\delta Q}{\delta t} - \left[\frac{dm_2}{dt}\left(u_2 + p_2v_2 + \frac{v_2^2}{2} + gz_2\right) + \frac{\delta W}{\delta t}\right] = \cancel{\frac{dE_{cv}}{dt}}\ 0$$

mass flow rate   energy flow rate + rate of Heat transfer

first law of thermodynamics for an control volume

At steady state [mass flow & Energy flow not varied with time]

$$\frac{dm_{cv}}{dt} = 0 \quad , \quad \frac{dE_{cv}}{dt} = 0$$

$$\frac{dm_1}{dt} = \frac{dm_2}{dt} = \frac{dm}{dt}$$

$$\boxed{\frac{dm}{dt}\left[\left(u_1 + p_1 v_1 + \frac{V_1^2}{2} + gz_1\right) + \frac{\delta Q}{dt} - \frac{dm}{dt}\left(u_2 + P_2 v_2 + \frac{V_2^2}{2} + gz_2\right) + \frac{\delta w}{dt}\right] = 0}$$

Per unit mass

$$\boxed{u_1 + P_1 v_1 + \frac{V_1^2}{2} + gz_1 + \frac{\delta Q}{\delta m} - \left[\left(u_2 + P_2 v_2 + \frac{V_2^2}{2} + gz_2\right) + \frac{\delta w}{\delta m}\right] = 0}$$

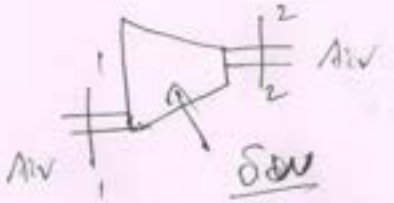
$$\boxed{\frac{\delta Q}{\delta m} - \frac{\delta w}{\delta m} = \left(h_2 + \frac{V_2^2}{2} + gz_2\right) - \left(h_1 + \frac{V_1^2}{2} + gz_1\right)}$$

Steady flow energy equation

$$\boxed{\frac{\delta Q}{\delta m} - \frac{\delta w}{\delta m} = h_2 - h_1}$$

for work interacting device $\left(\frac{\delta Q}{\delta m} = 0\right)$

$$\boxed{\frac{\delta w}{\delta m} = h_1 - h_2}$$

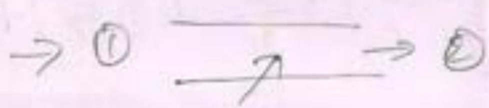


$$\frac{\delta w}{\delta m}$$

Heat interacting device

$u(T)$

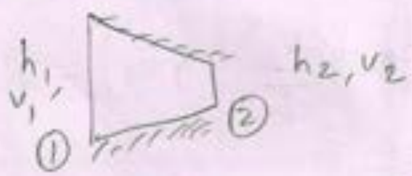
$\rho\,(P,v)$



$$\frac{\delta Q}{\delta m}$$

$$\boxed{\frac{\delta Q}{\delta m} = h_2 - h_1}$$

Adiabatic nozzle



$v_2 > v_1$

$h_2 < h_1$

$$\cancel{\frac{\delta Q}{\delta m}}^{\,0} - \cancel{\frac{\delta w}{\delta m}}^{\,0} = \left(h_2 + \frac{v_2^2}{2}\right) - \left(h_1 + \frac{v_1^2}{2}\right)$$

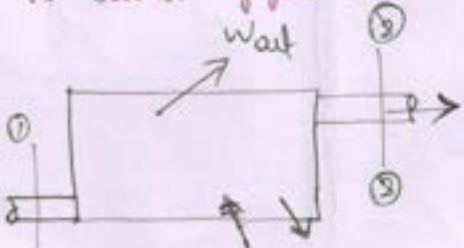
$$(h_2 - h_1) + \frac{v_2^2 - v_1^2}{2} = 0$$

$$\boxed{\frac{v_2^2 - v_1^2}{2} = h_1 - h_2}$$

Problems

Air flows steadily at the rate of 0.5 kg/s through an air compressor, entering at 7 m/s velocity, 100 kpa pressure, and 0.95 m^3/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in the compressor jackets absorbs heat from the air at the rate of 58 kw. (a) compute the rate of shaft work input to the air in kw. (b) Find the ratio of the inlet pipe diameter to outlet pipe diameter.?

Nov/Dec 2011



$V_1 = 7 m/s$

$P_1 = 100 kpa$

$v_1 = 0.95 \ m^3/kg$

$V_2 = 5 m/s$

$P_2 = 700 kpa$

$v_2 = 0.19 m^3/kg$

$Q = -58 kw$ (or) $-58 \ kJ/s$

$u_2 = (u_1 + 90) \ kJ/kg$

$$u_1 + P_1 v_1 + \frac{V_1^2}{2} + gz_1 + \frac{\delta Q}{\delta m} - \left(u_2 + P_2 v_2 + gz_2\right) - \frac{\delta W}{\delta m}$$

$$u_1 + P_1 v_1 + \frac{V_1^2}{2} + gz_1 + \frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = 0$$

$$\left(u_2 + P_2 v_2 + gz_2\right)$$

$$\frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = \left[(u_2 - u_1) + (P_2 v_2 - P_1 v_1) + \frac{V_2^2 - V_1^2}{2} + \cancel{(z_2 - z_1)}^{0} \right]$$

$$= 90 \text{ kJ/kg} + (700 \times 0.19 - 100 \times 0.95) \text{ kJ/kg} + \left(\frac{5^2 - 7^2}{2}\right) \times 10^{-3} \text{ kJ/kg}$$

per unit mass

$$= [90 + 38 + (-0.012)]$$

$$\frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = [127.98] \text{ kJ/kg}$$

for mass 0.5 kg/s

$$\frac{\delta Q}{\delta m} - \frac{\delta W}{\delta m} = 0.5 \times 127.98 = 63.99 \text{ kJ/s}$$

$$-\frac{\delta W}{\delta m} = (63.99 + 58) \text{ kJ/s}$$

$$\boxed{\frac{\delta W}{\delta m} = -122 \text{ kW}}$$

mass balance

$$\frac{dm_1}{dt} = \frac{dm_2}{dt}$$

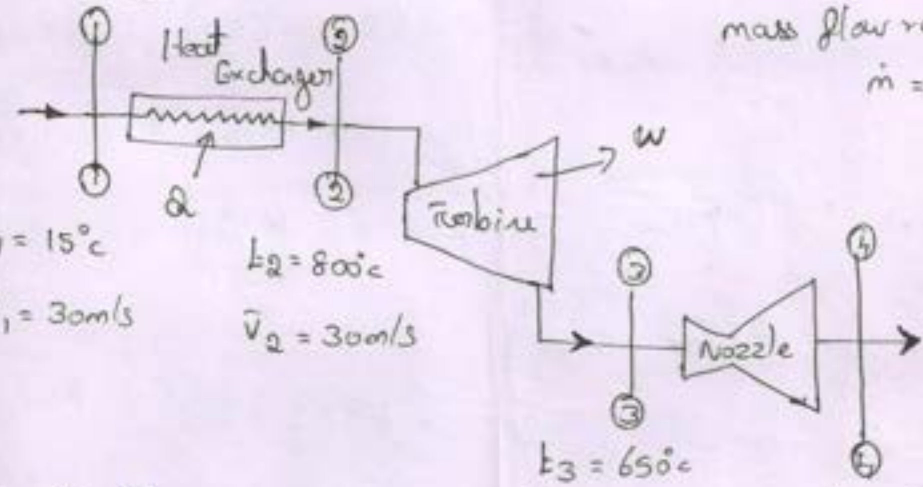
$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} \Rightarrow \frac{A_1}{A_2} = \frac{v_1}{v_2} \times \frac{V_2}{V_1}$$

$m^3 \times m/s$

$$\frac{A_1}{A_2} = \frac{0.95}{0.19} \times \frac{5}{7} = 3.57 \qquad \frac{\cancel{\pi/4}\, d_1^2}{\cancel{\pi/4}\, d_2^2}$$

$$\frac{d_1}{d_2} = \sqrt{3.57} = 1.89$$

⑧ Solution



mass flow rate
$\dot{m} = 2 kg/s$

$t_1 = 15°c$
$\bar{V}_1 = 30m/s$

$t_2 = 800°c$
$\bar{V}_2 = 30m/s$

$t_3 = 650°c$
$\bar{V}_3 = 60m/s$

$t_4 = 500°c$
$\bar{V}_4 = ?$

process ① - ②

steady flow energy equation

$$Q_{1-2} + (\underbrace{U_1 + P_1 v_1}_{h_1} + \frac{\cancel{V_1^2}}{2} + g\cancel{z_1}) = (\underbrace{U_2 + P_2 v_2}_{h_2} + \frac{\cancel{V_2^2}}{2} + g z_2) + \cancel{W_{1-2}}$$

$$Q_{1-2} = (h_2 - h_1)$$

$$= c_p (t_2 - t_1)$$

$$c_p = \left(\frac{\partial h}{\partial T}\right)_{p = constant}$$

$$= 1.005 (800 - 15)$$

$kJ/kg\,K \times K \times kg/s$

$$Q_{1-2} = 788.92 \text{ kJ/kg}$$

$$= 2 \times 788.92 = 1577.85 \text{ kJ/s (or) kw}$$

Steady flow energy equation for turbine

$$\cancel{Q_{2-3}}^{0} + (\underbrace{u_2 + P_2 v_2}_{h_2} + \frac{V_2^2}{2} + \cancel{gz_2}) = (\underbrace{u_3 + P_3 v_3}_{h_3} + \frac{V_3^2}{2} + \cancel{gz_3}) + w_{2-3}$$

$$w_{2-3} = (h_2 - h_3) + \frac{V_2^2 - V_3^2}{2}$$

$$= 2 \times \left[1.005\,(800-650) + \frac{(30^2 - 60^2)\times 10^{-3}}{2}\right]$$

$\frac{kJ}{kg\,K} K \times \frac{m^2}{s^2} \times \frac{kg}{s}$

per unit mass $= 150.75$ kJ/kg $+ (-1.35)$ kJ/kg

$\frac{m^2}{s^2} \times \frac{N \cdot s^2}{m \cdot s}$ $N \cdot m = J/s$

$$\boxed{W_{2-3} = 148.65 \text{ kJ/kg}}$$

$$\boxed{\begin{aligned} &1N = m \times g \\ &kg \times m/s^2 \\ &\Rightarrow kg = \frac{N \cdot s^2}{m} \end{aligned}}$$

For 2 kg/s

$$W_{2-3} = 297.3 \text{ kJ/s (or) kW}$$

Steady flow energy equation for nozzle

$$\cancel{Q_{3-4}}^{0} + (\underbrace{u_3 + P_3 v_3}_{h_3} + \frac{V_3^2}{2} + \cancel{gz_3}^{0}) = (\underbrace{u_4 + P_4 v_4}_{h_4} + \frac{V_4^2}{2} + \cancel{gz_4}) + \cancel{w_{3-4}}^{0}$$

$(m/s)^2 = \frac{kJ}{kg\,K} K$

$\frac{kN \cdot m \times m}{N \cdot s^2}$ $\frac{kN \cdot m}{s}$

$$\frac{V_4^2 - V_3^2}{2} \times 10^{-3} = h_3 - h_4 \quad \frac{kN \cdot m}{s} \frac{kg}{kg\,K} K \;\; \text{kJ/s}$$

$$= c_p (t_3 - t_4) \;\; \dot{m}$$

$$\text{kJ/s} \quad \frac{V_4^2 - 60^2 \times 10^{-3}}{2} = 1.005\,(650-500) = 150.75 \text{ kJ/kg}$$

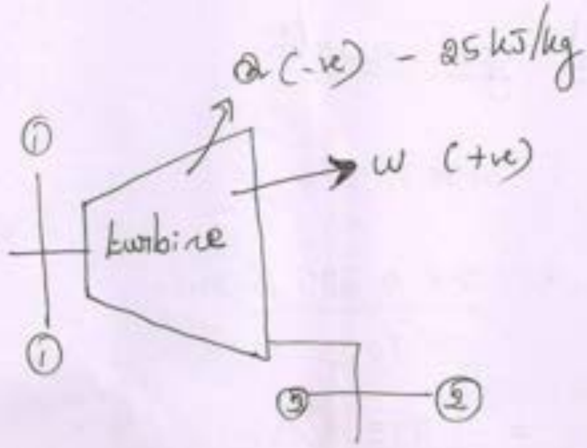
kN·m

$$= 301.5 \times 10^3 + 3.6 \times 10^3$$

$$V_4^2 = 305.1 \times 10^3 \, m^2/s^2$$

$$\boxed{V_4 = 552 \text{ m/s}}$$

6.



$\dot{m} = 5\,kg/s$

$V_1 = 50\,m/s$

$h_1 = 900\,kJ/kg$

$h_2 = 400\,kJ/kg$

$V_2 = 150\,m/s$

SFEE

$h_1 > h_2$

$$\Big(\underbrace{u_1 + P_1 v_1}_{h_1} + \frac{V_1^2}{2} + g\cancel{z_1}^{\,0}\Big) + Q_{1-2}$$

$$= \Big(\underbrace{u_2 + P_2 v_2}_{h_2} + \frac{V_2^2}{2} + g\cancel{z_2}^{\,0}\Big) + W_{1-2}$$

$$W_{1-2} = (h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} + Q_{1-2}$$

$$= (900 - 400)\,\frac{kJ}{kg} + \frac{50^2 - 150^2}{2} \times 10^{-3}\,kJ/kg$$

$$+ (-25)\,kJ/kg$$

$$= 500 + (-10) + (-25)$$

$$W_{1-2}/kg = 465\,kJ/kg$$

for 5 kg/s $= 465 \times 5 = 2325\,kJ/s$ (or) kW using ideal gas equation

$$P_1 \dot{V}_1 = \dot{m} R T_1$$

$$\dot{V}_1 = \frac{5 \times 0.285 \times 300}{100} \qquad \frac{kg/s \times kJ/kg\,K \times K}{kN/m^2}$$

$$= 4.275\ m^3/s \qquad = kJ/s \times m^2/kN$$

$$\text{Inlet Area} = \frac{\text{Volume flow rate}}{\text{velocity}} \qquad = \frac{kN\cdot m}{s} \times m^2/kN$$

$$= m^3/s$$

$$= \frac{m^3/s}{m/s} = m^2$$

$$A_1 = \frac{4.275}{50} = 0.0875 m^2$$

$$\pi/4\, d_1^2 = 0.0875$$

$$d_1^2 = 0.1088$$

$$d_1 = \sqrt{0.1088} = 0.32m$$

$$\boxed{d_1 = 0.32m}$$

---

(2) Given Data:

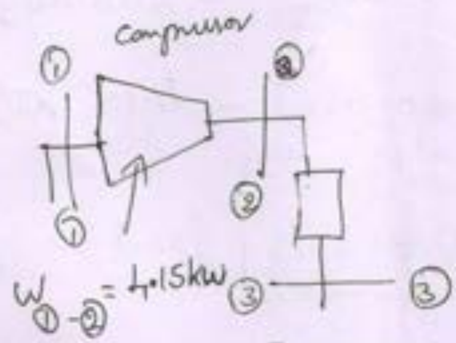
$$\dot{V}_1 = 2 m^3/min$$

$$P_1 = 0.11\ MP = 0.11 \times 10^6 Pa = 0.11 \times 10^6 N/m^2$$

$$T_1 = 293k$$

$P_2 = 1.5\ MPa = 1.5 \times 10^6\ N/m^2$

$T_2 = 384k$



$T_3 = 298k$

To find

$Q_{1-2} = ?$

$Q_{2-3} = ?$

Solution:

For ideal gas equation

$P_1 \dot{V}_1 = \dot{m} R T_1$

$$\dot{m} = \frac{0.11 \times 10^3 \times 2/60}{0.287 \times 293} = \frac{kN/m^2 \times m^3/s}{kJ/kg \cdot K \times K} = \frac{kJ/s}{kJ/kg}$$

$$\boxed{\dot{m} = 0.0436\ kg/s}$$

$= \cancel{kJ/s} \times \frac{kg}{\cancel{kJ}}$

$= kg/s$

SFEE

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \cancel{\frac{V_1^2}{2}} + \cancel{gZ_1} + Q_{1-2} = \underbrace{u_2 + P_2 v_2}_{h_2} + \cancel{\frac{V_2^2}{2}} + \cancel{gZ_2} + W_{1-2}$$

$$Q_{1-2} = (h_2 - h_1) + W_{1-2}$$

$$= C_v (T_2 - T_1) + W_{1-2}$$

$$= 0.718\,\underbrace{(384 - 293)}_{}^{\text{kJ/kg}} + (-4.15) \text{ kJ/s}$$

$$= 61.748 \text{ kJ/kg} - 4.15 \text{ kJ/s}$$

$$= \underbrace{(61.748 \times 0.044)}_{\text{kJ/s}} - 4.15 \text{ kJ/s}$$

$$\boxed{Q_{1-2} = -1.433 \text{ kJ/s}}$$ (Heat is rejected)

Heat transfer in cooler

$$\underbrace{u_2 + P_2 v_2}_{h_2} + \cancel{\frac{V_2^2}{2}} + \cancel{g z_2} + Q_{2-3} = \underbrace{u_3 + P_3 v_3}_{h_3} + \cancel{\frac{V_3^2}{2}} + \cancel{g z_3} + \cancel{W_{2-3}}$$

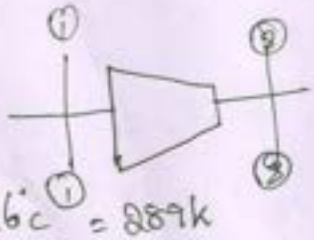
$$Q_{2-3} = h_3 - h_2$$

per unit mass $= c_p (T_3 - T_2) = 1.005\,(298 - 384)$ kJ/kg

$\dot{m} = 0.044$ kg/s

$$\boxed{Q_{2-3} = -3.8 \text{ kJ/s}}$$ (Heat is rejected)

③



$T_1 = 16°C = 289$ K

$P_1 = 100$ kPa

$h_1 = 391.2$ kJ/kg

$V_1 = 80$ m/s

$T_2 = 245°C = 518$ K

$P_1 = 0.6 \times 10^3$ kPa

$h_2 = 535.5$ kJ/kg

$V_2 = 160$ m/s

To find:

$W_{1-2} = ?$

Solution:

Steady flow Energy Equation for control volume

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \frac{V_1^2}{2} + g\cancel{z_1}^{\,0} + Q_{1-2}^{\,0} = \underbrace{u_2 + P_2 v_2}_{h_2}$$
$$+ \frac{V_2^2}{2} + g\cancel{z_2}^{\,0} + W_{1-2}$$

SFEE for Compressor:

$$W_{1-2} = (h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} \times 10^{-3}$$

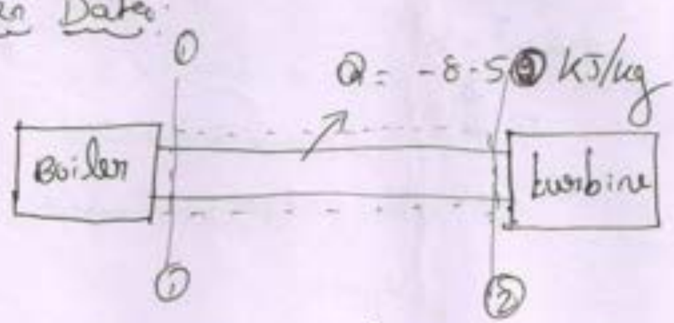
$$= (391.2 - 535.5) + \frac{(80^2 - 160^2)}{2} \times 10^{-3}$$

$$\boxed{W_{1-2} = -153.9 \text{ kJ/kg}}$$

∴ work input is given to the compressor.

(5) Given Data:

$d_1 = d_2 = 0.2m$



$P_1 = 4MPa = 4 \times 10^3 kpa$ $\quad$ $P_2 = 3.5 MPa = 3.5 \times 10^3$ kPa

$T_1 = 400°c = 673k$ $\quad$ $T_2 = 392°c = 665k$

$h_1 = 3213.6$ kJ/kg $\quad$ $h_2 = 3202.6$ kJ/kg

$v_1 = 0.07 m^3/kg$ $\quad$ $v_2 = 0.084 m^3/kg$

To find:

$\dot{m} = ?$

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

$$V_2 = \frac{A_1 V_1}{v_1} \cdot \frac{v_2}{A_2} = \frac{0.084}{0.07} \times V_1$$

$$\boxed{V_2 = 1.2\, V_1}$$

Solution:

Steady flow Energy Equation for control volume

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \frac{V_1^2}{2} + \cancel{g z_1} + Q_{1-2} = \underbrace{u_2 + P_2 v_2}_{h_2} + \frac{V_2^2}{2} + \cancel{g z_2} + \cancel{W_{1-2}}^{0}$$

$$h_1 + \frac{V_1^2}{2} + Q_{1-2} = h_2 + \frac{V_2^2}{2}$$

$$\frac{V_2^2 - V_1^2}{2} \times 10^{-3} = h_1 - h_2 + Q_{1-2}$$

$$\frac{1.2 V_1^2 - V_1^2}{2} \times 10^{-3} = (3213.6 - 3202.6) + (-8.5)$$

$$1.2 V_1^2 - V_1^2 = 2.5 \times 2 \times 10^3$$

$$\cancel{0.2 V_1^2 = 2.5 \times 2 \times 10^3}$$

$$\cancel{V_1^2 = 125 \times 10^3\ m^2/s^2}$$

$$\frac{V_1^2 (1.2^2 - 1^2)}{} = 2.5 \times 2 \times 10^3$$

$$V_1^2 = 11363.63\ m^2/s^2$$

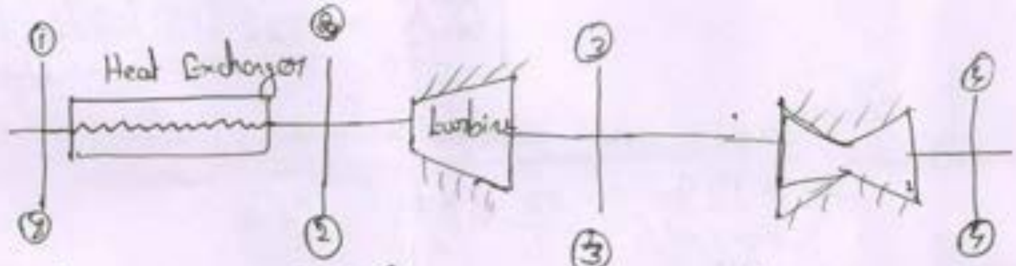
$$\boxed{V_1 = 106.6\ m/s}$$

$$\text{mass flow rate} = \frac{A_1 V_1}{v_1} = \frac{\frac{\pi}{4}(0.2)^2 \times 106.6}{0.07}$$

$$= 47.84 \text{ kg/s}$$

Given Data:

7



$T_1 = 27°C = 300k$ $\quad T_2 = 750°C = 1023k$ $\quad T_3 = 600°C = 873k$ $\quad V_3 = 60 m/s$ $\quad T_4 = 500°C = 773k$

$V_2 = 50 m/s$

No Heat interactions in turbine and nozzle

$c_p = 1.005 \text{ kJ/kg.k}$

To find:

$Q_{1-2} = ?$; $W_{2-3} = ?$; $V_4 = ?$

Solution:

Steady flow Energy Equation for control volume

$$\underbrace{U_1 + P_1 v_1}_{h_1} + \cancel{\frac{V_1^2}{2}} + \cancel{g z_1} + Q_{1-2} = \underbrace{U_2 + P_2 v_2}_{h_2} + \cancel{\frac{V_2^2}{2}} + \cancel{g z_2} + \cancel{W_{1-2}}^{0}$$

SFEE ~~for~~ for Heat Exchanger

$$Q_{1-2} = h_2 - h_1$$

$$= c_p (T_2 - T_1) = 1.005 (1023 - 300)$$

$$\boxed{Q_{1-2} = 726.615 \text{ kJ/kg}}$$

(ii) 2 - 3

SFEE for control volume

$$\underbrace{U_2 + P_2 V_2}_{h_2} + \frac{V_2^2}{2} + \cancel{gZ_2} + \cancel{Q_{2-3}}$$

$$= \underbrace{U_3 + P_3 V_3}_{h_3} + \frac{V_3^2}{2} + \cancel{gZ_3} + W_{2-3}$$

$$W_{2-3} = (h_2 - h_3) + \frac{V_2^2 - V_3^2}{2} \times 10^{-3}$$

$$= \underset{1.005(1023 - 873)}{c_p (T_2 - T_3)} + \frac{50^2 - 60^2}{2} \times 10^{-3}$$

$$= 150.75 + (-0.55)$$

$$\boxed{W_{2-3} = 150.25 \text{ kJ/kg}}$$

(iii) 3 - 4

SFEE for control volume

$$\underbrace{U_3 + P_3 V_3}_{h_3} + \frac{V_3^2}{2} + \cancel{gZ_3} + \cancel{Q_{3-4}}$$

$$= \underbrace{U_4 + P_4 V_4}_{h_4} + \frac{V_4^2}{2} + \cancel{gZ_4} + \cancel{W_{3-4}}$$

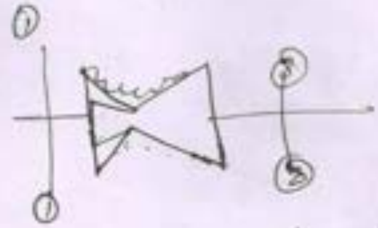
$$\frac{V_4^2 - V_3^2}{2} \times 10^{-3} = h_3 - h_4 = c_p (T_3 - T_4)$$

$$V_4^2 - 60^2 = 1.005\,(873 - 773) \times 2 \times 10^3$$

$$V_4^2 = 204600$$

$$\boxed{V_4 = 452.32 \text{ m/s}}$$

(9)



$h_1 = 3000$ kJ/kg
$V_1 = 60$ m/s
$A_1 = 0.1 m^2$
$v_1 = 0.187 m^3/kg$

$h_2 = 2762$ kJ/kg
$V_2 = ?$
$A_2 = ?$
$v_2 = 0.498 m^3/kg$

To find:
$\dot{m} = ?$
$V_2 = ?$
$A_2 = ?$

Solution:

SFEE for control volume

$$U_1 + P_1 v_1 + \frac{V_1^2}{2} + g\cancel{Z_1} + \cancel{Q_{1-2}}$$
$$= U_2 + P_2 v_2 + \frac{V_2^2}{2} + g\cancel{Z_2} + \cancel{W_{1-2}}$$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$\frac{V_2^2 - V_1^2}{2} \times 10^{-3} = h_1 - h_2 = \text{[illegible]}$$

$$V_2^2 - 60^2 = \text{[illegible]} \,(3000 - \text{[illegible]}) \times 2 \times 10^3$$

$$\boxed{V_2 = 692.57 \text{ m/s}}$$

~~for ideal gas equation~~

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

$\dot{m} =$

$\frac{m^2 \times m/s}{m^3/kg}$

(iii)

$v_2 = 0.498\ m^3/kg$

$\dot{m} = \frac{A_1 V_1}{v_1} = \frac{0.1 \times 60}{0.187}$

$\boxed{\dot{m} = 32.08\ kg/s}$

$A_2 = \frac{32.08 \times 0.498}{692.53}$

$\boxed{A_2 = 0.023\ m^2}$

12. Given Data

$w = 135\ kJ/kg$

$v_1 = 0.37\ m^3/kg$ $\qquad v_2 = 0.62\ m^3/kg$

$P_1 = 600\ kPa$ $\qquad P_2 = 100\ kPa$

$V_1 = 16\ m/s.$ $\qquad V_2 = 270\ m/s.$

$z_1 = 32\ m$ $\qquad Q_{1-2} = 9\ kJ/kg$

To find:

$\delta U = ?$

Solution

$$U_1 + P_1 v_1 + \frac{V_1^2}{2} + g z_1 + Q_{1-2} = P_2 v_2 + U_2 + \frac{V_2^2}{2} + g z_2 + W_{1-2}$$

$$u_1 - u_2 = (P_2 v_2 - P_1 v_1) + \frac{V_2^2 - V_1^2}{2} \times 10^{-3} + g(z_2 - z_1) + W_{1-2} - Q_{1-2}$$

$$= (100 \times 0.62 - 600 \times 0.37) + \frac{270^2 - 16^2}{2} \times 10^{-3} + 9.81 \times (0 - 32) \times 10^{-3} + 135 - (-9)$$

$$= -160 + 36.322 + (-0.288) + 144$$

$$\boxed{u_1 - u_2 = 20.034}$$

Internal energy decreases by $\underline{\underline{20.034}}$ kJ/kg

(13) Given Data:

$P_1 = 1.2\,MPa = 1.2 \times 10^3\,kpa$

$T_1 = 180°c = 180 + 273 = 453k$

$h_1 = 2785\,kJ/kg$

$V_1 = 33.3\,m/s$

$z_1 = 3m.$

$P_2 = 20\,kpa$

$h_2 = 2512\,kJ/kg$

$V_2 = 100\,m/s$

$z_2 = 0m$

$Q_{1-2} = -0.29\,kJ/s.$

$\dot{m} = 0.42\,kg/s$

To find

$W_{1-2} = ?$

Solution

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \frac{V_1^2}{2} + gz_1 + Q_{1-2} =$$

$$\underbrace{u_2 + P_2 v_2}_{h_2} + \frac{V_2^2}{2} + gz_2 + W_{1-2}$$

$$W_{1-2} = (h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2) + (Q_{1-2} \times 0.42)$$

$$= (2785 - 2512) + \frac{33.3^2 - 100^2 \times 10^{-3}}{2} + 9.81\,(3 - 0) \times 10^{-3} + (-0.1218)$$

$$= 273 + (-4.44) + 0.029 + (-0.1218)$$

For 0.42 kg/s

$$= 112.756 \text{ kJ/s (or) kW}$$

1 kJ = 1000 J

14. Given Data:

Number of person (N_P) = 4

number of fans (N_f) = 2 $\quad W_f = 0.18$ kJ/s (each) $\times 2$

number of lamps (N_l) = 3 $\quad W_l = \frac{100\text{ J/s}}{10^3} \times 3$ (each)

for 2 fans $\quad W_f = 0.36$ kW

for 3 lamps $\quad W_l = 0.3$ kW

mass of air $m = 80\ kg/hr = \frac{80}{3600}\ kg/s$

$= 0.022\ kg/s$

Enthalpy of air entering $(h_1) = 84\ kJ/kg$

Enthalpy of air leaving $(h_2) = 59\ kJ/kg$

Heat transfer from each person $(Q_p) = 630\ kJ/hr$

$= \frac{630}{3600} = 0.175\ kJ/sec$

for 4 persons $(Q_p) = 0.7\ kJ/s$

<u>To find:</u>

$Q_{1-2} = ?$

4 persons ($Q_p = 0.7\ kJ/s$)
2 fans, 3 lamps
$\dot{m} = 0.022\ kg/s$

$h_1 = 84\ kJ/kg$ $\quad h_2 = 59\ kJ/kg$

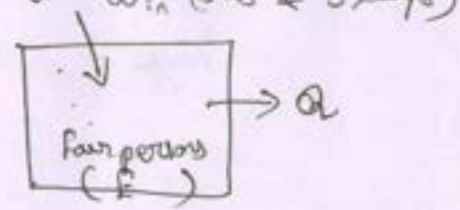
<u>Solution:</u>

Rate of energy increase = Rate of energy inflow − Rate of energy outflow

$$E = \left(h_1 + \cancel{\frac{V_1^2}{2}} + \cancel{z_1 g} + Q_{1-2}\right) = h_2 + \cancel{\frac{V_2^2}{2}} + \cancel{z_2 g} + W_{1-2}$$

~~84 kJ/kg + (−0.7) kJ/s = 59 kJ/kg + 0.66 kJ/s~~

~~(84 − 59) +~~



$Q = E - m(h_1 - h_2) - W$

$= -0.7 - 0.55 - 0.66$

$= -1.91\ kJ/s$

$E \rightarrow$ Energy increase

$= -np\,Q_p$

$= -0.7\ kJ/s$

$m(h_1 - h_2) = 0.55\ kW$

$W = 0.66\ kW$

---

4. $\boxed{\text{Closed System}}$

3. Given Data:

$P = a + bV$

$P_1 = 1000\ kPa$ $\quad V_1 = 0.20\ m^3$

$P_2 = 200\ kPa$ $\quad V_2 = 1.20\ m^3$

$U = 1.5PV - 85$

To find:

$Q_{1-2} = ?$

$U = ?$

Solution

change in internal energy $= (1.5 P_2 V_2 - 85) - (1.5 P_1 V_1 - 85)$

$\Delta U = U_2 - U_1 = 1.15 (P_2 V_2 - P_1 V_1)$

$= 1.15\,(200 \times 1.20 - 1000 \times 0.2)$

$\boxed{\Delta u = 46\,kJ}$

$\Delta u = 69\,kJ$

$P = a + bv$

$1000 = a + 0.2b \rightarrow (1)$

$200 = a + 1.2b \rightarrow (2)$

$800 = b$

$\boxed{b = -800}$ $kN/m^2 \times m^3$ kN

Sub b value in eq (1)

$1000 = a + 0.2(-800)$

$1000 = a - 160 \Rightarrow \boxed{a = 1160}$

$\therefore P = 1160 - 800V$

$$W_{1-2} = \int_{v_1}^{v_2} (1160 - 800v)\,dv$$

$$= \left[1160v - 800\frac{v^2}{2}\right]_{0.20}^{1.20}$$

$$= \left[1160\,[1.20 - 0.20) - \frac{800}{2}(1.20^2 - 0.20^2)\right]$$

$= 1160 - 560$

$= 600\,kJ$

$$Q = W + \Delta U$$

$$= 600 + 60$$

$$\boxed{Q = 660 kJ}$$

$$\Delta U = U_2 - U_1$$

$$U_2 = \Delta U + U_1$$

$$= 60 + (1.5 \times 1000 \times 0.2)$$

$$= \underline{360 kJ}$$

14. Given Data

Number of persons = 4

Number of fans = 2

Each ~~persons~~ fan consuming = 0.18 kW

$\therefore$ for 2 fans = 0.36 kW

Number of lamps = 3

Each lamp consumes = 100 W = 0.1 kW

$\therefore$ for 3 lamps = 0.3 kW

Work input for 2 fans & 3 lamps = 0.6 kW

mass flow rate $\dot{m}$ = 80 kg/hr

$$= \frac{80}{3600} \text{ kg/s} = 0.022 \text{ kg/s}$$

Enthalpy of air entering $(h_1) = 84\ kJ/kg$

Enthalpy of air leaving $(h_2) = 59\ kJ/kg$

Energy increase inside room $(E) = 630\ kJ/hr$

$$= \frac{630}{3600} = 0.175\ kJ/s$$

Energy increase for 4 persons $= 0.7\ kJ/s$

To find:

Heat Transferred = ?

Solution:

Energy increase = Rate of energy inflow - Rate of energy outflow.

$$E = \left\{\left[\left(h_1 + \cancel{\frac{v_1^2}{2}} + \cancel{gz_1}\right)\right] + Q_{1-2}\right\} - \left\{\left[\left(h_2 + \cancel{\frac{v_2^2}{2}} + \cancel{gz_2}\right)\right] + W_{1-2}\right\}$$

$$E = h_1 + Q_{1-2} - (h_2 + W_{1-2})$$

$$Q_{1-2} = E - [m(h_1 - h_2)] - W_{1-2}$$

$$= -0.7 - 0.55 - 0.66$$

$$\boxed{Q_{1-2} = -1.91\ kJ/s\ (or)\ kW}$$

$$Q_{1-2} = E + m(h_2 - h_1) - W_{1-2}$$

$$+ 0.022(59-84)$$

10. Given Data:

$\dot{V}_a = 270 m/s$

$T_a = -15°c = 258k$

$T_g = 600°c = 873k$

$h_a = 260 kJ/kg$; $h_g = 912 kJ/kg$

$\frac{m_f}{m_a} = 0.0190$

$E_f = 44.5 MJ/kg = 44500 kJ/kg$

$Q = -21 kJ/kg$

To find:

$E_g = 0.05 \times 44500 \times \frac{0.0190}{1.0190}$

$V_g = ?$

Solution:

$$M_a\left(h_a + \frac{V_a^2}{2}\right) + M_f \times E_f - Q$$
$$= m_g\left(h_g + \frac{V_g^2}{2} + E_g\right)$$

$$1\left(260 + \frac{270^2 \times 10^{-3}}{2}\right) + (0.0190 \times 44500) - 21$$
$$= 1.0190\left(912 + \frac{V_g^2 \times 10^{-3}}{2} + 41.48\right)$$

$$\boxed{V_g = 541.58 m/s}$$

15. Given Data:

$\dot{m} = 5kg$

$T_1 = 40°C$

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

$V_2 = 2V_1$

$P = constant$

To find:

1. $V_2 - V_1 = ?$
2. $W = ?$
3. $\Delta u = ?$
4. $\Delta H = ?$

Solution:

From ideal gas equation

$$P_1 V_1 = m R T_1$$

$$V_1 = \frac{5 \times 0.287 \times 313}{100} = 4.49 m^3$$

Final volume $V_2 = 2 \times 4.49 = 8.98 m^3$

(i) change in volume $= V_2 - V_1 = 8.98 - 4.49$

$= 4.49 m^3$

2. work transfer, $W = \int_{v_1}^{v_2} P\,dv = P(v_2 - v_1)$

$$= 100(8.98 - 4.49)$$

$$\boxed{W = 449\,kJ}$$

3. change in internal Energy

$$\Delta u = mc_v(T_2 - T_1)$$

for constant pressure process

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

$$T_2 = T_1\left(\frac{V_2}{V_1}\right) = 313\left(\frac{8.98}{4.49}\right)$$

$$= 626k$$

$$\Delta u = 5 \times 0.714\,(626 - 313)$$

$$\boxed{\Delta u = 1117.41\,kJ}$$

4. change in enthalpy

$$\Delta H = mc_p(T_2 - T_1)$$

$$= 5 \times 1.005\,(626 - 313)$$

$$= 1572.825\,kJ$$

Work input Rotary → fluid (compressor) (Turbine)

compressible flow → $\rho \neq$ constant [Gases]

In compressible flow → ρ = constant [Liquid]

11. Given Data:

Incompressible flow $\rho_1 = \rho_2 = 1000 kg/m^3$

$P_1 = 1.15 MPa$ $\quad$ $P_2 = 0.05 MPa$

$V_1 = 30 m/sec$ $\quad$ $V_2 = 15.5 m/sec$

$z_1 = 10m$ $\quad$ $z_2 = 2m$

$\dot{V} = 40 m^3/sec \therefore v_1 = v_2 = 40 m^3/sec$

To find:

Net Energy transfer = ?

Solution:

$$\rho = \frac{mass}{volume} \Rightarrow mass = \rho \times v$$

$$= 1000 \times 40$$

$$\boxed{m = 40{,}000 \ kg/sec}$$

SFEE

$$m\left[h_1 + \frac{v_1^2}{2} + z_1 g\right] + \cancel{Q_{1-2}} = m\left[h_2 + \frac{v_2^2}{2} + z_2 g\right] + W_{1-2}$$

$$m\left[(u_1 + P_1 v_1) + \frac{v_1^2}{2} + z_1 g\right] = m\left[u_2 + P_2 v_2 + \frac{v_2^2}{2} + z_2 g\right]$$

$$W_{1-2} + (U_2 - U_1) = m\left((P_1 v_1 - P_2 v_2) + \frac{V_1^2 - V_2^2}{2} + (z_1 - z_2)\cdot g\right]$$

$$= 40{,}000\left[(1.15\times10^6 \times 40 - 0.05\times10^6\times40) + \frac{30^2 - 15.5^2}{2} + (10-3)\,9.81\right]$$

$= 1.76\times10^{12}$ J/s

$= 1.76\times10^6$ MW

16. Given Data:

1 bar $= 10^6$ Pa

$= 100$ kPa

$= 0.1$ MPa

$m = 10$ kg/min $= 0.166$ kg/s

$P_1 = 1.5$ bar

$\rho_1 = 26$ kg/m³ $\Rightarrow v_1 = \frac{1}{26} = 0.038$ m³/kg

$V_1 = 110$ m/s

$u_1 = 910$ kJ/kg

$P_2 = 5.5$ bar

$\rho_2 = 5.5$ kg/m³ $\Rightarrow v_2 = \frac{1}{5.5} = 0.1818$ m³/kg

$V_2 = 190$ m/s

$u_2 = 710$ kJ/kg

$Q = -55$ kJ/s

$z_2 - z_1 = 55$ m.

To find:

$\Delta h = ?$

$w = ?$

Solution:

(i) $\Delta h = h_2 - h_1 = (u_2 - u_1) + (P_2 v_2 - P_1 v_1)$

$= (710 - 910) + (550 \times 0.1818 - 150 \times 0.038)$

$$\boxed{h_2 - h_1 = -105.71 \text{ kJ/kg}}$$

(ii) SFEE

$$m\left(h_1 + \frac{V_1^2}{2} + gz_1\right) + Q_{1-2} = m\left(h_2 + \frac{V_2^2}{2} + gz_2\right) + W_{1-2}$$

$$W_{1-2} = m\left[(h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)\right] + Q_{1-2}$$

$$= 0.167\left[105.785 + \frac{110^2 - 190^2}{2 \times 1000} - \frac{(55 \times 9.81)}{1000}\right] - 55$$

$$= 0.167\{105.785 - 12 - 0.539\} - 55$$

$$\boxed{W_{1-2} = -39.42 \text{ kJ/s (or) kW}}$$

17. <u>Given Data:</u>

$P_2 = P_3 = 1\,bar = 100\,kpa$

$V_1 = 0.2\,m^3$

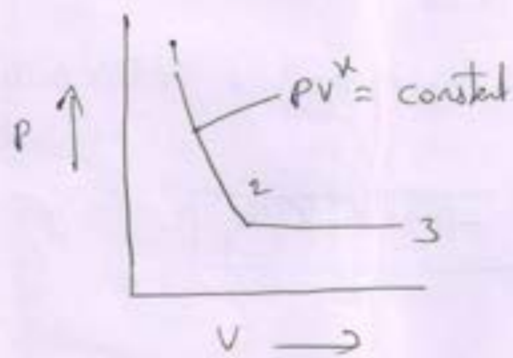
$h_2 - h_1 = 100\,kJ$

$P_1 = 4\,bar = 400\,kN/m^2$ (or) kpa

$c_p = 1\,kJ/kgk$

$T_1 = 150^\circ c = 423\,k$

$c_v = 0.714$



<u>To find:</u>

Total work done = ?

<u>Solution.</u>

$$\boxed{c_p - c_v = R}$$

$$1 - 0.714 = 0.286\ \cancel{kJ/kg}\ kJ/kgk$$

$$\boxed{\frac{c_p}{c_v} = \gamma} \Rightarrow \gamma = \frac{1}{0.714} = 1.4$$

Process 1-2 adiabatic $\cancel{Q} = 0$

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

$$T_2 = T_1\left(\frac{P_2}{P_1}\right) = 423\left(\frac{100}{400}\right)^{\frac{0.4}{1.4}}$$

$$\boxed{T_2 = 284.66k}$$

work done

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{\gamma-1} = \frac{mR(T_1 - T_2)}{\gamma-1}$$

$$P_1V_1 = mRT_1$$

$$400 \times 0.2 = m \times 0.286 \times 423$$

$$\boxed{m = 0.66\ kg/s}$$

$$W_{1-2} = \frac{0.66 \times 0.286(423 - 284.66)}{0.4}$$

$$= 65.41\ kJ$$

2-3 constant pressure process $\rightarrow W = 0$

$\cancel{Q = W + \Delta U}$

$W = \Delta G_1$

$$Q = \Delta H = mc_p(T_3 - T_2)$$

$$h_3 - h_2 = mc_p(T_3 - T_2) \qquad Q = \cancel{W}^{0} + \Delta u$$

Solution

$$U = 7.5PV$$

$$\Delta u = u_2 - u_1 = 7.5\,(P_2V_2 - P_1V_1)$$

now

$$P_1V_1^{1.4} = P_2V_2^{1.4}$$

$$V_2 = V_1 \left(\frac{P_1}{P_2}\right)^{1/1.4}$$

$$= 0.05 \left(\frac{1000}{2000}\right)^{1/1.4}$$

$$\boxed{V_2 = 0.03 m^3}$$

$$\therefore \quad \Delta u = 7.5\,(2000 \times 0.03 - 1000 \times 0.05)$$

$$\boxed{\Delta u = 75 kJ}$$

$$\cancel{w = \frac{2\times10^3 \times 0.03 - 1\times10^3 \times 0.05}{\gamma - 1}}$$

$$w =$$

$$W = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{1\times10^3 \times 0.05 - 2\times10^3 \times 0.03}{1.4-1}$$

$$\boxed{W = -25 kJ}$$

$$Q = W + \Delta U$$

$$= 75 - 25$$

$$\boxed{Q = 50\,kJ}$$

(b) $Q = 180\,kJ$

$$W = Q - \Delta U$$

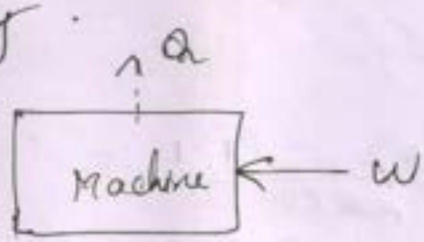
$$= 180 - 75$$

$$\boxed{W = 105\,kJ}$$

PMM1

Perpetual Motion Machine of first kind

Machine which would continuously supply mechanical work without some other form of energy disappearing simultaneously.



violates Ist law

PMMI is impossible

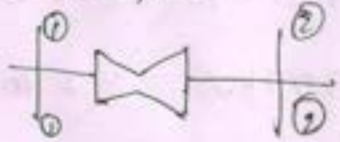
1. Given Data:

$\dot{m} = 600\ kg/hr$

$P_1 = 2MPa = 2\times10^6\ N/m^2$

$T_1 = 127^\circ c = 127+273 = 400k$

$V_1 = 300\ m/s$



$P_2 = 0.5\ MPa = 0.5\times10^6\ N/m^2$

To find:

(i) Exit velocity of air $(v_2) = ?$

(ii) $A_1 = ?$ & $A_2 = ?$

Solution:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{2\times10^6}{0.5\times10^6}\right)^{\frac{1.4-1}{1.4}} = 1.486$$

$$\therefore T_2 = 1.486 \times 400 = 594.4k$$

$$\boxed{T_2 = 594.4k}$$

SFEE

$$\underbrace{U_1 + P_1v_1}_{h_1} + g\cancel{z_1} + \frac{v_1^2}{2} + \cancel{Q_{1-2}} = \underbrace{U_2 + P_2v_2}_{h_2} + g\cancel{z_2} + \frac{v_2^2}{2} + \cancel{W_{1-2}}$$

$$\frac{v_2^2 - v_1^2}{2} = h_1 - h_2$$

$$= c_p\left(t_1 - t_2\right)$$

$= \cancel{1.005\,(400 - 594.4)}$ kJ/kg

$\cancel{0.166\left(\frac{V_2^2 - 300^2}{2}\right) = -195.37 \times 0.166}$ $\frac{J}{g} \cdot \frac{N \cdot m}{\frac{N \cdot s^2}{m}}$

$\cancel{\left(\frac{V_2^2 - 300^2}{2}\right) = -2.027\ kJ/sec}$ $\frac{N \cdot m^2}{N \cdot s^2}$

1000

N

$\frac{V_2^2 - 300^2}{2} = -195.37 \times 10^3\ J/kg$

$V_2^2 = (-195.37 \times 10^3 \times 2) + 300^2$

$-390740 + 90000$

$\frac{m^2}{s^2} \times kg/sec \quad \frac{N \cdot s^2}{m\,sec}$

$J/sec = kJ/sec$

$1kJ = J$

$\frac{V_2^2 - 300^2}{2 \times 1000} = 1.005\,(400 - 594.4)$

$= 0.166 \times 2000 \left[-195.37 + \frac{300^2}{2000}\right]$

$V_2^2 = \cancel{2000\,(...)}$

$\boxed{V_2 = 283.35\ m/s}$

kJ/sec

$\frac{kJ/sec \times kJ/kgK \times K}{N/m^2}$

$\frac{J}{sec}$

$\frac{N\,m}{sec}$

From ideal gas equation

$P_1 v_1 = R T_1$

$2 \times 10^6 \times v_1 = 0.287 \times 400$

$v_1 = \frac{0.287 \times 400}{2 \times 10^6}$

$\frac{Nm}{sec} \times \frac{m^2}{N}$

m^3/sec

$\boxed{v_1 = 0.0574\ m^3/kg}$

~~0.005~~(

Inlet mass flow rate $\dot{m} = \frac{A_1 V_1}{u}$

$$0.167 = \frac{\pi/4\, D_1^2 \times 300}{0.0574}$$

$$\frac{0.167 \times 0.0574}{0.784 \times 3000} = D_1^2$$

$$\boxed{d_1 = 0.0064 m}$$

w.k.t for adiabatic process

$$\frac{v_2}{v_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{2}{0.5}\right)^{1/1.4} = 2.692$$

$$v_2 = 2.692 \times 0.0574 =$$

$$\boxed{v_2 = 0.155\ m^3/kg}$$

By conservation of mass

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

$$\frac{\pi/4\,(0.0064)^2 \times 300}{0.0574} = \frac{\pi/4\, D_2^2 \times 283.35}{0.155}$$

$$\boxed{d_2 = 10.82\ mm}$$

2. Given Data:

$\dot{m} = 2750\ kg/min = \frac{2750}{60} = 45.83\ kg/sec$

$P_1 = 0.8\ bar = 0.8 \times 10^5\ N/m^2 = 0.8 \times 10^2\ kN/m^2$

$P_2 = 2.8\ bar = 2.8 \times 10^5\ N/m^2 = 2.8 \times 10^2\ kN/m^2$

$Z_1 = -2m$

$Z_2 = 5m$

$d_1 = 15cm = 0.15m \quad d_2 = 10cm = 0.1m$

To find:

$W_{1-2} = ?$

Solution

$$\cancel{U_1} + P_1 v_1 + g z_1 + \frac{V_1^2}{2} + \cancel{Q_{1-2}} = \cancel{U_2} + P_2 v_2 + g z_2 + \frac{V_2^2}{2} + W_{1-2}$$

$$W_{1-2} = \dot{m}\left[(P_1 v_1 - P_2 v_2) + g(z_1 - z_2) + \frac{V_1^2 - V_2^2}{2}\right]$$

$$\dot{m} = \frac{A_1 V_1}{v_1} \Rightarrow V_1 = \frac{\dot{m} \times v}{\frac{\pi}{4} \times d_1^2 \times \rho} = \frac{45}{\frac{\pi}{4} \times 0.15^2 \times 1000} \qquad v = \frac{1}{\rho}$$

$$= 2.59\ m/s$$

$$\dot{m} = \frac{A_2 V_2}{v_2} \Rightarrow V_2 = \frac{\dot{m}}{\frac{\pi}{4} \times d_2^2 \times \rho}$$

$$= \frac{45 \times 4}{\pi \times 0.1^2 \times 1000}$$

$$= 5.83\ m/s$$

$$W_{1-2} = 45.83\left[(80\times0.001 - 280\times0.001) + 9.81(-2-5) + \frac{2.59^2 - 5.83^2}{2\times1000}\right.$$

$\rho = \frac{1}{v}$

$$= 45.83\,(-0.2 - 68.67 - 0.0136) \quad 0.001$$

$= \cancel{45}$

$\frac{kg}{sec}\frac{kJ}{kg} \times \frac{m^3}{kg}$

$\frac{kN\cdot m}{sec}$

7. Given Data:

$\frac{N\cdot m}{m\,sec}$

$\frac{m}{s^2} \times m \times kg/sec$

$\frac{N\cdot m}{m\,sec}$

J/sec

$P_1 = 1\,MPa = 1\times10^3\,kPa$

$P_2 = 2\,MPa = 2\times10^3\,kPa$

$V_1 = 0.05\,m^3 \quad Q = 180\,kJ$

$U = 7.5\,PV$

To find

(i) $\Delta U = ?$

$W_{1-2} = ?$

$Q_{1-2} = ?$

(ii) If $Q = 180\,kJ \quad W = ?$

Solution

$U = 7.5\,PV$

$\Delta U = U_2 - U_1 = 7.5\,(P_2V_2 - P_1V_1)$

w.k.t

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{1.4}} = \left(\frac{1\times10^3}{2\times10^3}\right)^{1/1.4}$$

$$\frac{V_2}{V_1} = 0.609$$

$v_2 = 0.609 \times 0.05$

$\boxed{v_2 = 0.03\ m^3}$

$\therefore \Delta U = 7.5\left(2\times10^3 \times 0.03 - 1\times10^3 \times 0.05\right)$

$\boxed{\Delta U = 75\ kJ}$

$\frac{kN}{m^2}\times m^3$ kJ

work done $= \dfrac{P_1V_1 - P_2V_2}{\gamma - 1}$

$= \dfrac{2\times10^3 \times 0.03 - 1\times10^3\times0.05}{1.4-1}$

$\boxed{W = 25\ kJ}$

w.k.t

$Q = W + \Delta U$

$= 25 + 75$

$\boxed{Q = 100\ kJ}$

(ii) when $Q = 180\ kJ$

$Q = W + \Delta U$

$W = Q - \Delta U = 180 - 75$

$\boxed{W = 105\ kJ}$

9. Given Data:

No. of persons = 85

Room size = 10×8 m

Ceiling height = 5 m

Each person gives up heat = 350 kJ/hr

Time (t) = 10 min

$C_v = 0.718$ kJ/kg·K

$R = 0.287$ kJ/kg·K

Each person occupies (V_p) = 0.05 m^3

To find:

Air temperature rise Δt = ?

Solution

Volume of the room $V_R = 10 \times 8 \times 5$ m

$= 400 m^3$

∴ Volume of air $V_a = V_R - (V_p \times n)$

$= 400 - (0.05 \times 25)$

$\boxed{V_a = 398.75 m^3}$

From ideal gas equation

$$PV = \dot{m} R T$$

mass of air, $\dot{m} = \frac{P V_a}{R T}$

$$= \frac{101.325 \times 398.75}{0.287 \times 293}$$

$$\boxed{m = 479 kg}$$

By first law of thermodynamics

$$Q = W + \Delta U$$

Assume heat addition at constant volume process

$$\therefore W = 0$$

$$\therefore Q = \Delta U = \text{Heat/person} \times \text{No. of persons}$$

$$= 350 \times 25$$

$$\boxed{Q = 8750 \text{ kJ/hr}}$$

$$\boxed{Q = 145.83 \text{ kJ/min}}$$

for 10 minutes $Q = 145.83 \times 10$

$$\boxed{Q = 1458.33 \text{ kJ}}$$

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

$$\frac{1458.33}{472.29 \times 0.718} = \Delta T$$

$$\boxed{\Delta T = 4.3 °c}$$

$$\frac{\frac{kN}{m^2} \times m^3}{\frac{kJ}{kg\,K} \times K}$$

$$\frac{kJ \times kg}{kJ}$$

15. Given Data:

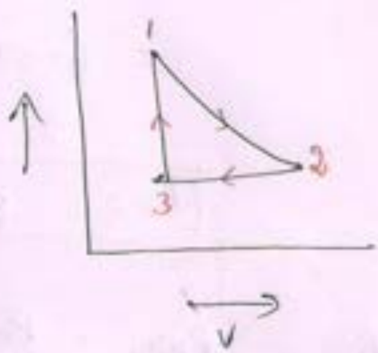
$m = 0.003\,kg$

$P_1 = 6 \times 1.01325 = 6.0795\,bar$

$T_1 = 160^\circ c = 160 + 273 = 433k$

$V_2 = 2V_1$

$P_2 = P_3 \quad V_3 = V_1$



To find.

$w_{net} = ?$

Solution:

For nitrogen, the gas constant

$$R = \frac{8314}{28} = 296.93\ J/kg \cdot k$$

From ideal gas equation

$$P_1 V_1 = m R T_1$$

$$V_1 = \frac{m R T_1}{P_1} = \frac{0.003 \times 433 \times 296.93}{6.0795 \times 100}$$

$$\boxed{V_1 = 0.6344 \times 10^{-4}\,m^3}$$

$$\boxed{V_2 = 2V_1 = 1.26 \times 10^{-3}\,m^3}$$

For adiabatic process

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$\frac{6.0795 \times 10^5 \, N/m^2}{10^3}$

$$P_2 = P_1 \left[\frac{V_1}{V_2}\right]^{\gamma}$$

$\frac{kN}{m^2} \times m^3$ kJ

$$= 6.0795 \left(\frac{1}{2}\right)^{1.4}$$

$$\boxed{P_2 = 2.303 \text{ bar}}$$

$$W_{1-2} = \frac{P_2 V_2 - P_1 V_1}{1-\gamma} = \frac{(230.3 \times 1.26 \times 10^{-3}) - (607.95 \times 0.6344 \times 10^{-4})}{1 - 1.4}$$

$$\boxed{W_{1-2} = 0.629 \text{ kJ}}$$

$$W_{2-3} = \int_2^3 p\,dv = P_2 (V_3 - V_2)$$

$$= 230.3 \left(0.6344 \times 10^{-4} - 1.26 \times 10^{-3}\right)$$

$$= -0.2755 \text{ kJ}$$

work done during the process 3-1

$W_{3-1} = 0$ since $dv = 0$

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

$$=$$

16. Given Data:

$P_1 = 784 \text{ kPa} = 7.84 \text{ bar}$

$T_1 = 220^\circ c = 273 + 220 = 493k$

$P_2 = 98 \text{ kPa} = 0.98 \text{ bar}$

$A_2 = 0.0006 m^2$

To find:

$V_2 = ?$

$\dot{m} = ?$

Solution:

wkt

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

$$T_2 = 493\left(\frac{0.98}{7.84}\right)^{\frac{0.4}{1.4}}$$

$$\boxed{T_2 = 272.158k}$$

from ideal gas equation

$$P_2 V_2 = R T_2$$

$$V_2 = \frac{0.287 \times 272.158}{98}$$

$$\boxed{V_2 = 0.797 m^3/kg}$$

$$\frac{kJ/kg \cdot K \times K}{kN/m^2}$$

$$= \frac{kJ}{kg} \times \frac{m^2}{kN}$$

$$= \frac{kN \cdot m \cdot m^2}{kg \cdot kN}$$

SFEE

$$\underbrace{u_1 + P_1 v_1}_{h_1} + g\cancel{z_1} + \frac{v_1^2}{2} + \cancel{Q_{1-2}} = \underbrace{u_2 + P_2 v_2}_{h_2} + g\cancel{z_2} + \frac{v_2^2}{2} + \cancel{w_{1-2}}$$

$$\frac{v_2^2 - v_1^2}{2} = h_1 - h_2$$

$$\frac{v_2^2}{2} = h_1 - h_2 = c_p (t_1 - t_2)$$

$$= 1.005 (493 - 272.15)$$

$$= 221.95 \text{ kJ/kg}$$

$$= \cancel{666.25}$$

$$v_2^2 = 221.95 \times 2000 \text{ m}^2/\text{s}^2$$

$$\boxed{v_2 = 666.25 \text{ m/sec}}$$

$\frac{kJ}{kg} \cdot \cancel{W}^{\times} \cancel{K}$

$\frac{kJ}{\frac{N \cdot s^2}{m}}$

$\frac{kg \cdot m \cdot m \cdot 1000}{kg \cdot s^2}$

17. Given Data:

$\dot{m} = 1 \text{ kg/s}$ $v_1 = 100 \text{ m/s}$

$T_1 = 293 \text{ k}$ $v_2 = 150 \text{ m/s}$

$W = 15 \text{ kW}$ $c_p = 1.005 \text{ kJ/kg.k}$

Adiabatic condition $\therefore Q = 0$

To find

$t_2 = ?$

solution:

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \boxed{\cancel{g z_1} + \frac{v_1^2}{2} + \cancel{Q_{1-2}}} = \underbrace{u_2 + P_2 v_2}_{h_2} + g\cancel{z_2} + \frac{v_2^2}{2} + w_{1-2}$$

$$h_1' + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} + W_{1-2}$$

$$h_1 - h_2 = \frac{V_2^2 - V_1^2}{2} + W_{1-2}$$

$$c_p(t_1 - t_2) = \frac{V_2^2 - V_1^2}{2 \times 1000} + W_{1-2}$$

$$1.005\,(293 - t_2) = \frac{150^2 - 100^2}{2000} + (-15)$$

$$294.46 - 1.005 t_2 = -8.75$$

$$-1.005 t_2 = -8.75 - 294.46$$

$$1.005 t_2 = 8.75 + 294.46$$

$$\boxed{t_2 = 301.70\,k}$$

18. Given Data:

$V_1 = 0.001\,m^3$

$T_1 = 273\,k$

$V_2 = 0.0005\,m^3$

To find:

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

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

$$T_2 = (2)^{1.4-1} \times 273 = 360.22\,k$$

$$T_2 - T_1 = 360.22 - 273 = 87.23\,k$$

$$\boxed{T_2 - T_1 = 87.23\,k}$$

19. Given Data:

$h_1 = 2800\ kJ/kg$ $h_2 = 2600\ kJ/kg$

$V_1 = 50 m/s$ $v_2 = 0.495\ m^3/kg$

$Q = 0$

$A_1 = 0.09 m^2$ $A_2 = ?$

Assume

$v_1 = 1\ m^3/kg$

To find:

$V_2 = ?$

$\dot{m} = ?$

$A_2 = ?$

Solution:

$$\underbrace{u_1 + P_1 v_1}_{h_1} + \cancel{g z_1} + \frac{V_1^2}{2} + Q_{1-2} = \underbrace{u_2 + P_2 v_2}_{h_2} + \cancel{g z_2} + \frac{V_2^2}{2} + W_{1-2}$$

$$h_1 + \frac{V_1^2}{2} + \cancel{Q_{1-2}} = h_2 + \frac{V_2^2}{2} + \cancel{W_{1-2}}$$

$$\frac{V_2^2 - V_1^2}{2 \times 1000} = h_1 - h_2$$

$$V_2^2 - 50^2 = 2000\,(2800 - 2600)$$

$$\boxed{V_2 = 634.42\ m/s}$$

By conservation

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} = \dot{m}$$

$$\dot{m} = \frac{A_1 v_1}{v} = \frac{0.09 \times 50}{1} =$$

$$\boxed{\dot{m} = 4.5 \, kg/s}$$

$$\frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2}$$

$$\frac{0.09 \times 50}{1} = \frac{A_2 \times 634.43}{0.495}$$

$$\boxed{A_2 = 0.0035 \, m^2}$$

Second Law of thermodynamics.

→ Directional constant of natural process.

Directional constant

① Liquid always flow from higher elevation to lower elevation.

② Heat always flow from high temperature to low temperature.

③ Material always diffuse from high concentration to low concentration.

External agency

~~Revers~~ * Reverse of this process never happened

* if this happened with the aide of external source (or) external agency.

→ Moving wheel brought to rest by applying brake. But the reverse of this pulling the brake never possible.

→ Electrical current is pass through on electrical conductor wire become hot.

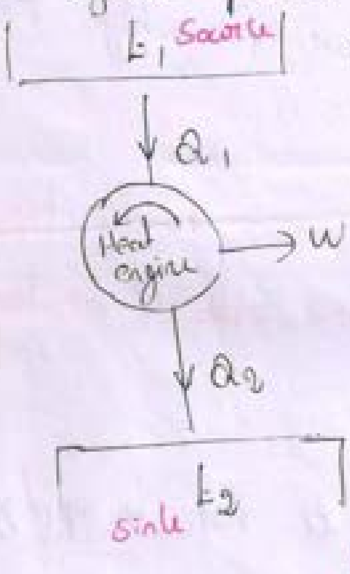
reverse of this never possible

Numbers of process takes place in both ...

Heat a body (or) cold a body
(Low → High)   (High → low)

Expand a gas (or) compress a gas
(H pressure → low pressure)   (Low pressure → High pressure)
(work is delivered)   work is given

Heat engine is a device that the system operates in a cyclic process



Thermal reservoir (or) source – is a system of infinite heat capacity.

$W = Q_1$

$$\boxed{W = Q_1 - Q_2}$$

$Q_2 \neq 0$

$t_2 < t_1$

Thermal efficiency

$$\eta_t = \frac{W}{Q_1}$$

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

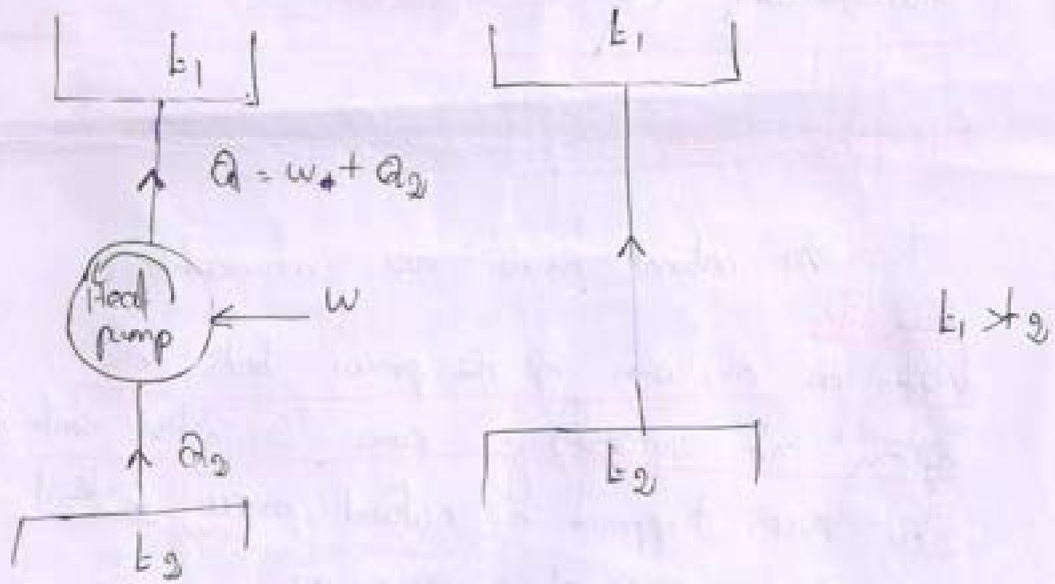
$$\boxed{\eta_t = 1 - \frac{Q_2}{Q_1}}$$

$\boxed{\eta_t \neq 1}$ ideal case does not happen

Kelvin - Planck statement:

It is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.

It take heat and must reject heat for that we must have two different temperature



$$\boxed{\begin{array}{ll} Q \rightarrow w & (w < Q) \\ w \rightarrow Q & (Q = w) \end{array}}$$ Ideal condition

Heat $\longrightarrow$ Low grade energy

work $\longrightarrow$ high grade energy

Clausius statement of the IInd law

It is impossible to construct a device which operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body

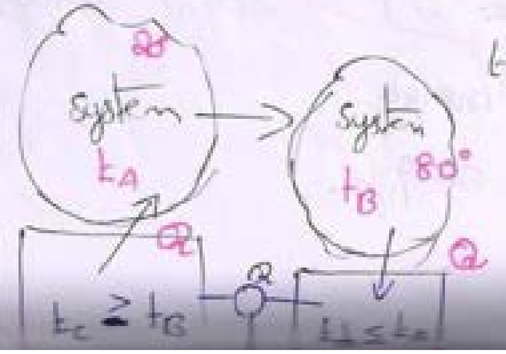
spontaneously heat cannot flow from a cooler to a hotter. But it can be done by heat pump i.e it can take some work from surrounding (it cause some effect in surrounding)

Reversible process

All natural process are irreversible

Reversible

After the conclusion of the process both the system and surroundings come to initial state. This never happened in natural process without any change in the rest of the universe.



$t_B > t_A$

$t_B = t_C \rightarrow$ slow process at the end

$t_C > t_B \rightarrow$ process occurs

~~so~~ c.i.t.c irreversible.

[Heat pump required work from surroundings (it cause some effects in surrounding)]

∴ It is irreversible

[Similarly during expansion of gas the work delivered is not equal to the work ~~obtain~~ required to compress the gas, due to friction.]

Causes of irreversibilities

* Lack of thermodynamic equilibrium
  - mechanical equilibrium: $dp = 0$
  - Thermal equilibrium: $dT = 0$
  - chemical equilibrium: $dc = 0$, $d\mu_c = 0$ (chemical potential)

* Dissipative effects
  1. mechanical friction
  2. fluid viscosity
  3. inelasticity
  4. electrical resistance

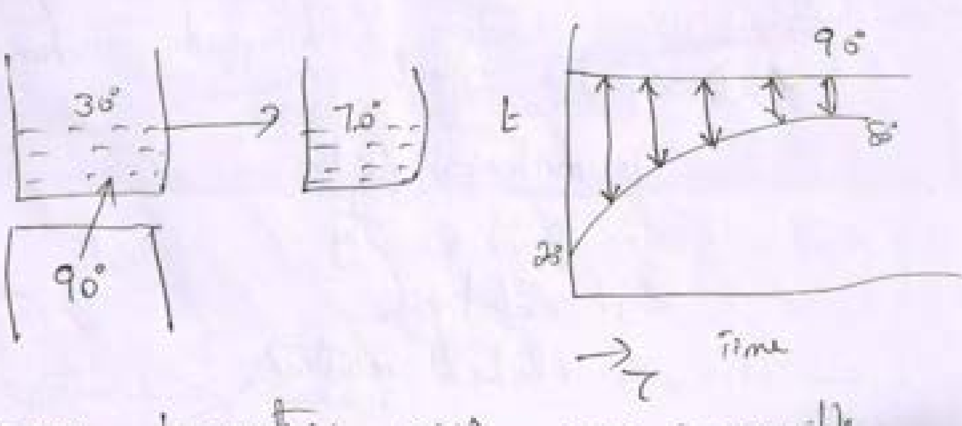
If a process ~~has~~ is thermodynamic equilibrium and have no dissipative effects the process is reversible. All the natural process have

Process	perfectly reversible	reversible in the limit
~~mechanical~~ mechanical work transfer	$\Delta P = 0$	$\Delta P \to 0$ (dP)
Heat transfer process	$\Delta T = 0$	$\Delta T \to 0$ (dT)
mass transfer	$\Delta c = 0$	$\Delta c \to 0$ (dc)
chemical reaction	$\Delta \mu_c = 0$	$\Delta \mu_c \to 0$ ($d\mu_c$)

$\boxed{\text{No dissipative effect}}$

reversible process in the limit means (infinitely small) dissipative effect also very less.

Reversible Heat transfer process



$\Rightarrow$ more temperature gradient means more irreversible process.

$\Delta T \uparrow$ irreversible ↑

Reversible cycle (or) Reversible heat Engine

(or) Heat pump

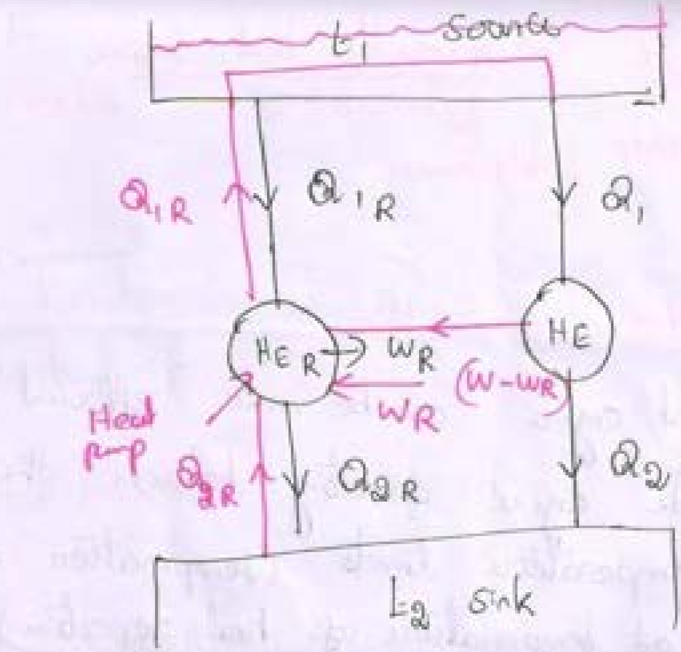
Carnot's theorem:

① No heat engine can be more efficient than a reversible engine operating between the ~~same~~ same temperature limits (temperature of heat addition and temperature of heat rejection) and all ② reversible heat engines operating between the same temperature limits have the same efficiency.

② Two temperatures are fixed and operate different engines, but all engines are ~~different~~ reversible engines, but their design is different, fluid is different, system is different then they yield unique efficiency.

① Two temperatures are fixed and operate no. of irreversible heat engines they yield different efficiency.

maximum efficiency of irreversible engine is lower than reversible engine efficiency.



$Q_{1R} = Q_1$

$\boxed{\eta_R > \eta \quad \text{poss}}$

$$\eta_R = \frac{W_R}{Q_{1R}}$$

$$\eta = \frac{W}{Q_1}$$

Assume

$\eta > \eta_R$

$W > W_R$

It violates kelvin-planck statement

Assumption is wrong.

$$\boxed{\eta_R > \eta}$$

~~Frozen~~

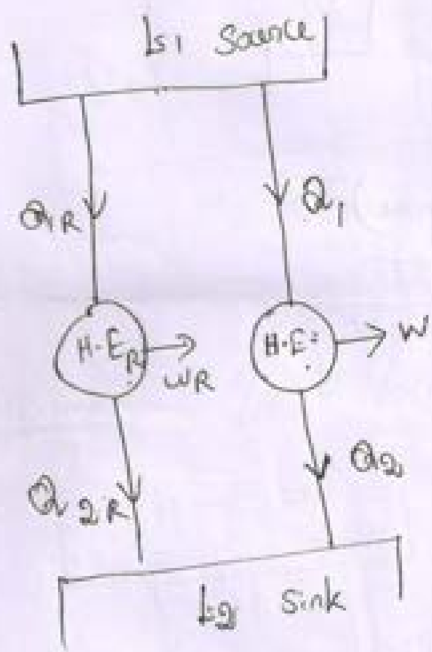
~~conspiracy~~

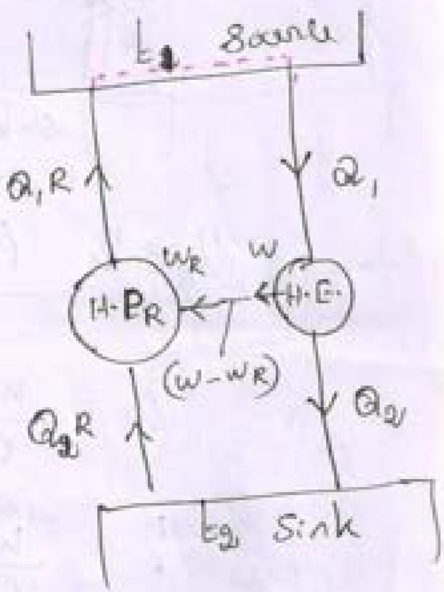
~~sweeps~~

~~Prohibitory~~

~~Regret~~

$t_1 > t_2$





$Q_{1R} = Q_1$

$\eta_R > \eta$ (to be proved)

$$\eta_R = \frac{W_R}{Q_{1R}}$$

$$\eta = \frac{W}{Q_1}$$

Assume

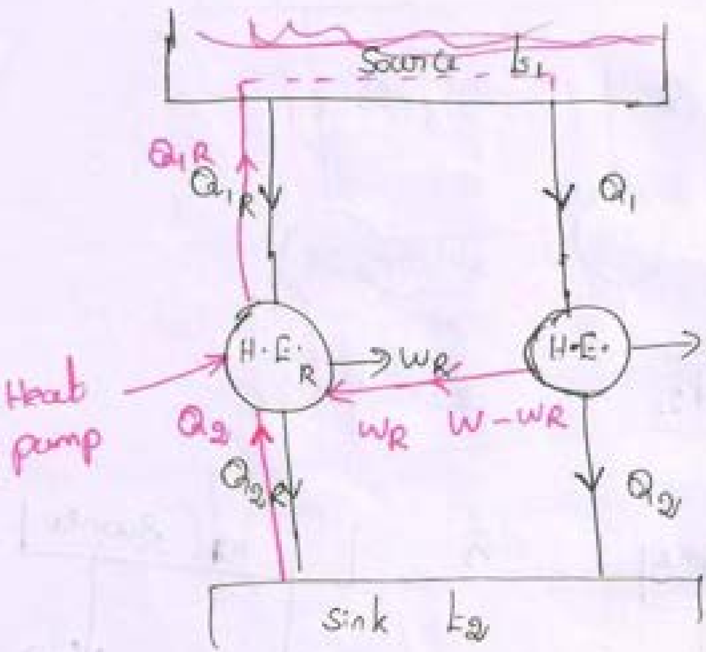
$\eta > \eta_R$

$W > W_R$

violates Kelvin-planck

$\boxed{\eta < \eta_R}$

$\eta_R = \eta$



$Q_{1R} = Q_1$

$\eta_R > \eta$ (to be prove)

$$\eta_R = \frac{W_R}{Q_1 R}$$

$$\eta = \frac{W}{Q_1}$$

$W_R > W$

Assume

$\eta > \eta_R$

$W > W_R$

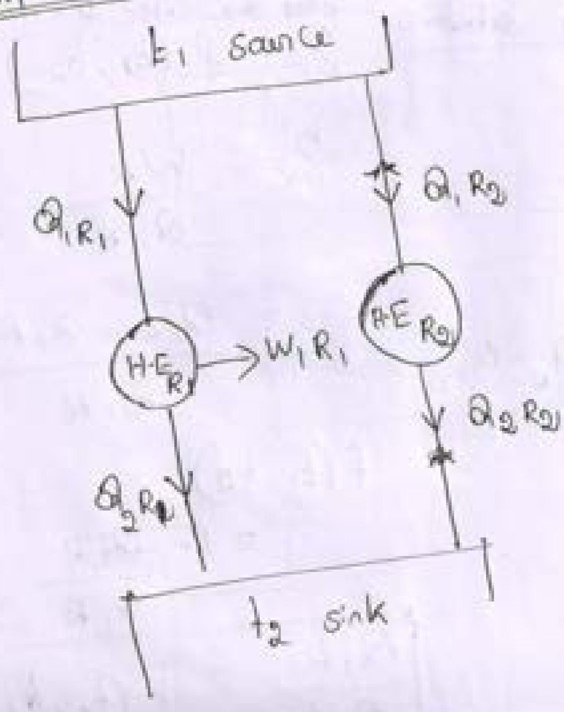
It violates kelvin- planck statement

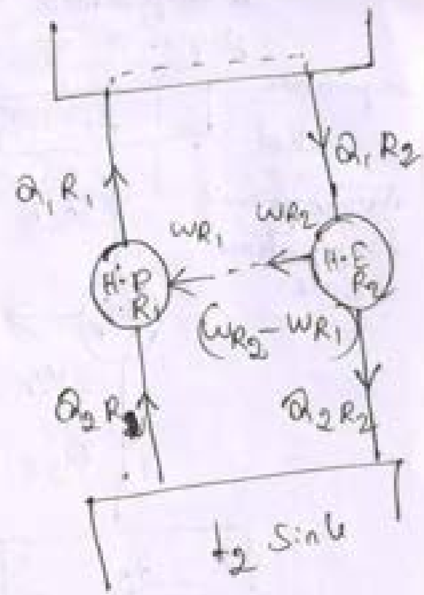
$\therefore \eta_R > \eta$

$\eta_{R_1} = \eta_{R_2}$ (To be proved)

Assume $\eta_{R_1} < \eta_{R_2}$ ~~(to be proved)~~

$W_{R_1} < W_{R_2}$



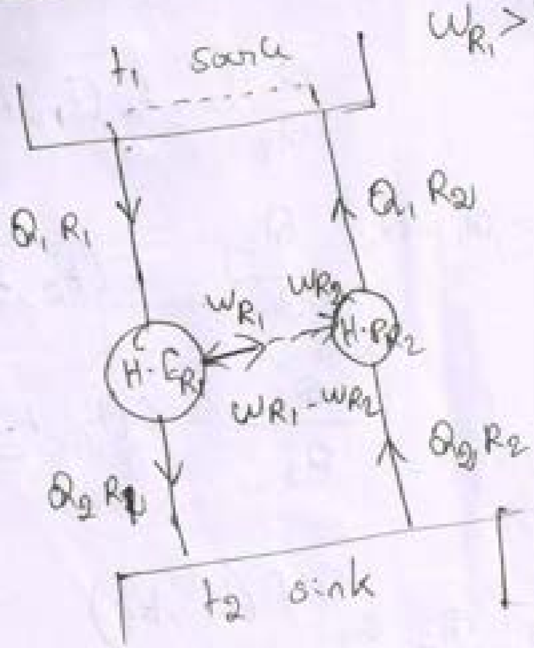


violates kelvin planck statement

Assume $\eta_{R_1} > \eta_{R_2}$

$\therefore \eta_{R_1} < \eta_{R_2}$ assumption is wrong

$W_{R_1} > W_{R_2}$



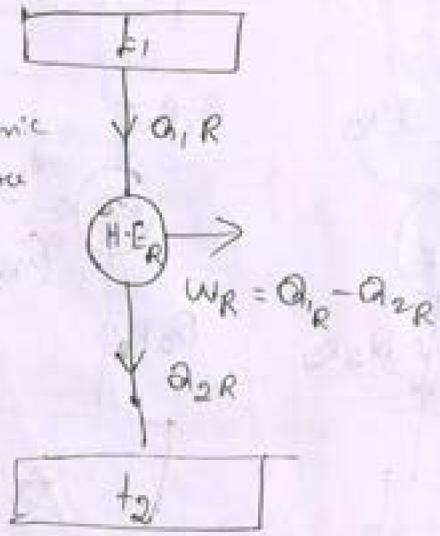
violates kelvin planck statement

$\therefore \eta_{R_1} > \eta_R$ assumption is wrong

$\boxed{\eta_{R_1} = \eta_{R_2}}$

Absolute thermodynamic scale of temperature

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



$$\eta_R = f(t_1, t_2)$$

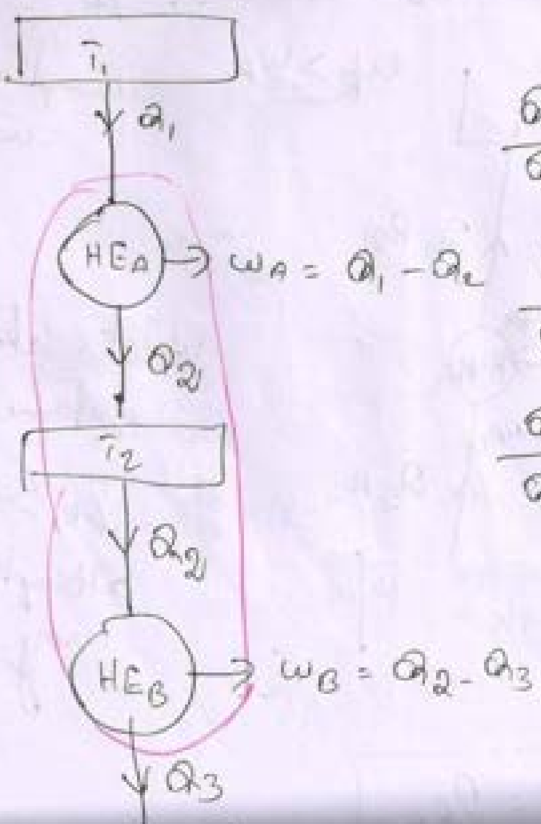
$$\eta_R = \frac{W_R}{Q_1 R}$$

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

$$f(t_1, t_2) = 1 - \frac{Q_2 R}{Q_1 R}$$

$$\boxed{\frac{Q_1 R}{Q_2 R} = f(t_1, t_2)}$$

$t_1 > t_2 > t_3$



$$\frac{Q_1}{Q_2} = f_1(t_1, t_2) = \frac{\phi(T_1)}{\phi(T_2)}$$

$$\frac{Q_2}{Q_3} = f(t_2, t_3) = \frac{\phi(T_2)}{\phi(T_3)}$$

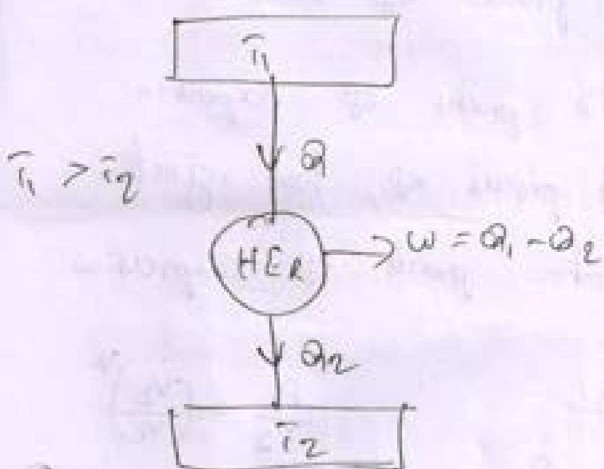
$$\frac{Q_1}{Q_3} = f(t_1, t_3) = \frac{\phi(T_1)}{\phi T_3}$$

$$f(t_1, t_2) = \frac{f(t_1, t_3)}{f(t_2, t_3)} = \frac{Q_1}{Q_3} \times \frac{Q_3}{Q_2}$$

$$\frac{Q_1}{Q_3} = \frac{Q_1/Q_3}{\frac{Q_2}{Q_3}} \Rightarrow = \frac{Q_1/\cancel{Q_3}}{Q_2/\cancel{Q_3}}$$

$$\boxed{f(t_1, t_2) = \frac{\phi(t_1)}{\phi(t_2)}} = \frac{T_1}{T_2}$$

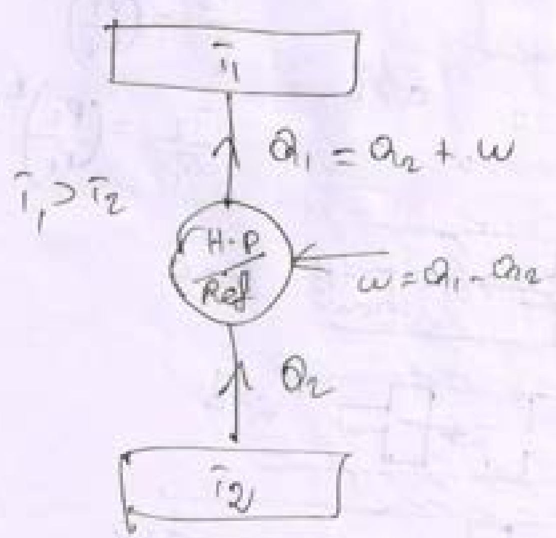
$$\boxed{\frac{Q_1}{Q_2} = \frac{T_1}{T_2}}$$



$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

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

$$\boxed{\eta_{rev} = 1 - \frac{T_2}{T_1}}$$



$$(C \cdot O \cdot P)_{H \cdot P} = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

$$(C \cdot OP)_{Ref} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

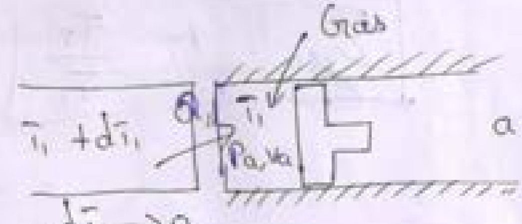
$$\boxed{C.OP._{HP} = 1 + COP_{ref}}$$

$$(COP)_{rev\,HP} = \frac{T_1}{T_1 - T_2} \qquad \frac{Q_1 - \cancel{Q_2} + \cancel{Q_2}}{Q_1 - Q_2}$$

$$(COP)_{rev,\,ref} = \frac{T_2}{T_1 - T_2}$$

Carnot's Engine : (He thought to find out a engine very close to the reversible engine}

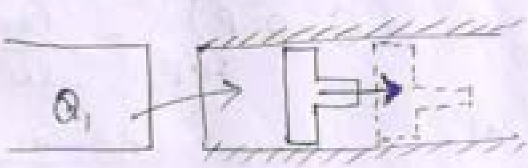
* Reversible isothermal process of heat addition
* Reversible adiabatic process of expansion
* Reversible isothermal process of heat rejection
* Reversible adiabatic process of compression



a

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

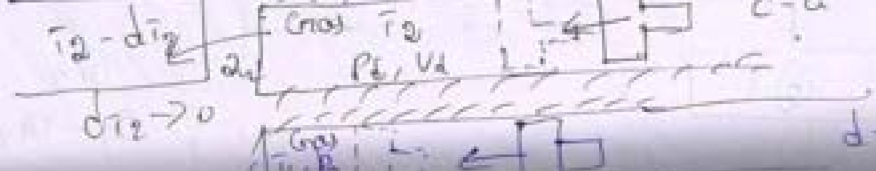
$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1}$$



a - b

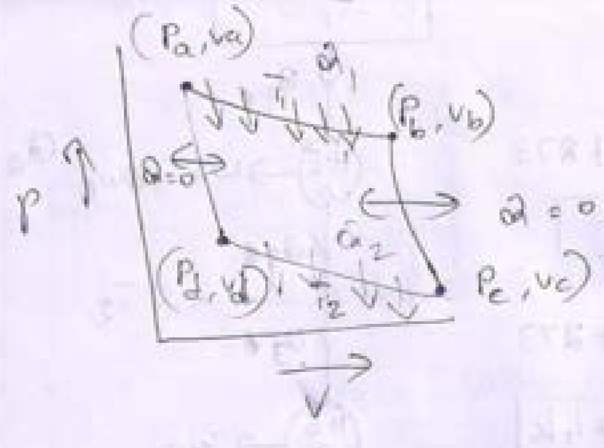
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

b - c



c - d

d - a



$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

---

(1) Two reversible heat engine A and B are arranged in series. Engine A rejecting heat directly to engine B, receives 200kJ at a temperature of 421°c from a hot source, while temperature B is in communication with cold sink at a temperature of 4.4°c. If the work output of A is twice that of B, find

1. The intermediate temperature between A and B.
2. The efficiency of each engine and
3. The heat rejected to the cold sink.

Given Data:

$Q_1 = 200 kJ$

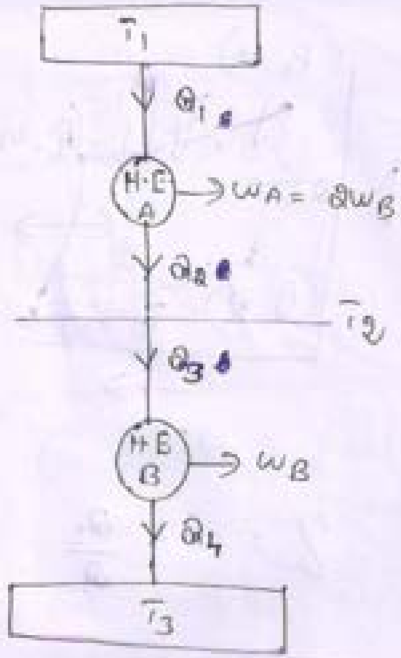
$T_1 = 421^\circ c + 273$

$\boxed{T_1 = 694 k}$

$T_3 = 4.4^\circ c + 273$

$\boxed{T_3 = 277.4 k}$

$W_A = 2 W_B$



$\because Q_2 = Q_3$

To find:

$T_2 = ?$

$\eta_A = ?$

$\eta_B = ?$

solution:

$W_A = Q_1 - Q_2$

$W_A = 200 - Q_2$

For reversible heat engine A

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \Rightarrow \frac{200}{Q_2} = \frac{694}{T_2}$$

$$200 T_2 = 694 Q_2$$

$$Q_2 = \frac{200}{694} T_2 = 0.288 T_2$$

$$\boxed{Q_2 = 0.288 T_2}$$

$W_A = 200 - 0.288 T_2 \rightarrow ①$ $\because W_B = \frac{W_A}{2}$

$W_B = Q_3 - Q_4$

$$W_B = 0.288T_2 - Q_4 \rightarrow (3)$$

Equate (2) & (3)

$$100 - 0.144T_2 = 0.288T_2 - Q_4$$

$$-Q_4 = 100 - 0.144T_2 - 0.288T_2$$

$$Q_4 = -100 + 0.144T_2 + 0.288T_2$$

$$\boxed{Q_4 = 0.432T_2 - 100}$$

For reversible heat engine B

$$\frac{Q_3}{Q_4} = \frac{T_2}{T_3}$$

$$\frac{0.288T_2}{0.432T_2 - 100} = \frac{T_2}{277.4}$$

$$\frac{79.89T_2}{0.432T_2 - 100} = T_2$$

$$\frac{79.89T_2}{\cancel{0.432T_2 - 100}} = T_2(0.432T_2 - 100)$$

$$0.432T_2^2 - 100T_2 - 79.89T_2 = 0$$

$$0.432T_2^2 - 179.89T_2 = 0$$

$$0.432T_2 = 179.89$$

$$T_2 = \frac{179.89}{0.432}$$

$$\boxed{T_2 = 416.41K}$$

$Q_2 = 0.288 \times 416.41$

$$\boxed{Q_2 = 119.93\ kJ}$$

$Q_4 = (0.432 \times 416.41) - 100$

$$\boxed{Q_4 = 79.88\ kJ}$$

$$\eta_A = 1 - \frac{Q_2}{Q_1}$$

$$= 1 - \frac{119.93}{200}$$

$$\boxed{\eta_A = 40.03\%}$$

$$\eta_B = 1 - \frac{Q_4}{Q_3}$$

$$= 1 - \cancel{\frac{119.93}{79.88}}\ \frac{79.88}{119.93}$$

$$\boxed{\eta_B = 33.39\%}$$

(2) A reversible heat engine operates between two reservoirs at 827°c and 27°c. Engine drives a carnot refrigerator maintaining -13°c and rejecting heat to reservoir at 27°c. Heat input to the engine is 2000kJ and network available is 300kJ. How much heat is transferred to refrigerant and total

heat rejected to reservoir at 27°C?

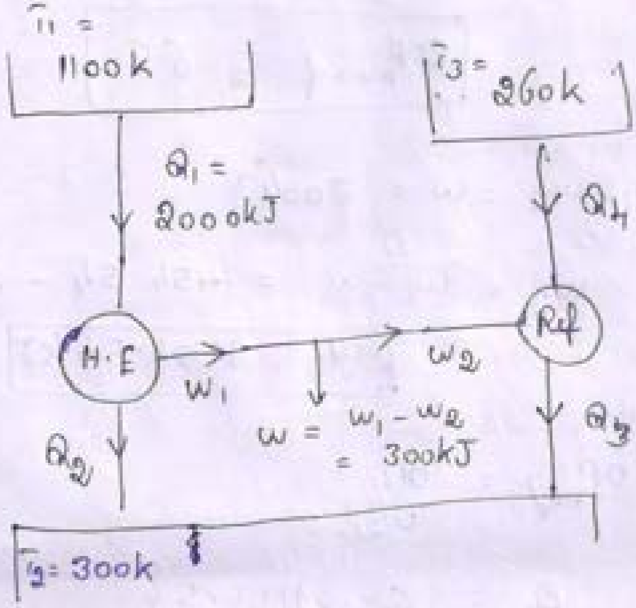
Given Data:

$T_1 = 1100K$

$T_2 = 300K$

$T_3 = 260K$

$Q_1 = 2000kJ$



To find:

$Q_4 = ?$

$Q_2 + Q_3 = ?$

Solution:

$$\eta_{rev\,H\cdot E} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{1100}$$

$$\eta_{rev\,H\cdot E} = 0.727$$

$$\eta_{H\cdot E} = \frac{Q_1 - Q_2}{Q_1} = \frac{W_1}{Q_1}$$

$$W_1 = 0.727 \times 2000$$

$$\boxed{W_1 = 1454.54\,kJ}$$

$$COP_{ref} = \frac{Q_4}{W_2} = \frac{Q_4}{Q_3 - Q_4}$$

$$COP_{rev \cdot ref} = \frac{T_3}{T_2 - T_3} = \frac{260}{300 - 260}$$

$$\boxed{COP_{rev \cdot ref} = 6.5}$$

$$W_1 - W_2 = W = 300kJ$$

$$W_2 = W_1 - W = 1454.54 - 300$$

$$\boxed{W_2 = 1154.54 kJ}$$

$$COP_{ref} = \frac{Q_4}{W_2}$$

$$Q_4 = 6.5 \times 1154.54$$

$$\boxed{Q_4 = 7504.51 kJ}$$

$$Q_3 = Q_4 + W_2$$

$$= 7504.51 + 1154.54$$

$$\boxed{Q_3 = 8659.05 kJ}$$

$$W = Q_1 - Q_2$$

$$Q_2 = Q_1 - W_1$$

$$= 2000 - 1454.54$$

$$\boxed{Q_2 = 545.46 kJ}$$

Total heat rejection to 27°C reservoir

$$= Q_2 + Q_3 = 9204.51 kJ$$

③ A carnot heat engine receives heat from a reservoir at 1173k at a rate of 800kJ/min and rejects the waste heat to the ambient air at 300k. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at 268k and transfers it to the same ambient air at 300k. Determine the maximum rate of heat removal from the refrigerated space and the total rate of heat rejection to the ambient air?

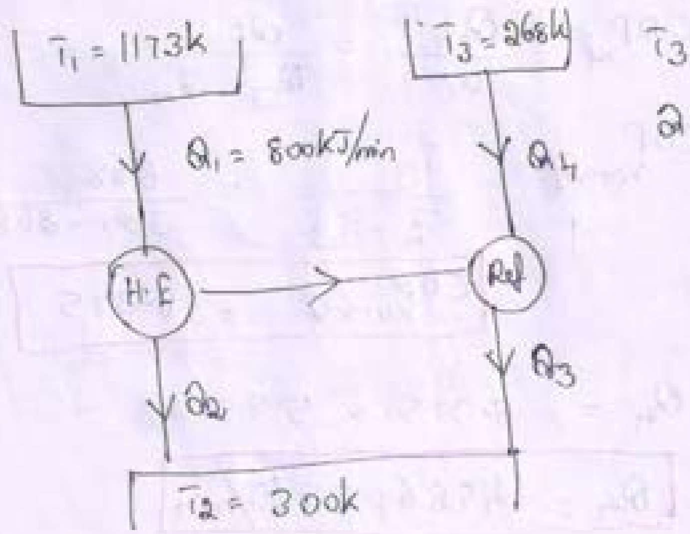
Given Data:

$T_1 = 1173k$

$T_2 = 300k$

$T_3 = 268k$

$Q_1 = 800kJ/min$



To find:

$Q_H = ?$

$Q_2 + Q_3 = ?$

Solution:

$$\eta_{H.E} = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$\eta_{rev.H.E} = \frac{T_1 - T_2}{T_1} = \frac{1173 - 300}{1173}$$

$$= 0.744$$

$$\eta_{H.E} = \frac{W}{Q_1}$$

$$W = 0.744 \times 800$$

$$\boxed{W = 595.39 \text{ kJ/min}}$$

$$W = Q_1 - Q_2$$

$$Q_2 = Q_1 - W = 800 - 595.39$$

$$\boxed{Q_2 = 204.64 \text{ kJ/min}}$$

$$COP_{ref} = \frac{Q_4}{W} = \frac{Q_4}{Q_3 - Q_4}$$

$$COP_{rev.ref} = \frac{T_3}{T_2 - T_3} = \frac{268}{300 - 268}$$

$$\boxed{COP_{rev.ref} = 8.375}$$

$$Q_4 = 8.375 \times 595.39$$

$$\boxed{Q_4 = 4986.39 \text{ kJ/min}}$$

$$W_2 = Q_3 - Q_4$$

$$Q_3 = W_2 + Q_4 = 595.39 + 4986.39$$

$$\boxed{Q_3 = 5581.78 \text{ kJ/min}}$$

Total heat rejection to ambient air

$$= Q_2 + Q_3 = 204.64 + 5581.5$$

$$= 5786.14\ kJ/min$$

(4) In a carnot cycle the maximum pressure and temperature are limited to 18bar and 410°c. The volume ratio of isentropic compression is 6 and isothermal expansion is 1.5. Assume the volume of the air at the beginning of isothermal expansion as $0.18 m^3$. Show the cycle on P-V diagram and determine. 1. The pressure and temperature at main points of the cycle. (2) Thermal efficiency

Given Data:

$P_1 = 18 bar$

$T_1 = T_2 = 410°c = 683k$

$\frac{V_3}{V_2} = \frac{V_4}{V_1} = 6 \qquad \frac{V_2}{V_1} = 1.5$

$V_1 = 0.18 m^3$

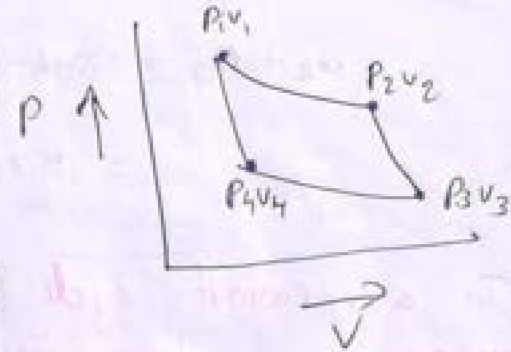
To find:

T & P for all point = ?

$\eta = ?$

Solution.

④-① Adiabatic compression



$$\frac{T_4}{T_1} = \left(\frac{V_1}{V_4}\right)^{\gamma-1}$$

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} = 6^{0.4}$$

$$\boxed{T_4 = 333.2k} = T_3$$

$$\frac{T_1}{T_4} = \left(\frac{P_1}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{P_1}{P_4} = \left(\frac{T_1}{T_4}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\boxed{P_4 = 1.46 bar}$$

P V T

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

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

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

①-② Isothermal expansion

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2} = \frac{18}{1.5} = 12 bar$$

②-③ Adiabatic expansion process

$$\frac{P_3}{P_2} = \left(\frac{V_2}{V_3}\right)^{\gamma} =$$

$$P_3 = P_2 \left(\frac{V_1}{V_4}\right)^n = 12 \times \left(\frac{1}{6}\right)^{1.4}$$

$$\boxed{P_3 = 0.47 \text{ bar}}$$

$$\frac{V_4}{V_1} = \frac{V_3}{V_2}$$

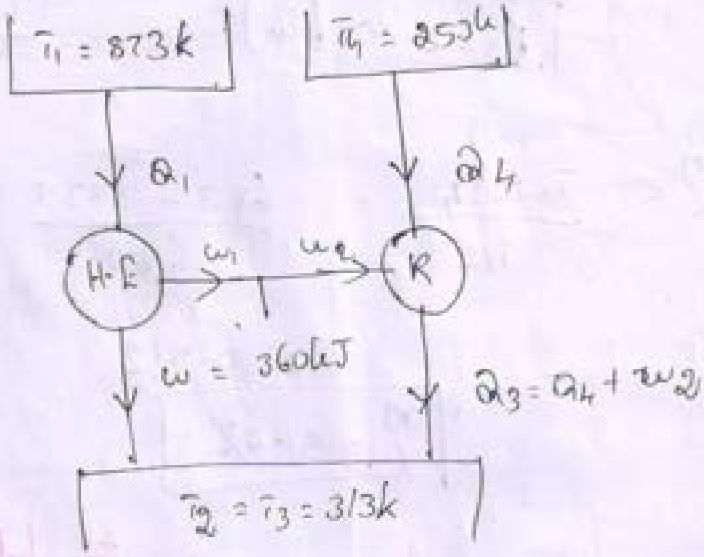
$$\eta = \frac{T_1 - T_2}{T_1} = \frac{683 - 333.2}{683}$$

$$= 0.512$$

$$\boxed{\eta = 51.2\%}$$

(5) A reversible heat engine operates between two reservoirs at temperatures of 600°C and 40°C. The engine drives a reversible refrigerator which operates between reservoirs at temperatures of 40°C and 80°C. The heat transfer to the engine is 2000 kJ and the network output of the combined engine refrigerator plant is 360 kJ. Evaluate the heat transfer to the refrigerant and the net heat transfer to the reservoir at 40°C. Reconsider given that the efficiency of the heat engine and the COP of the refrigerator are each 40% of their maximum possible values.

Given Data:



solution

$$\eta_{H \cdot E} = 1 - \frac{Q_2}{Q_1} = \frac{w_1}{Q_1}$$

$$\eta_{rev \cdot H \cdot E} = 1 - \frac{T_2}{T_1} = 1 - \frac{313}{873}$$

$$= 0.642$$

$$w_1 = 0.642 \times 2000 = 1284kJ$$

$$COP_{ref} = \frac{Q_4}{w_2} = \frac{Q_4}{Q_3 - Q_4}$$

$$COP_{rev \cdot ref} = \frac{T_4}{T_3 - T_4} = \frac{253}{313 - 253} = 4.22$$

$$COP = \frac{Q_4}{w_2}$$

$W = W_1 - W_2 = 360 kJ$

$W_2 = W_1 - W = 1284 - 360 = 924 kJ$

$Q_4 = 4.22 \times 924 = 3899 kJ$

$Q_3 = Q_4 + W_2 = 924 + 3899 = 4823 kJ$

$Q_2 = Q_1 - W_1 = 2000 - 1284 = 716 kJ$

Heat rejected 40°c reservoir

$= Q_2 + Q_3 = 716 + 4823 = 5539 k$

$\eta = 0.4 \eta_{rev}$

$= 0.4 \times 0.642 = 0.256$

$W_1 = 0.256 \times Q_1 = 513.6 kJ$

$W_2 = 513.6 - 360 = 153.6 kJ$

$COP = 0.4 \times COP_{rev} = 0.4 \times 4.22 = 1.69$

$Q_4 = 153.6 \times 1.69 = 259.6 kJ$

$Q_3 = 259.6 + 153.6$

$= 413.2 kJ$

$Q_2 = Q_1 - W_1 = 2000 - 513.6$

$\boxed{Q_2 = 1486.4 kJ}$

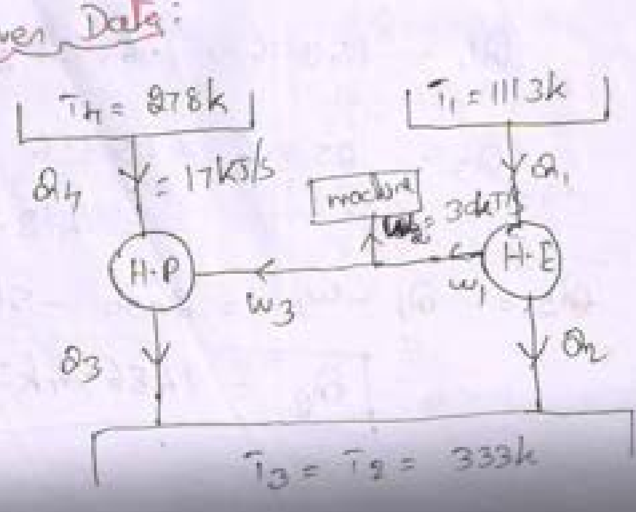
Heat rejected to 40°c reservoir

$= Q_2 + Q_3 = 413.2 + 1486.4$

$= 1899.64 J$

(6) A heat pump working on the 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 rejects heat to a reservoir at 60°c. The reversible heat engine in addition to driving the heat pump, also drives a machine that absorbs 30kw. If the heat pump extracts 17 kJ/s from the 5°c reservoir, Determine (1) the rate of heat supply from the 840°c source, and (2) the rate of heat rejection to the 60°c sink.

Given Data:



To find:

$Q_1 = ?$

$Q_2 + Q_3 = ?$

Solution

$$COP_{H.P} = \frac{Q_3}{W_3}$$

$$COP_{rev\,H.P} = \frac{T_3}{T_3 - T_4} = \frac{333}{333-278}$$

$$= 6.05$$

$$COP_{H.P} = \frac{Q_3}{W_3} = \frac{Q_3}{W_1 - W_2} = 6.05$$

$$\frac{Q_3}{W_1 - 30} = 6.05$$

$$\boxed{Q_3 = 6.05 W_1 - 181.5}$$

$$COP_{HP} = \frac{Q_3}{Q_3 - Q_4} = 6.05$$

$$Q_3 = 6.05 (Q_3 - 17)$$

$$Q_3 = 6.05 Q_3 - 102.35$$

$$\boxed{Q_3 = 20.36 \text{ kJ/s}}$$

$\eta_{ref} = \frac{Q}{Q_1} = 0.40$

$Q_3 = 6.05 w_1 - 181.5$

$\frac{20.36 + 181.5}{6.05} = w_1$

$\boxed{w_1 = 33.36 \, kJ/s}$

$\eta_{H.E} = \frac{w_1}{Q_1} = 0.70$

$\frac{33.36}{Q_1} = 0.70$

$\boxed{Q_1 = 47.6 \, kJ/s}$

$w_1 = Q_1 - Q_2$

$Q_2 = Q_1 - w_1$

$Q_2 = 47.6 - 33.36$

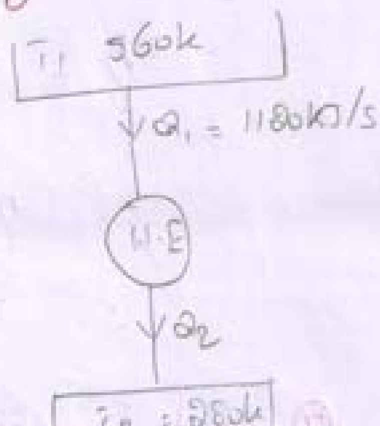
$\boxed{Q_2 = 14.306 \, kJ/s}$

$Q_2 + Q_3 = 14.306 + 20.36$

$= 34.66 \, kJ/s$

7. An engine is supplied with 1120 kJ/s of heat. The source and sink temperature are maintained at 560°k and 280°k. Determine whether the following cases represent the reversible, irreversible (or) impossible heat engines.

1) 900kw of heat rejected.
2) 560kW of heat rejected
3) 108kw of heat rejected.



solution

carnot method

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

$$= \frac{560 - 280}{560}$$

$$= 0.5$$

case (i)

$Q_2 = 900$ kJ/s (or) kw

$$\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{1120 - 900}{1120}$$

$$= 0.196$$

$$\eta < \eta_{carnot}$$

∴ It is irreversible engine.

case (ii)

$$\underline{Q_2 = 560\,kw \text{ (or) } kJ/s}$$

$$\eta = \frac{1120 - 560}{1120}$$

$$\eta = 0.5$$

$$\eta = \eta_{carnot} \quad \therefore \text{ it is reversible engine}$$

case (iii)

$$\underline{Q_2 = 108\,kw \text{ (or) } kJ/s}$$

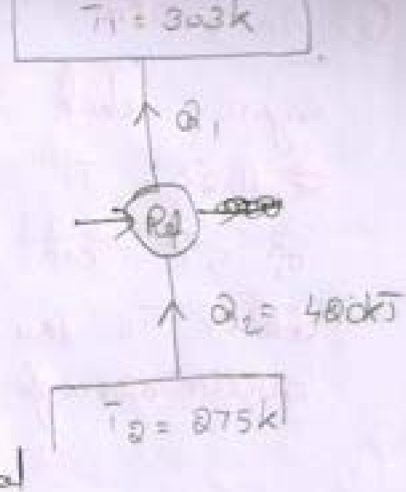
$$\eta = \frac{1120 - 108}{1120} = 0.9$$

$$\eta > \eta_{carnot}$$

$\therefore$ It is impossible engine.

7. A house hold refrigerator is maintained at a temperature of 275k. Every time the door is opened, warm material is placed inside, introducing an average of 420 kJ, but making only a small change in the temperature of the refrigerator. The door is opened 20 times a day, and the refrigerator operates at 15% of the ideal COP. The cost of work is Rs 2.50 per kW hr. what is the bill for the month of April for this refrigerator? The atm... is at 303k.

Solution



$$COP_{rev.ref} = \frac{T_2}{T_1 - T_2}$$

$$= \frac{275}{303 - 275}$$

$$= 9.82$$

$$COP_{actual} = 0.15 \times COP_{ideal}$$

$$= 1.47$$

$$COP_{actual} = \frac{Q_2}{Q_1 - Q_2}.$$

$$1.47 = \frac{420}{Q_1 - Q_2}$$

$$Q_1 - Q_2 = \frac{420}{1.47} = 285.71 \, kJ$$

$$Q_1 = 285.71 + 420 = 705.71 \, kJ$$

cost of work is 2.50 Rs per kWhr

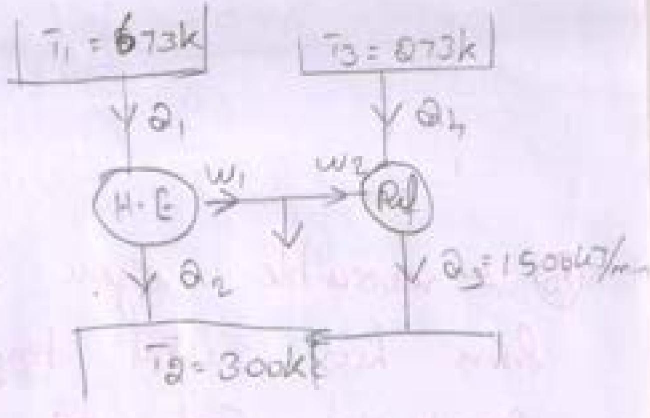
April Monthly bill for the refrigerator

$$= \frac{285.71 \times 2.50 \times 20 \times 30}{3600}$$

$$= Rs \; 119.04$$

$$\frac{kJ \times Rs \times}{3600}$$

(9) A reversible heat pump is used to maintain a temperature of 0°c in a refrigerator when it rejects the heat to the surroundings at 27°c. If the heat is removed rate from the refrigerator is 1500kJ/min. Determine the COP of the machine and work input required. If the required input to run the pump is developed by a reversible engine which receives heat at 400°c and rejects heat to atmosphere, then determine the overall COP of the system.



Given Data

$T_3 = 273k$

$T_1 = 673k$

$T_2 = 300k$

Solution

$$(COP)_{ref.rev} = \frac{T_3}{T_2 - T_3} = \frac{273}{300-273}$$

$$= 10.11$$

$$(COP) = \frac{Q_4}{W_2} = \frac{Q_3 - W_2}{W_2}$$

$$= \frac{1500 - W_2}{W_2}$$

$Q_3 - Q_4 = W_2$

$-Q_4 = W_2 - Q_3$

$$11.11 \, W_2 = 1500$$

$$W_2 = \frac{1500}{11.11} = 135.01 kJ/min$$

$= W_1$

$$\eta_{H.E_{rev}} = \frac{T_1 - T_2}{T_1} = \frac{673 - 300}{673}$$

$$= 55.42\%$$

$$\eta_{H.E} = \frac{W_1}{Q_1} \Rightarrow Q_1 = \frac{135.01}{0.55}$$

$$= 243.6\,kJ/min.$$

$$(COP)_{HP} = (COP)_{ref} + 1$$

$$= 10.11 + 1 = 11.11$$

$$\text{overall COP system} = (COP)_{HP} + (COP)_{ref}$$

$$= 11.11 + 10.11$$

$$= 21.22$$

(10) A reversible engine is supplied with heat from two constant temperature sources at 900k and 600k and rejects heat to a constant temperature sink at 300k. If the engine executes a numbers of complete cycles while developing 100kw, and rejecting 3600 KJ of heat per minute and efficiency of the engine.

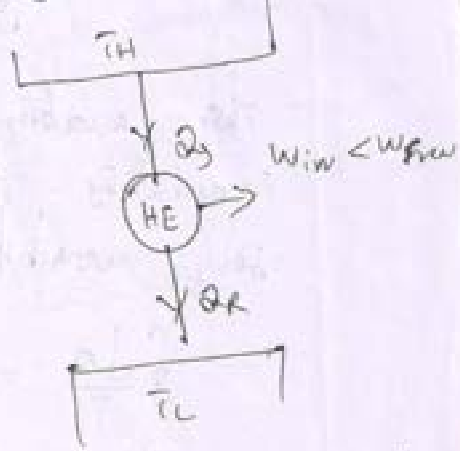
clausius inequality :

It states that " when a system undergoes a cyclic process the summation of $\frac{dQ}{T}$ around a closed cycle is less than (or) equal to zero.

Consider a engine operating between two fixed temperature reservoirs T_H and T_L. Let dQ_S unit of heat be supplied at temperature T_H and dQ_R units of heat be rejected at temperature T_L during a cycle.

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

Reversible heat engine.



irreversible heat engine

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

$$\frac{dQ_S - dQ_R}{dQ_S} \le \frac{T_H - T_L}{T_H}$$

$$1 - \frac{dQ_R}{dQ_S} \le 1 - \frac{T_L}{T_H}$$

$$\frac{dQ_R}{dQ_S} \le \frac{T_L}{T_H}$$

$$\frac{dQ_R}{T_L} \le \frac{dQ_S}{T_H}$$

$$\frac{dQ_R}{T_L} - \frac{dQ_S}{T_H} \le 0$$

$$\oint \frac{dQ}{T_S} \le 0$$

This equation is known as clausius inequality. It provides the criterion of the reversibility of a cycle.

$\oint \frac{dQ}{T} = 0$ the cycle is reversible.

$\oint \frac{dQ}{T} < 0$ the cycle is irreversible and possible.

$\oint \frac{dQ}{T} > 0$, the cycle is impossible.

Concept of entropy.

It is an index of unavailability (or) degradation of energy. This unavailability of energy is measured by entropy. It is an important thermodynamic property of the working substance.

S ↑ addition of heat

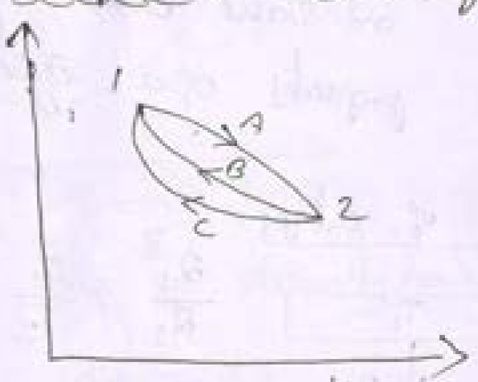
S ↓ removal of heat

∴ It is function of quantity of heat with respect to temperature.

$$ds = \frac{\text{change of heat transfer}}{\text{Absolute temperature}}$$

$$= \frac{dQ}{T} \quad kJ/k.$$

Entropy - A property of a system



For this cyclic reversible process, the entropy equation is

$$\oint \frac{dQ}{T} = 0 = \int_{1A}^{2A} \frac{dQ}{T} + \int_{2B}^{1B} \frac{dQ}{T} \rightarrow (1)$$

Let us consider the cycle 1-2-1 i completed by another reversible process 2-C-1

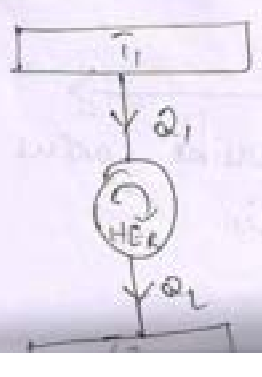
$$\oint \frac{dQ}{T} = 0 = \int_{1A}^{2A} \frac{dQ}{T} + \int_{2C}^{1C} \frac{dQ}{T} \rightarrow (2)$$

Sub (2) from (1)

$$\int_{2B}^{1B} \frac{dQ}{T} = \int_{2C}^{1C} \frac{dQ}{T}$$

from the above equation we conclude that the $\int \frac{dQ}{T}$ is the same for all reversible path between states 1 and 2 it is independent of path and fn of end states only. Hence entropy is a property of a system.

Birth of entropy



$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

$$\frac{Q_1}{T_1} - \frac{Q_2}{T_2} = 0$$

$$\frac{Q_1}{T_1} + \frac{(-Q_2)}{T_2} = 0$$

State of

$$\oint \left(\frac{dQ_R}{T}\right) = 0 \qquad ds = \frac{dQ_R}{T}$$

$$\oint ds = 0 \qquad \Delta S = \int \frac{dQ_R}{T}$$

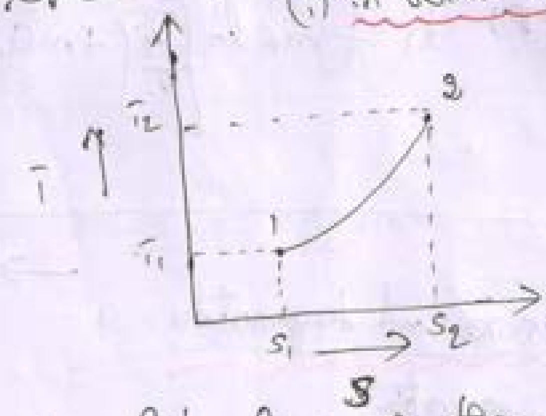
$$S_2 - S_1 = \int_1^2 \frac{dQ_R}{T}$$

Entropy of ideal gas

consider a ideal gas heated from state ① to ② and thus temperature is increased from T_1 to T_2. During the heating process, there should be some change in entropy on the gas.

Expression for change in entropy of ideal gas

(i) in terms of temperature and volume



By first law of thermodynamics

$$dQ = dw + dU$$

$$= p.dv + mC_v dT \rightarrow ①$$

Dividing equation (1) by T

$$\frac{dQ}{T} = \frac{P}{T}dV + mc_v\frac{dT}{T} \qquad \left\{ \begin{array}{l} \because \frac{dQ}{T} = ds \\ \because PV = mRT \end{array} \right.$$

$$ds = MR\frac{dv}{V} + mC_v\frac{dT}{T} \longrightarrow (2)$$

Integrating the above equation from (1) to (2)

$$\int_1^2 ds = mR\int_1^2 \frac{dV}{V} + mC_v\int_1^2 \frac{dT}{T}$$

$$[s]_1^2 = mR[\ln V]_1^2 + mC_v[\ln V]_1^2$$

$$s_2 - s_1 = mR[\ln V_2 - \ln V_1] + mC_v [\ln T_2 - \ln T_1]$$

$$\boxed{\text{change in entropy } ds = mR\ln\left[\frac{V_2}{V_1}\right] + mC_v\ln\left[\frac{T_2}{T_1}\right] \text{ W/K}} \longrightarrow (3)$$

(ii) In terms of pressure and temperature

By gas equation

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\boxed{\frac{V_2}{V_1} = \frac{P_1}{P_2}\frac{T_1}{T_2}} \longrightarrow (4)$$

substituting (4) in (3)

$$ds = mR\ln\left(\frac{P_1}{P_2}\cdot\frac{T_2}{T_1}\right) + mC_v\ln\left(\frac{T_2}{T_1}\right)$$

$$= m.R.\ln\left(\frac{P_1}{P_2}\right) + m.R.\ln\left(\frac{T_2}{T_1}\right) + m.C_v\ln\left(\frac{T_2}{T_1}\right)$$

$$= m.R.\ln\left(\frac{P_1}{P_2}\right) + m(C_p - C_v)\ln\left(\frac{T_2}{T_1}\right) + mC_v.\ln\left(\frac{T_2}{T_1}\right)$$

$$= mR.\ln\left(\frac{P_1}{P_2}\right) + m.C_p\ln\left(\frac{T_2}{T_1}\right) - mC_v.\cancel{\ln\left(\frac{T_2}{T_1}\right)} + m.C_v\cancel{\ln\left(\frac{T_2}{T_1}\right)}$$

$$\boxed{ds = m.R\ln\left(\frac{P_1}{P_1}\right) + m.C_p\ln\left(\frac{T_2}{T_1}\right)\ \text{kJ/K}} \rightarrow (5)$$

(ii) In terms of pressure and volume

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad \therefore \boxed{\frac{T_2}{T_1} = \frac{P_2}{P_1}\cdot\frac{V_2}{V_1}} \rightarrow (6)$$

substituting eq (6) value in eq (3)

$$ds = m.R\ln\left(\frac{V_2}{V_1}\right) + m.C_v\ln\left(\frac{P_2}{P_1}\cdot\frac{V_2}{V_1}\right)$$

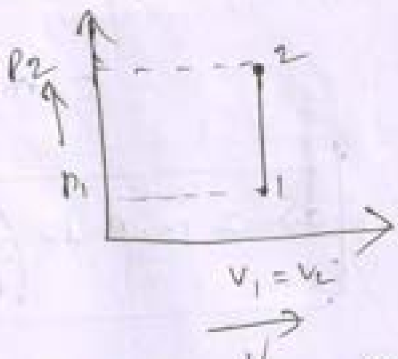
$$= m(c_p - c_v)\ln\left(\frac{v_2}{v_1}\right) + m\cdot c_v \ln\left(\frac{P_2}{P_1}\right) + m\cdot c_v \ln\left(\frac{v_2}{v_1}\right)$$

$$= m\cdot c_p \ln\left(\frac{v_2}{v_1}\right) - \cancel{m c_v \ln\left(\frac{v_2}{v_1}\right)} + m c_v \ln\left(\frac{P_2}{P_1}\right) + \cancel{m\cdot c_v \ln\left(\frac{v_2}{v_1}\right)}$$

$$\boxed{ds = m\cdot c_p \ln\left(\frac{v_2}{v_1}\right) + m c_v \ln\left(\frac{P_2}{P_1}\right)\ \text{kJ/K}} \rightarrow (7)$$

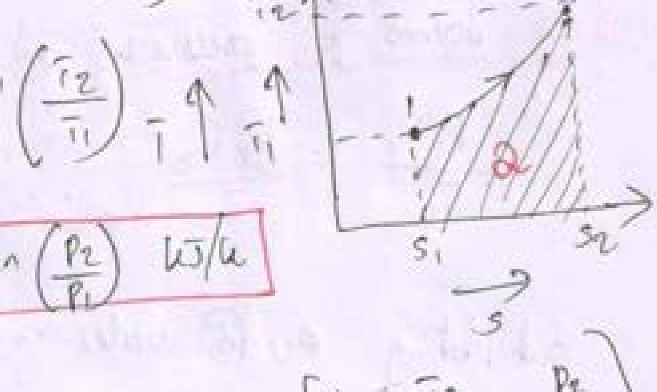
Applications of change in entropy for different processes.

(i) Constant volume process



$$ds = mR\ln\left(\cancel{\frac{v_2}{v_1}}\right)^0 + m c_v \ln\left(\frac{T_2}{T_1}\right)$$

$$ds = m c_v \ln\left(\frac{T_2}{T_1}\right)$$



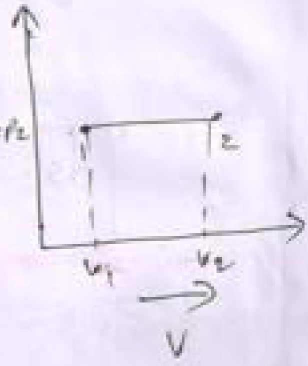
$$\boxed{ds = m c_v \cdot \ln\left(\frac{P_2}{P_1}\right)\ \text{kJ/K}}$$

$$\left[\because \frac{T_2}{T_1} = \frac{P_2}{P_1}\right]$$

(b) constant pressure process:

from eq (5)

$$ds = \cancel{mR \ln\left(\frac{P_2}{P_2}\right)}^{0} + mc_p \ln\left(\frac{T_2}{T_1}\right)$$



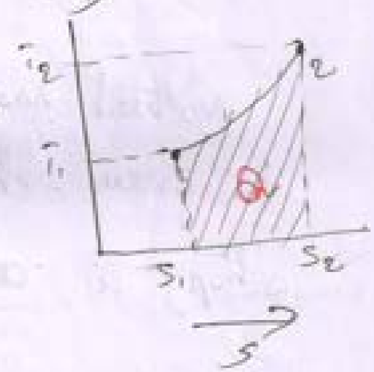
$$\frac{V_2}{V_1} = \frac{T_2}{T_1}$$

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

$$\cancel{ds = mR \ln\left(\frac{V_2}{V_1}\right) + mc_v \ln\left(\frac{V_2}{V_1}\right)} \quad \frac{V_2}{V_1} = \frac{T_2}{T_1}$$

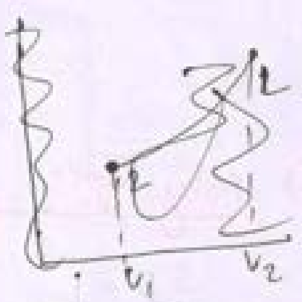
$$P_1 = P_2$$

$$\boxed{ds = mc_p \ln\left(\frac{T_2}{T_1}\right)}$$

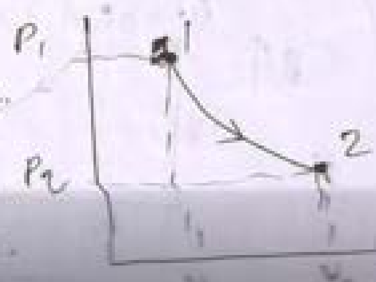


(c) constant temperature process:

$$ds = mR \ln\left(\frac{V_2}{V_1}\right) + \cancel{mc_v \ln\left(\frac{T_2}{T_1}\right)}^{0}$$



$$ds = mR \ln\left(\frac{V_2}{V_1}\right) \text{kJ/K.}$$

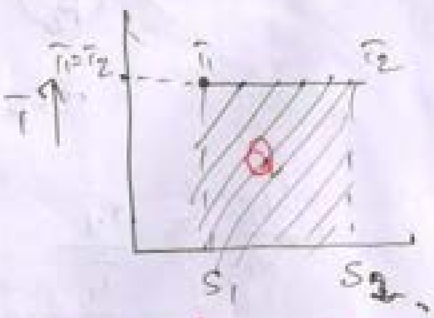


multiplying and dividing by $\frac{P_2}{T}$ on right hand side.

$$ds = \frac{mRT \ln\left(\frac{V_2}{V_1}\right)}{T}$$

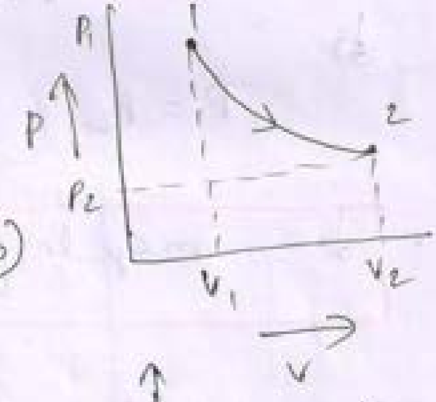
$\because Q = mRT\left(\ln\frac{V_2}{V_1}\right)$

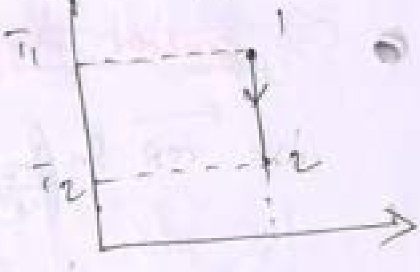
$$\boxed{ds = \frac{Q}{T}}$$



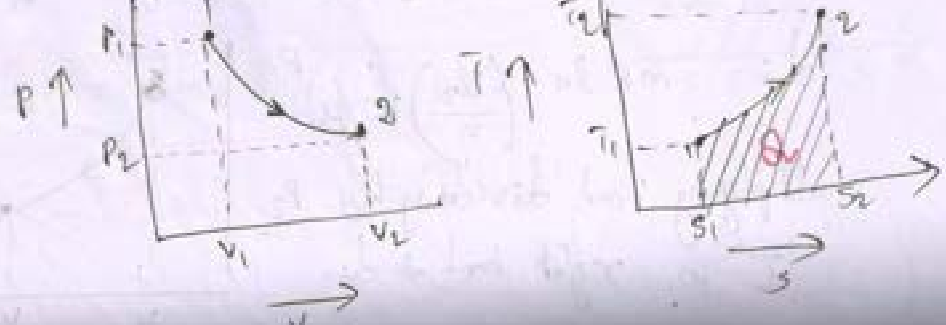
(d) Reversible adiabatic (or) isentropic process:

No heat transfer during the process, change in entropy is zero ($ds = 0$)





(e) Polytropic process:



Heat transfer during polytropic process is given by

$$dQ = \left[\frac{\gamma - n}{\gamma - 1}\right] \times W$$

$$dQ = \left[\frac{\gamma - n}{\gamma - 1}\right] \times P dV$$

$\gamma \rightarrow$ Adiabatic index
$n \rightarrow$ Polytropic index
$W \rightarrow$ work done.

Dividing both side by 'T'

$$\frac{dQ}{T} = \left[\frac{\gamma - n}{\gamma - 1}\right] \times \frac{P}{T} \times dV$$

$$ds = \left[\frac{\gamma - n}{\gamma - 1}\right] \times \frac{mR}{V} dV$$

$PV = mRT$
$\frac{P}{T} =$

Integrating both sides from ① to ②

$$\int_1^2 ds = \left[\frac{\gamma - n}{\gamma - 1}\right] \times mR \int_1^2 \frac{dV}{V}$$

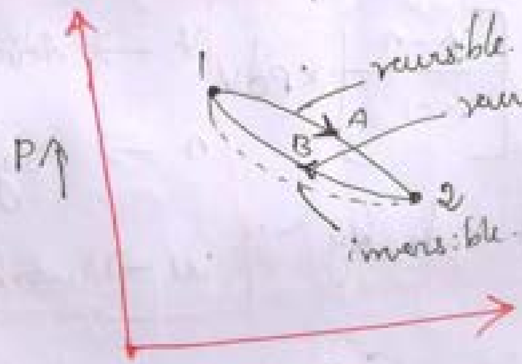
$$S_2 - S_1 = \left[\frac{\gamma - n}{\gamma - 1}\right] \times mR \left[\ln V\right]_1^2$$

$$\boxed{ds = \left[\frac{\gamma - n}{\gamma - 1}\right] \times mR \ln \left[\frac{V_2}{V_1}\right]}$$

Principle of increase of Entropy

we know that change of entropy for reversible process

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



V

System undergoes a change of state from ① to ② by a reversible process 1-A-2 and returns to state ① either by an internally reversible process 2-B-1 (or) by an irreversible process 2-C-1

for the reversible cycle 1-A-2-B-1

$$\int_{1A}^{2A} \frac{dQ}{T} + \int_{2B}^{1B} \frac{dQ}{T} = 0 \rightarrow ①$$

for irreversible cycle 1-A-2-C-1, clausius inequality is applied as follows

$$\int_{1A}^{2A} \frac{dQ}{T} + \int_{2C}^{1C} \frac{dQ}{T} \le 0 \rightarrow ②$$

subtracting eq ① from ②

$$\int_{2C}^{1C} \frac{dQ}{T} - \int_{2B}^{1B} \frac{dQ}{T} \le 0 \rightarrow ③$$

on reversing the limit and rearranging the equation

$$\int_{1B}^{2B} \frac{dQ}{T} \geq \int_{1C}^{2C} \frac{dQ}{T} \longrightarrow (4)$$

Since the process 2-B-1 is reversible

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

Substituting this value in eq (4) equation

$$\int_{1}^{2} ds \geq \int_{1C}^{2C} \frac{dQ}{T}$$

(or)

$$ds \geq \frac{dQ}{T} \longrightarrow (5)$$

where the equality sign refers the reversible process & inequality sign refers the irreversible process. So the effect of irreversibility is always to increase the entropy of the system.

From this equation, the entropy of a system increases when the heat is supplied to the system.

Entropy of an isolated system can never decrease. It always increases and remains constant only when the process is reversible. This is known as Principle of increase of entropy.

Applications of Entropy Principle:

1. Transfer of heat through a finite temperature difference.
2. mixing of two fluids.
3. maximum work obtainable from two finite bodies at temperatures T_1 & T_2.

Problem

2 kg of water at 90°c is mixed with 3kg of water at 10°c in an isolated system. Calculate the change of entropy due to the mixing process.

Given Data:

$m_1 = 2kg \qquad m_2 = 3kg$

$T_1 = 90°c \qquad T_2 = 10°c = 283k$

$\Delta S = \Delta S_1 + \Delta S_2$

To find:

$\Delta S = ?$

Solution

$$T_f = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{m_1 c_1 + m_2 c_2}$$

CP of water $= 4.187$ kJ/kgk

$$T_f = \frac{2 \times 4.187 \times 363 + 3 \times 4.187 \times 283}{2 \times 4.817 + 3 \times 4.187}$$

$$\boxed{T_f = 314k}$$

$$\Delta S = mc \ln\left(\frac{T_f}{T_1}\right) + m_2 c_2 \ln\left(\frac{T_f}{T_2}\right)$$

$= 2 \times 4.187 \times \ln\left(\frac{314}{36[illegible]}\right) + 3 \times 4.18[illegible]$

$=$ [illegible]

Ten grams of water at 20°c is converted into ice at −10°c at constant atmospheric pressure. Assuming specific heat of liquid water to remain constant at 4.2 J/kg K and that of ice to be half of the value and taking the latent heat of fusion of ice at 0°c to be 335 J/kg. calculate the total entropy change of the system

C_p of ice = 2.093 J/kg K.

Given Data:

$m = 10g$

$T_w = 20°c$

$T_{ice} = -10°c$

$C_{p_1} = 4.2 J/kgK.$

$h_{fg} =$

To find:

$\Delta s = ?$

solution:

Heat absorbed from the water to form 10g of ice

1kJ = 1000J

Q = Heat absorbed from the liquid
+ Latent heat
+ Heat absorbed from
the solid phase.

$Q = m_w c_{pw} (T_1 - 0) + h_{fg}$
$+ m_{ice} c_{p\,ice} (0 - T_2)$

$= 10 \times 4.2 (20 - 0) + 335 + 10 \times 2.093$
$(0 - (-10))$
$= 0.84 + 3.35 + 0.21$

$\boxed{Q = 4399.3\,J}$ 4.4 J

Entropy change of atmosphere
$\Delta S_{system} = \frac{Q}{T}$

$= \frac{4399.3}{273} =$

$\boxed{\Delta S_{system} = 16.12\ J/K}$ = 0.016 J/K

Entropy change of the system from
20°C to 0°C

$\Delta S_1 = m_w c_{pw} \ln\left(\frac{T_0}{T_1}\right)$

$= 10 \times 4.2 \ln\left(\frac{273}{293}\right)$

$\boxed{\Delta S_1 = -2.77\,J/K}$ = -2.96×10^{-3} J/K.

Entropy change of the system from
0 to −10°C

$\Delta S_2 = m_{ice} \, c_{p\,ice} \ln\left(\frac{T_2}{T_0}\right)$

$= 10 \times 2.093 \ln\left(\frac{263}{273}\right)$

$= -0.781 J/k.$ $= -7.8 \times 10^{-5}$

$\therefore$ Total entropy change $\Delta S = \Delta S_1 + \Delta S_2 + \Delta S_{system}$

$= -2.97 - 0.781 + 16.12$

$$\boxed{\Delta S = 12.369 \ J/k}$$

Satisfactorily

50 kg of water is at 313k and enough ice at -5°c is mixed with water in an adiabatic vessel such that at the end of the process all the ice melts and water at 0°c is obtained. Find the mass of ice required and the entropy change of water and ice. Given Cp of water = 4.2 kJ/kg-k, Cp of ice = 2.1 kJ/kg.k. and latent heat of ice = 335 kJ/kg.

Energy balance

$$m_w c_{pw} T_1 + m_i c_{pi} T_2 + m_i \cdot L = (m_w + m_i) c_{pw} T_3$$

$$(50 \times 4.2 \times 313) + (m_{ice} \times 2.1 \times 268) + m_{ice} \times 335 = (50 + m_{ice}) \times 4.2 \times 273$$

$$65730 + 562.8\, m_{ice} + 335\, m_{ice} = 1146.6\, m_{ice} + 57330$$

$$65730 + 897.8\, m_{ice} = 1146.6\, m_{ice} + 57330$$

$$1146.6\, m_{ice} - 897.8\, m_{ice} = 65730 - 57330$$

$$\boxed{m_{ice} = 33.76\ kg}$$

change in entropy of water

$$\Delta S_w = m_w c_{pw} \ln\left(\frac{T_1}{T_3}\right)$$

$$= 50 \times 4.2 \ln\left(\frac{313}{273}\right)$$

$$= 28.714\ kJ/K$$

change in entropy of ice ΔS_{ice}

$$= m_{ice} c_{pice} \ln\left(\frac{T_2}{T_3}\right) + \frac{m_{ice} L}{T_3}$$

$$= \cancel{4.36}\,33.76 \times 2.1 \ln\left(\frac{278}{258}\right)$$

$$= 1.310 + 41.427 + \frac{39.36 \times 335}{273}$$

$$\boxed{\Delta S:G = \cancel{4.12\,kJ}/k}$$

$42.73\ kJ/k$

<u>Availability</u> (maximum useful energy obtained from source)

$$\eta_{HE} = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1} \rightarrow (1)$$

$$\eta_{HE} = \frac{W}{Q} \rightarrow (2)$$

Equate (1) & (2)

$$\frac{W}{Q} = 1 - \frac{T_2}{T_1}$$

$$\text{useful energy } (W) = \left(1 - \frac{T_2}{T_1}\right) Q.$$

$$\text{Available energy } A \cdot E = \left(1 - \frac{T_2}{T_1}\right) Q$$

$$T_2 = T_0$$

$$A \cdot E = \left(1 - \frac{T_0}{T_1}\right) Q.$$

$$= Q - \frac{T_0}{T_1} Q$$

$$\boxed{\therefore \text{ Entropy Principle } \Delta S = \frac{Q}{T_1}}$$

$$\boxed{A.E = Q - T_0 \Delta S}$$

Unavailable Energy:

$$U.A.E = \text{Total heat energy} - \text{Available energy}$$

$$= Q - [Q - T_0 \Delta S)$$

$$= T_0 \Delta S$$

unavailable energy = loss in available energy (or) Irreversibility (or) Principle of entropy generation.

Closed system

$$\text{Availability } \phi = Q - T_0 \Delta S$$

open system

$$\text{Availability } B = (h_1 - h_2) - T_0 (S_1 - S_2)$$

Irreversibility:

$$\boxed{I = W_{max} - W_{act}}$$

problem:

A single stage air turbine is to operate with air inlet pressure and [illegible] [illegible] [illegible] bar and [illegible] K. During the expansion the turbine losses are 20 kJ/kg to the surroundings which is of 1 bar and 300k. For 1 kg of mass flow rate determine (i) decrease in availability (ii) maximum work (iii) the irreversibility.

Given Data:

$P_1 = 1 \text{ bar}$

$T_1 = 600k$

$Q = -20 \text{ kJ/kg}$

$P_2 = 1 \text{ bar}$

$T_2 = 300k$

$m = 1 \text{ kg}$

To find

(i) Decrease in availability $\psi - \psi_2 = ?$

(ii) Maximum work $W_{max} = ?$

(iii) irreversibility $I = ?$

Solution

$$\Delta S = S_2 - S_1 = m \left[c_p \ln \left(\frac{T_2}{T_1} \right) - R \ln \left(\frac{P_2}{P_1} \right) \right]$$

$$= 1 \left[1.005 \ln \left(\frac{300}{600} \right) - 0.287 \ln \left(\frac{1}{1} \right) \right]$$

$$= -0.697 \text{ kJ/kgk}.$$

ADDITIONAL SHEET

DESIGN OF R.C ELEMENTS

CONCRETE

* Mixing of cement + Coarse Aggregate + fine Aggregate
* Grade of cement → 33, 43, 53
* Coarse Aggregate → 20 mm, 40 mm

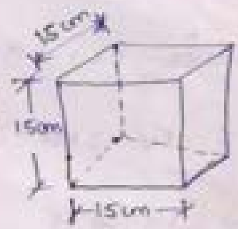
Grade of Concrete:

Mix M_{15} → Represents compressive strength of concrete @

M_{20} 28 days of curing of 150 × 150 × 150 mm cube

M_{25}

M_{30}



* For M_{15} Grade of concrete After 28 days curing the compressive stress = 15 N/mm²

* If Grade of concrete is Increased ⇒ The compressive stress will also be Increased like 20 N/mm² − M_{20}

25 N/mm² − M_{25}

* Now Min. Requirement for the grade of concrete is M_{20} and not M_{15} → It is for previous.

Availability change (or) decrease in availability

$$\psi_1 - \psi_2 = m\left[(h_1 - h_2) - T_0(s_1 - s_2)\right]$$

$$= m\left(c_p(T_1 - T_2) - T_0(s_1 - s_2)\right]$$

$$= 1 \times 1.005(600 - 300) - 300(-0.692)]$$

$$= 510.6 \text{ kJ/kg}$$

SFEE

$$h_1 + Q = h_2 + W$$

$$W = m\left[(h_1 - h_2) + Q\right]$$

$$= m\left[c_p(T_1 - T_2) + Q\right]$$

$$= 1\left[1.005(600 - 300) - 20\right]$$

$$\boxed{W = 281.5 \text{ kJ/kg}}$$

Irreversibility

$$I = W_{max} - W$$

$$= 510.6 - 281.5$$

$$= 229.1 \text{ kJ/kg}$$

By energy balance

$$m_1 u_1 + m_2 u_2 = m_3 u_3$$

At 0.2MPa

$$h_g = h_1 = 2706.7 kJ/kg$$

$$u_1 = h_1 - p_1 v_1 = 2706.7 kJ/kg$$

At 0.5MPa

$$h_2 = hf + x_2 hfg$$

$$v_2 = 2327.03$$

$$h_3 = h_m = \frac{5 \times 2706.7 + 10 \times 2327.03}{15}$$

$$\boxed{h_3 = 2453.6 kJ/kg}$$

<u>12.16</u>

3.

$m_1 = 5kg$	$m_2 = 10kg$
$x_1 = 1.0$	$x_2 = 0.8$
$P_1 = 0.2MPa$	$P_2 = 0.5MPa$

At $0.2MPa$

$$v_g = v_1 = 0.8857$$

$$V_1 = m_1 v_1 = 5 \times 0.8857 = 4.4285 m^3$$

At $0.5MPa$

$$v_2 = v_f + x_2(v_g - v_f)$$

$$= 0.30101 m^3/kg$$

$$V_2 = m_1 v_1 = 10 \times 0.30101$$

It is adiabatic expansion

$$s_1 = s_2 = 6.926 \ kJ/kg.K$$

for 0.1 bar

$s_f = 0.649$ $\qquad s_{fg} = 7.502 \ kJ/kg.K$

$s_g = 8.151$

$s_g > s_2$

$\therefore$ It is wet steam.

$$6.926 = 0.649 + x_2 (7.502)$$

$$\boxed{x_2 = 0.8367}$$

$h_2 = 2194 \ kJ/kg$ $\qquad u_2 = v_f + x_2 (v_g - v_f)$

$V_2 = \sqrt{2(h_1 - h_2)}$

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

$= 3(3410.6 - 2240)$

$= 3511.8$ kJ/sec

⑥ <u>Given Data:</u>

$P_1 = 1 \text{MPa} \ (10 \text{bar}) \quad T_1 = 250°c$

$P_2 = 0.1 \text{bar} \quad \dot{m} = 1 \text{kg/s}$

<u>Solution</u>

<u>SFEE</u>

$$\dot{m}\left(h_1 + \cancel{\frac{v_1^2}{2}}^{0} + \cancel{z_1 g}^{0}\right) + \cancel{Q} = \dot{m}\left(h_2 + \frac{v_2^2}{2} + \cancel{z_2 g}\right) + \cancel{W}$$

$$\dot{m}(h_1) = \dot{m}\left(h_2 + \frac{v_2^2}{2}\right)$$

$h_1 = 3410.6\ kJ/kg$;

$S_1 = 6.799\ kJ/kg.k$

It is adiabatic expansion $S_1 = S_2$

$S_2 = 6.799\ kJ/kg.k.$

<u>At 0.2 bar</u>

$Sf = 0.832\ kJ/kg.k$

$Sfg = 7.077\ kJ/kg.k.$

$Sg = 7.909.$

$S_2 < Sg.$

∴ It is in the saturated region

∴ To find dryness fraction

$S_2 = Sf + x_2 (Sfg)$

for 9 MPa = 90 bar ; $T_1 = 400°c$

superheated steam table.

$h_2 = 3121.2 \ kJ/kg$

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

$= 3(3121.2 - 185.7)$

$= 2995.5 \ kJ/sec.$

9

Given Data:

$\dot{m} = 3 kg/sec$

$P_1 = 70 bar$

$T_1 = 500°c$

$P_2 = 0.2 bar$

Diameter of tube $= 0.03m$

$\dot{V} = \frac{3}{1000} \; m^3/sec$

~~1 litre = 1000 m³~~

$1 m^3 = 1000$ litre

$P_2 = 9MPa \quad T_2 = 400°c$

SFEE

$$\dot{m}\left[h_1 + \cancel{\frac{V_1^2}{2}} + \cancel{z/g}\right) + Q = \dot{m}\left[h_2 + \cancel{\frac{V_2^2}{2}} + \cancel{z_2 g}\right] + W$$

$$\dot{m} = \frac{\text{volume rate}}{v_1} = m^3/sec \times \frac{kg}{m^3}$$

$v_1 =$ Specific volume of Compressed liquid water at 10 MPa and 30°c = v_f at 30°c

from steam table

$v_f = 0.001004 \; m^3/kg$

$$\text{workdone } (W) = \frac{P_1 u_1 - P_2 u_2}{1.13 - 1}$$

$$= \frac{1100 \times 0.17739 - 100 \times 1.48}{0.13}$$

$$(W) = 362.53 \text{ kJ}$$

change in internal energy

$$\Delta u = u_1 - u_2$$

$$= (h_1 - P_1 u_1) - (h_2 - P_2 u_2)$$

$$= (h_1 - h_2) - (P_1 u_1 - P_2 u_2)$$

$$= [2779.7 - 2390.90]$$

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

$$= 417.5 + (0.874 \times 2257.9)$$

$$\boxed{h_2 = 2390.90 \text{ kJ/kg}}$$

$$= [1100 \times 0.17735 - 100 \times 1.48]$$

Solution:

From steam table at 1.1 MPa = 11 bar [dry saturated]

$$v_1 = v_{g_1} = 0.17739 \ m^3/kg$$

$$h_1 = h_g = 2779.7 \ kJ/kg$$

From polytropic relation

$$p_1 v_1^{1.13} = p_2 v_2^{1.13}$$

W.K.T

$$\frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^n$$

$$v_2 = \left(\frac{p_1}{p_2}\right)^{1/1.13} \times v_1$$

$$= 0.17739 \left(\frac{11}{1}\right)^{1/1.13}$$

(iii) At a temperature of 199.9°c

At $P_f = 10$ bar $t_{sat} = 179.9°c$

$T_f = 199.9°c$

$T > t_{sat}$

$\therefore$ superheated steam

At 10 bar $T = 199.9°c$

$h = 2826.8$ kJ/kg

$s = 6.692$ kJ/kg·k

$v = 0.2059$ m^3/kg

$$\rho = \frac{1}{v} = \frac{1}{0.2059} = 4.856 \text{ kg/m}^3$$

$$\text{Density } (\rho) = \frac{1}{v} = \frac{1}{0.1556} = 6.426 \text{ kg/m}^3$$

$$\text{Internal energy } (U) = h - pv$$

$$= 2373.48 - 1000 \times 0.1556$$

$$= 2217.88 \text{ kJ/kg}$$

$$\text{Entropy } (S) = S_f + x\, S_{fg}$$

$$= 2.138 + [0.8 \times 4.445)$$

$$= 5.694 \text{ kJ/kg·k}$$

(ii) Dry and saturated :

$$h = h_g = 2776.2 \text{ kJ/kg}$$

$$v = v_g = 0.19430 \text{ m}^3\text{/kg}$$

~~10~~ 12 & 16

Q. Given Data:

$m = 1 kg$ $\quad C_{ps} = 2.25\ kJ/kg$

$P_1 = 10 bar$

To find:

$h = ?$ $\quad s = ?$

$u = ?$

$\rho = ?$

$v = ?$

Solution:

(i) wet and 0.8 dry

From steam tables at $P_1 = 10 bar$

$h_f = 762.6\ kJ/kg$ $\quad v_f = 0.001127\ m^3/kg$

$v_g = 0.19430\ m^3/kg$

$u_1 = h_1 - p_1 v_1$

$= 2203.22 \text{ kJ/kg}$

$Q = \Delta u = u_2 - u_1$

$-1320 = 3(u_2 - 2203.22)$

$\boxed{\therefore u_2 = 1763.22 \text{ kJ/kg}}$

<u>for 18 bar</u> $t_{sat} = 207.1$

$T_1 = 207.1 + 273 = 480.1\text{K}$

<u>Formula for constant volume process</u>

$u_2 - u_1 = c_v (T_2 - T_1)$

$1763.22 - 2203.22 = 2.1(T_2 - 480.1)$

~~1763~~

$\boxed{T_2 = 270.576\text{k}}$

7. Given Data:

mass = 3kg

pressure = 18 bar

Volume (V) = 0.2550 m^3

$\boxed{Q = ?}$

To find

$x = ?$

$U_2 = ?$

$P = ?$

$S_2 - S_1 = ?$

workdone = ?

$u = 393.09$ kJ/kg.

<u>From steam table. corresponding to 7 MPa</u> = 70 bar

$v_f = 0.00135$ m³/kg $h_f = \cancel{1267}$ 1267.4 kJ/kg

$v_g = 0.0\cancel{27}368$ m³/kg $h_{fg} = 1506.0$ kJ/kg.

$$v = v_{f_2} + x(v_{g_2} - v_{f_2})$$

$$0.0025 = 0.00135 + x($$

$$\boxed{x_2 = 0.441}$$

$$v = 1.316.$$

$$Q = \cancel{W}^{0} + \Delta u$$

Given Data:

volume = constant

workdone = 0 (volume is constant)

Specific volume of mixture

$$v = \frac{V}{m} = \frac{0.03}{12} = 0.0025\ m^3/kg$$

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

At 80 kPa = 0.8 bar.

$v_f = 0.001039\ m^3/kg$

$v_g = 2.0869$

$v = v_f + x(v_g - v_f)$

$1810.85 m_2 = 241.81$

$$m_2 = \frac{241.81}{1810.85} =$$

$$\boxed{m_2 = 0.1335}$$

$$W_T = 1(h_1 - h_2) + (1 - m_1)(h_2 - h_3)$$

$$+ (1 - m_1 - m_2)(h_3 - h_4)$$

$$= 797.48 \text{ kJ/kg}$$

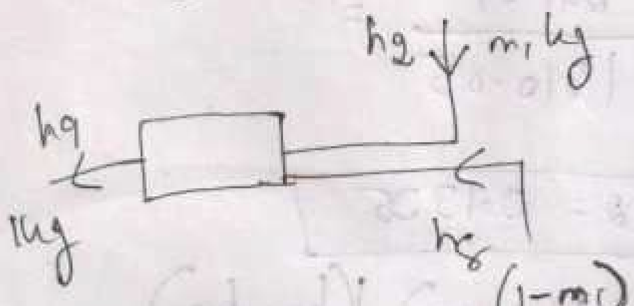
$$Q_{in} = (h_1 - h_9) = 2391.48 \text{ kJ/kg}$$

~~Eagdx~~ = ew

$$w_p = 1(h_{10} - h_9) + (1 - m_1)(h_8 - h_7)$$

$$+ (1 - m_1 - m_2)(h_6 - h_5)$$

Energy for hp heater



$$m_1(h_2-h_9) + (1-m_1)(h_9-h_8) = 1\text{kg}\; h_9$$

$$m_1(2716.9 - 632.2) + (1-m_1)(632.2 - 419.04) = 632.2$$

$$2084.7m_1 + 213.16 - 213.16m_1 = 632.2$$

$$1871.54m_1 = 419.04$$

$$\boxed{m_1 = 0.22\text{kg}}$$

$s_1 = s_2 = s_3 = s_4$

$$6.7664 = 1.8418 + x_2 \times 4.9961$$

$$\boxed{x_2 = 0.986}$$

$$h_2 = 632.2 + 0.986 \times 2114.3$$

$$\boxed{h_2 = 2716.9\ kJ/kg}$$

$$6.7664 = 1.3069 + x_3 \times 6.0480$$

$$\boxed{x_3 = 0.903}$$

$$h_3 = 419.04 + 0.903 \times 2257.0$$

$$\boxed{h_3 = 2457.1\ kJ/kg}$$

$$6.7664 = 0.6493 + x_4 \times 7.5010$$

$$\boxed{x_4 = 0.816}$$

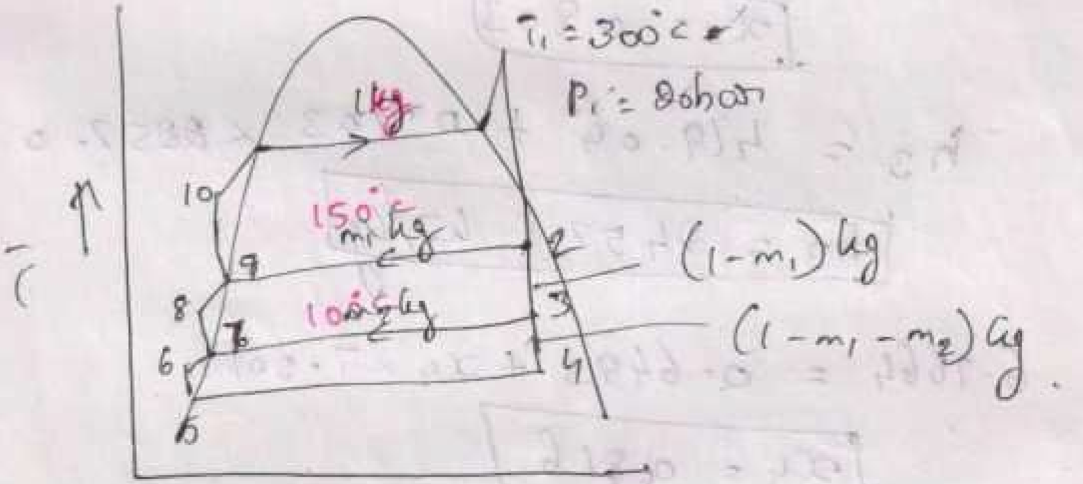
Temperature rise per heater $= \frac{166}{3} = 55^\circ c$

Temperature at which the first heater operates $= 212 - 55^\circ c = 157^\circ c$

$= 150^\circ c$

Temperature at which the second heater operates $= 157 - 55^\circ c$

$= 102^\circ c = 100^\circ c$



15. Given Data:

$P_1 = 20 bar$

$T_1 = 300^\circ c$

$P_4 = 0.1 bar$

To find:

$x_4 = ?$

$w_{net} = ?$

$\eta_{cycle} = ?$

steam rate = ?

Solution:

$P_1 = 20 bar$

$t_{sat} = 212^\circ c$

$T_1 > t_{sat}$

$$W_T = 1(h_1 - h_2) + (1-m)(h_2 - h_3)$$

$$= (3232.5 - 2830) + (1 - 0.169)(2830 - 2240)$$

$$= 402.5 + (0.831 \times 590)$$

$$\boxed{W_T = 892.79 \text{ kJ/kg}}$$

$$W_p = (1-m)(h_5 - h_4) + (h_7 - h_6)$$

$$= (1 - 0.169)(192.29 - 191.8) + (642.83 - 640.1)$$

$$= 4.05 \text{ kJ/kg}$$

$$W_{net} = W_T - W_P$$

$$= 892.79 - 4.05$$

$$\boxed{W_{net} = 888.74 \text{ kJ/kg}}$$

w_{in} (pump 1) $= h_5 - h_4$

$h_5 = 0.4949 + 191.8$

$\boxed{h_5 = 192.29 \text{ kJ/kg}}$

Stage: 6

$h_6 = h_f = 640.1 \text{ kJ/kg}$ $[P_6 = 5 \text{ bar} = P_2$

$v_f = v_6 = 0.001061$

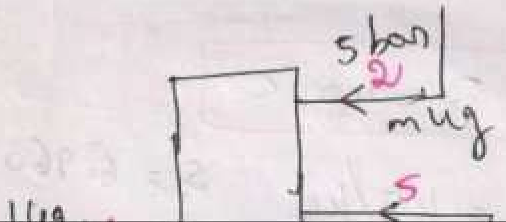
Stage: 7

w_{in} (pump 2) $= h_7 - h_6 = v_6 (P_7 - P_6)$

$h_7 = 0.001061 (3000 - 500) + 640.1$

$\boxed{h_7 = 648.83 \text{ kJ/kg}}$

Energy Balance

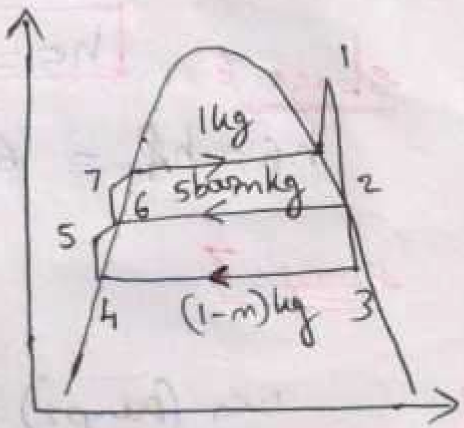


13. Given Data:

$P_1 = 30$ bar

$T_1 = 400°C$

$P_3 = P_4 = 0.1$ bar



To find:

$W_T = ?$

$\eta_{cycle} = ?$

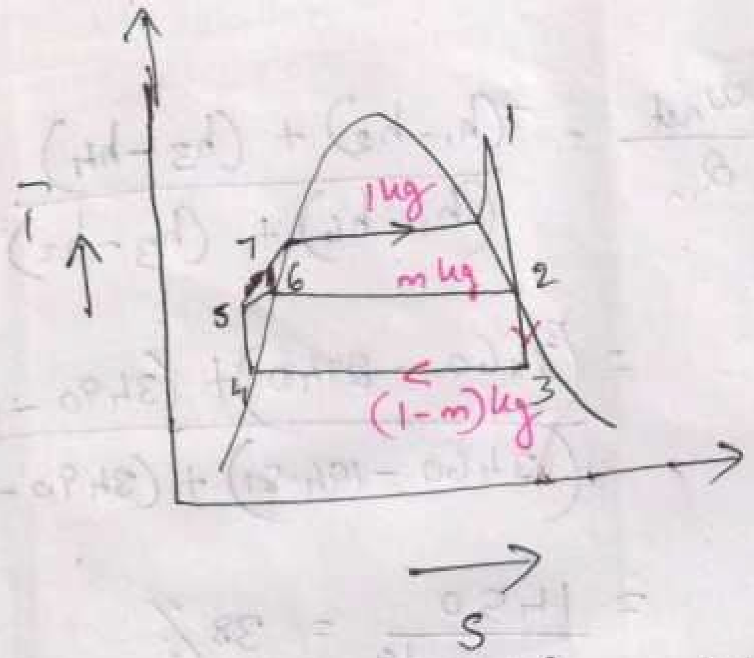
steam rate $= ?$

Solution:

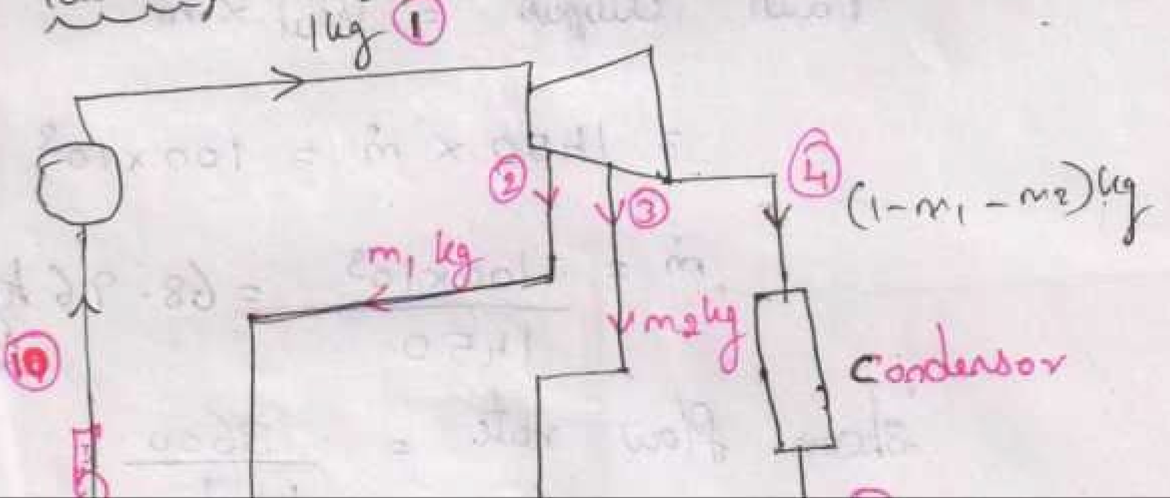
stage:1 At $\boxed{P_1 = 30 \text{bar} \quad T_1 = 400°C}$

$S_1 = 6.960$ kJ/kg.k

$h_1 = 3230.9$ kJ/kg



Two stage Regenerative cycle



$$\eta_{cycle} = \frac{W_{net}}{Q_{in}} = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_6) + (h_3 - h_2)}$$

$$= \frac{(3460 - 2940) + (3490 - 2560)}{(3460 - 194.81) + (3490 - 2940)}$$

$$= \frac{1450}{3815.19} = 38\%$$

$$\text{Power Output} = W_{net} \times \dot{m}$$

$$= 1450 \times \dot{m} = 100 \times 10^3$$

$$\dot{m} = \frac{100 \times 10^3}{1450} = 68.96 \text{ kg/s}$$

$$\text{steam flow rate} = \frac{3600}{W_{net}}$$

Power output = 100 MW = 100×10^3 kW
(or)
kJ/s

= $W_{net} \times \dot{m}$

<u>from mollier chart</u>

At $P_1 = 30$ bar $T_1 = 500°C$

$h_1 = 3460$ kJ/kg

At $P_2 = 5$ bar $s_1 = s_2$

$h_2 = 2940$ kJ/kg

At $P_2 = P_3 = 5$ bar $T_3 = 500°C$

$h_3 = 3490$ kJ/kg

At $P_4 = 0.1$ bar $s_3 = s_4$

$h_4 = 2560$ kJ/kg

$$w_T = (h_1 - h_2) + (h_3 - h_4)$$

$$= 1800 \text{ kJ/kg}$$

$$w_P = 15.1399 \text{ kJ/kg}$$

$$w_{net} = w_T - w_P$$

$$= 1784.86$$

$$Q_3 = (h_1 - h_6) + (h_3 - h_2)$$

$$= (3455 - 206.9399) + (3590 - 2785)$$

$$= 4053.06 \text{ kJ/kg}$$

$$\eta_{ther} = \frac{w_{net}}{Q_{in}} = 0.44$$

$$Q = h_1 - h_4 = 3159.3 - 175.89$$

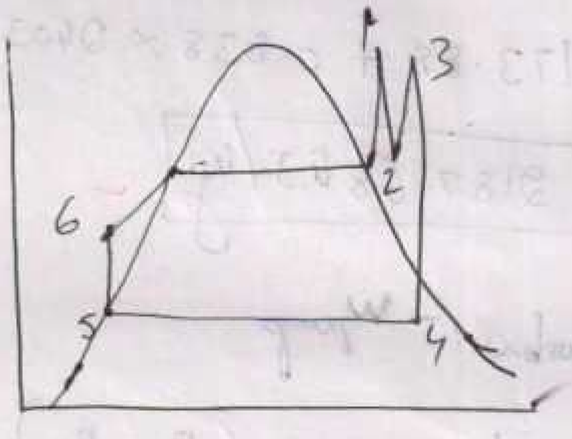
$$= 2983.4\ kJ/kg$$

$$\eta_{cycle} = \frac{w_{net}}{Q_1} = \frac{969.61}{2983.4}$$

$$= 32.5\%$$

16 marks

10. Given Data:



$P_1 = 150\ bar$

$T_1 = 550°C$

$P_4 = 0.1\ bar$

$x_4 = 0.95$

$T_3 = T_1$

$h_1 = 3450\ kJ/kg$

~~stage: 2~~

stage: 2

$\boxed{P_2 = 0.08 \text{ bar}}$

$s_1 = s_2 = 6.9917$

$6.9917 = 0.5926 + x_2 \times (7.636)$

$\boxed{x_2 = 0.838}$

$h_2 = 173.88 + 0.838 \times 2403.1$

$\boxed{h_2 = 2187.68 \text{ kJ/kg}}$

$w_{net} = w_{turbine} - w_{pump}$

$w_{pump} = h_4 - h_3 = v_3 (P_4 - P_3)$

N·m/kg   kg/sec

N·m/kg ×

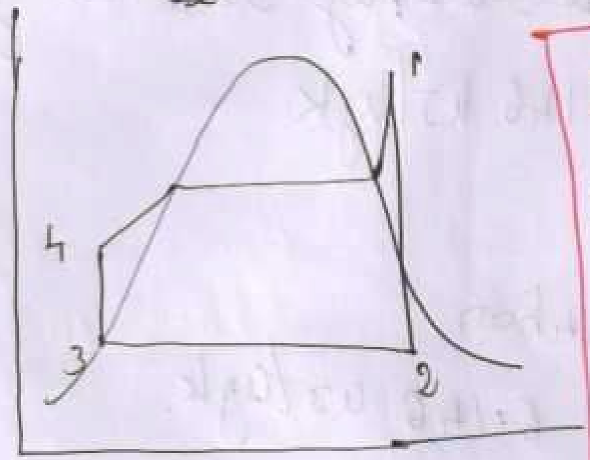
1 J = N/m²   J/kg × kg/S

(12) Given Data:

$P_1 = 20$ bar

$T_1 = 360°C$

$P_2 = 0.08$ bar



If $\eta_p = 80\%$; $\eta_T = 80\%$

$w_p = \frac{2.008}{0.8}$

$= 2.51$ kJ/kg

$W_T = 0.8 \times 777.29$

$W_{net} = 777.29 - 2.51$

$= 774.78$ kJ/kg

% $= 969.61 - 774.78$

To find:

(i) Wnet

$\eta = ?$

(ii)

Stage: 1

$P_1 = 20 MPa = 200 bar$

$T_1 = 500^\circ C$

$h_1 = \cancel{3060.5 \, kJ/kg}$ $3241.1 \, kJ/kg$

$S_1 = 6.146 \, kJ/kgK$

Stage: 2

$P_2 = P_3 = 14 bar$

$S_1 = S_2 = 6.146 \, kJ/kgK.$

$h_2 = 2660 \, kJ/kg$

work done $= (h_1 - h_2) + (h_3 - h_4)$

$=$

$s_4 = s_f + x_4 s_{fg}$

$= 0.476 + (0.9 \times 7.920)$

$\boxed{s_4 = 7.604 \text{ kJ/kgK}}$

stage: 3

$\underline{s_3 = s_4} = 7.604$

$T_3 = 500^\circ C$

$P_3 = 14 \text{ bar}$

$h_3 = 3473.9 \text{ kJ/kg}$

stage: 5

$P_5 = 0.05 \text{ bar}$

$h_f = h_5 = 137.8$

$v_f = v_5 = 0.001030 \text{ m}^3/\text{kg}$

stage: 6

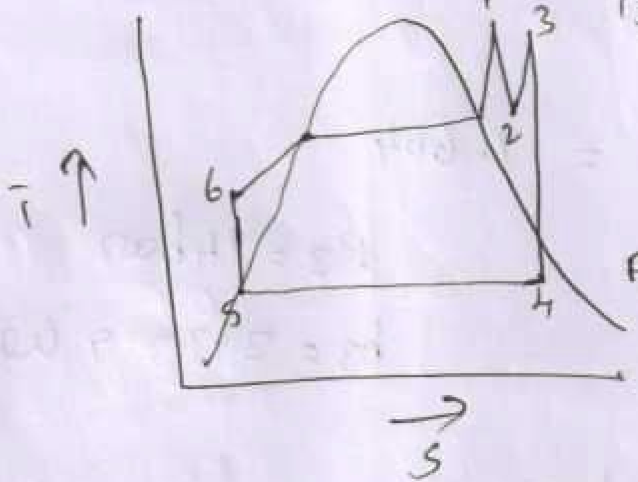
200 bar

6. <u>Given Data:</u>

$P_1 = 80\ MPa$

$T_1 = 500^\circ C$

$T_3 = 500^\circ C$



$P_4 = 0.005\ MPa$

$x_4 = 0.90$

<u>To find:</u>

$P_2 = ?$

$\eta = ?$

$\omega = ?$

19 bar, 350°C   19 bar 400°

20 bar, 350°C   20 bar 400°

$$h_1 = 3160.84 \text{ kJ/kg}$$

$$h_3 = h_f = 173.9 \text{ kJ/kg}$$

$$w_p = h_4 - h_3$$

$$= v_3 (P_4 - P_3)$$

$$\boxed{w_p = 1.997 \text{ kJ/kg}}$$

$$h_4 = 1.997 + 173.9$$

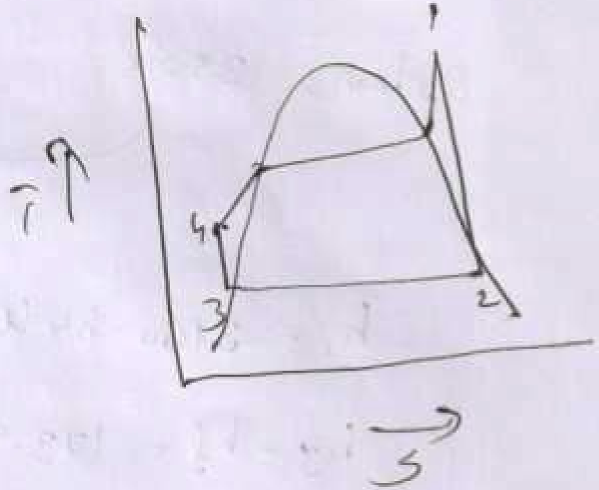
$$= 175.89$$

(ii) Given Data

$T_1 = 633K$
$= 360°C$

$P_2 = 8kpa$

$x_2 = 0.85$



Solution

stage: 2

$h_f = 173.9 \; kJ/kg$

$h_{fg} = 2403.2 \; kJ/kg$

$s_f = 0.593 \; kJ/kgK$

$s_{fg} = 7.637 \; kJ/kgK$

$v_f = 0.001008 \; m^3/kg$

$s_2 = s_f + x_2 + s_{fg}$

$= 7.085$

$\frac{350 \cancel{+} (350 - 400) \times 10}{50}$

~~$s_1 = s_4 = 6.35$ kJ/kgk without reheat~~

$T_1 = 460°C$

$6.$

$$w_{in\,(pump)} = v_5 (P_6 - P_5)$$

$$= 0.001010 (120 \times 100 - 10)$$

$$w_{in}(pump = 12.10 \text{ kJ/kg}$$

$$w_{in(pump)} = h_6 - h_5$$

$$h_6 = 12.10 + 191.8$$

$$\boxed{h_6 = 203.9 \text{ kJ/kg}}$$

$$Q_{in} = (h_1 - h_6) + (h_3 - h_2)$$

$$\eta = \frac{W_{net}}{}$$

$$= (3240 - 203.9)$$

$h_4 = 191.8 + 0.8778 \times 2392.9$

$= 2292.29 \text{ kJ/kg}$

<u>without reheat</u>

$S_4 = 0.649 + 0.7592 \times 7.502$

$\boxed{S_4 = 6.35 \text{ kJ/kgK}}$

$S_3 = S_4 = 6.35$ (without reheat)

$T_1 = 460°C$

<u>By linear interpolation</u>

$P_1 = 120 \text{ bar}$

$400 = 3005.6$

$500 = 3323.8$

$3005.6 + \frac{(3005.6 - 3323.8)}{100} \times 60$

$h_1 = 3240 \text{ kJ/kg}$

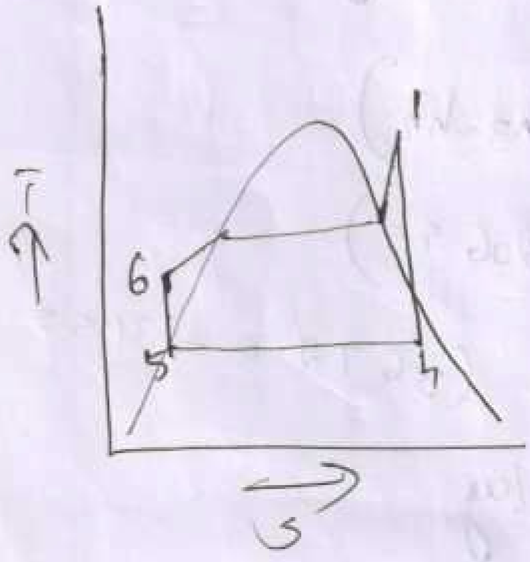
12 <u>Given Data</u>

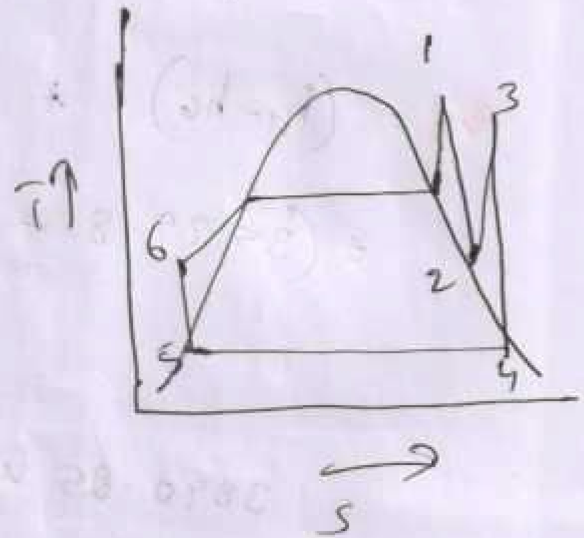
$T_1 = 733k$

$P_4 = 10 kPa$

$x_4 = 0.8778$ (with reheat)

$x_4 = 0.7592$ (without reheat)





<u>stage: 4</u>

Stage: 2

$P_2 = P_3 = 40 bar$

$s_1 = s_2 = 6.676 \ kJ/kgK$

$T_2 = 375^\circ C$

$\boxed{h_2 = 3155.4 \ kJ/kg}$

$q_{in} = (h_1 - h_6) + (h_3 - h_2)$

$= (3579.8 - 206.95)$

$+ (3672.8 - 3155.4)$

$= 3890.25 \ kJ/kg$

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

stage: 5

$P_5 = 10\,kPa$

$h_5 = 191.8\ kJ/kg$

$v_5 = 0.001010\,m^3/kg$

stage: 6

$P_6 = 15\,mpa$

$= 150\,bar$

$\therefore P_6 = P_1$

$15\,mpa = 15000\,kpa$

$1\,bar = 100\,kpa$

~~[illegible]~~

$1\,bar = 0.1\,mpa$

$s_6 = s_5$

$(w_{in})_{pump} = h_6 - h_5$

$h_6 = (w_{in})_{pump} + h_5$

$= v_5(P_6 - P_5) + h_5$

(9)

Solution

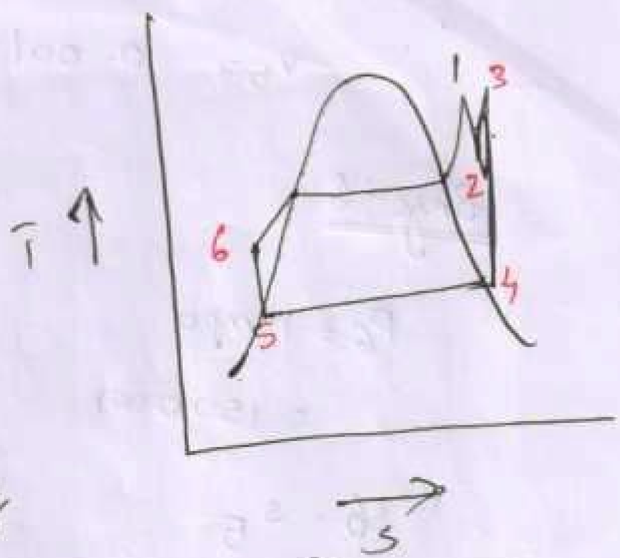
Stage : 4

$P_4 = P_5$

$P_1 = 15 MPa$

$T_1 = 878 K$

$P_4 = 10 kPa$



$P_4 = 10 kPa$

$x_4 = 0.896$

$s_4 = s_f + x_4 s_{fg}$

$= 0.649 + (0.896 \times 7.502)$

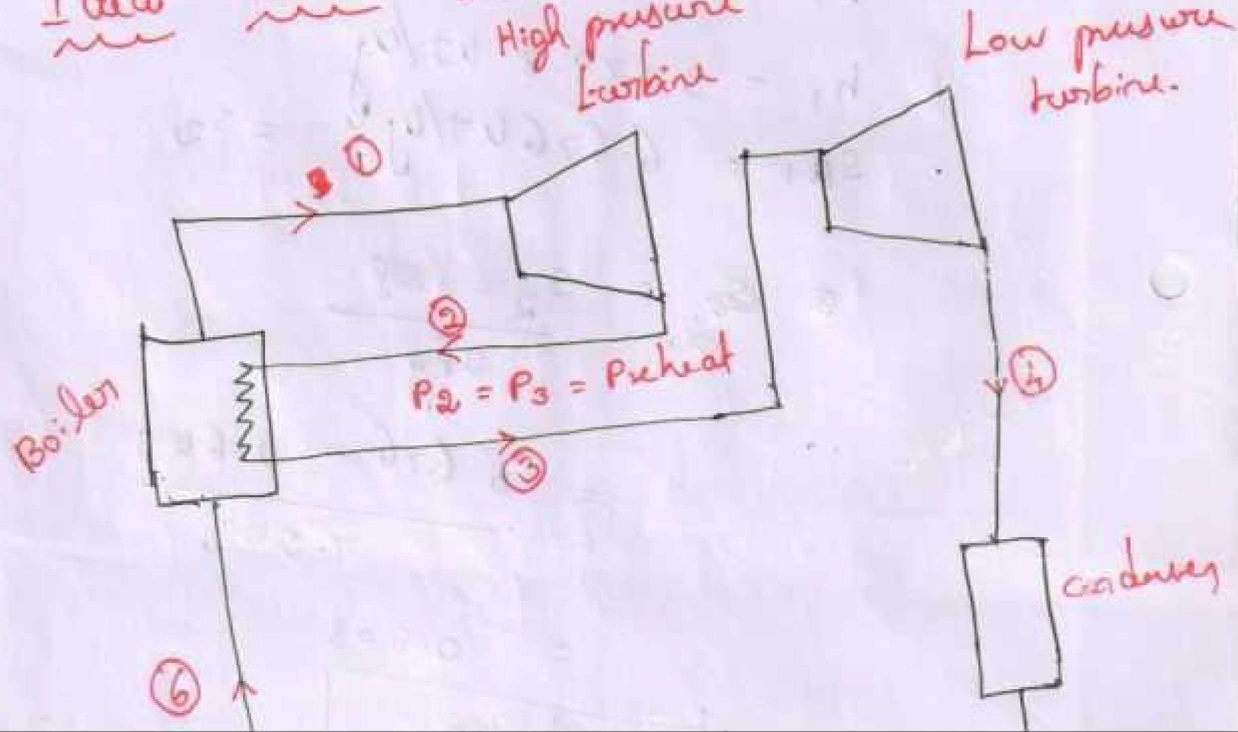
$\boxed{s_4 = 7.37 kJ/kg K}$

$h_4 = h_f + x_4 h_{fg}$

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}}$$

$$\boxed{\eta_{th} = 43\%}$$

Ideal Reheat Rankine cycle



$w_{in} = h_4 - h_3$

$h_4 = (w_{in})_{pump} + h_3$

$= 15.13 + 191.8$

$\boxed{h_4 = 206.93 \text{ kJ/kg}}$

step $s_2 = s_1$

$P_1 = 15 \text{ mpa}$ $T_1 = 600°c$

$h_1 = 3579.8 \text{ kJ/kg}$

$s_1 = 6.676 \text{ kJ/kg k} = s_2$

$x_2 = \frac{s_2 - s_f}{s_{fg}}$

$= \frac{6.676 - 0.649}{7.502}$

$= 0.803$

$$q_{in} = h_1 - h_4$$

$$= 3681 - 194.85$$

$$\boxed{q_{in} = 3486.15 \text{ kJ/kg}}$$

$$q_{out} = h_2 - h_3$$

$$= 2379.6 - 191.8$$

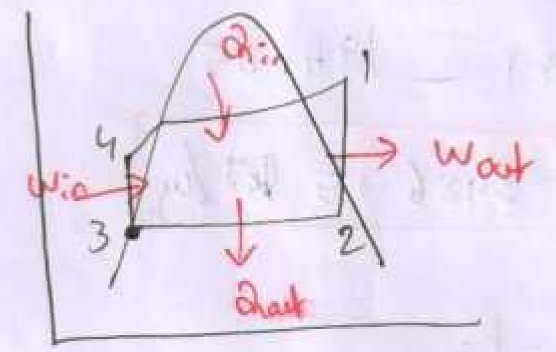
$$\boxed{q_{out} = 2187.8 \text{ kJ/kg}}$$

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{2187.8}{3486.15}$$

$$\boxed{\eta_{th} = 37.45\,\%}$$

(b)



stage ① $(s_1 = s_2)$

$P_1 = 3\ \text{mpa}$ $\qquad h_1 = 3681.\ \text{kJ/kg}$

$T_1 = 873\ \text{K}$ $\qquad S_1 = 7.508\ \text{kJ/kg K}.$

Dryness fraction $x_2 = \dfrac{s_2 - s_f}{s_{fg}}$

for pressure 10 kpa.

$s_f = 0.649\ \text{kJ/kg k}.$

In pressure 10kpa = 0.10 bar

$sf = 0.649$ kJ/kgk

$sfg = 7.502$ kJ/kgk

$$x_2 = \frac{6.747 - 0.649}{7.502}$$

$$\boxed{x_2 = 0.812}$$

$$h_2 = hf + x_2 hfg$$

$$= 191.8 + 0.812\,(2392.9)$$

$$\boxed{h_2 = 2136.8 \text{ kJ/kg}}$$

$$Q_{in} = h_3 - h_4$$

$$= 3117.5 - 194.85$$

Solution

stage ③ $P_2 = P_3 = 10 kPa$

$$h_f = h_3 = 191.8\ kJ/kg$$

$$v_{f_1} = v_3 = 0.001010\ m^3/kg$$

stage: ④

$$(S_3 = S_4)$$

$$(W_{in})_{pump} = v_1 (P_2 - P_1)$$

$$= 0.001010 (3000 - 10)$$

$$\boxed{W_{in} = 3.02\ kJ/kg}$$

$$(W_{in})_{pump} = h_4 - h_3$$

$1\ bar = 100 kpa$

$= 100 kN/m^2$

$h_4 - h_3 = 4.05$

$h_4 = 4.05 + h_3$

$h_3 = h_{f_2}$ at 0.2bar

$= 251.5\ kJ/kg$

$h_4 = 4.05 + 251.5$

$= 255.55\ kJ/kg.$

$Q_1 = 2800 - 255.55$

$$\boxed{Q_1 = 2544.45\ kJ/kg}$$

$$\eta_{cy} = \frac{w_{net}}{Q_1} = \frac{799.24}{2544.45} \times 100$$

$$\boxed{\eta_{cy} = 31.44\ \%}$$

$$Ratio = \frac{W_P}{W_T} = \frac{4.05}{803.29}$$

$$s_1 = s_2 = sf_2 + x_2 \times sfg_2$$

$$6.069 = 0.832 + x_2 \times 7.077$$

$$x_2 = \frac{6.069 - 0.832}{7.077}$$

$$= 0.7400$$

$$h_2 = hf_2 + x_2 \times hfg_2$$

$$= 251.5 + 0.74 \times 2358.4$$

$$\boxed{h_2 = 1996.71} \text{ kJ/kg}$$

Pump work $w_p = h_4 - h_3$

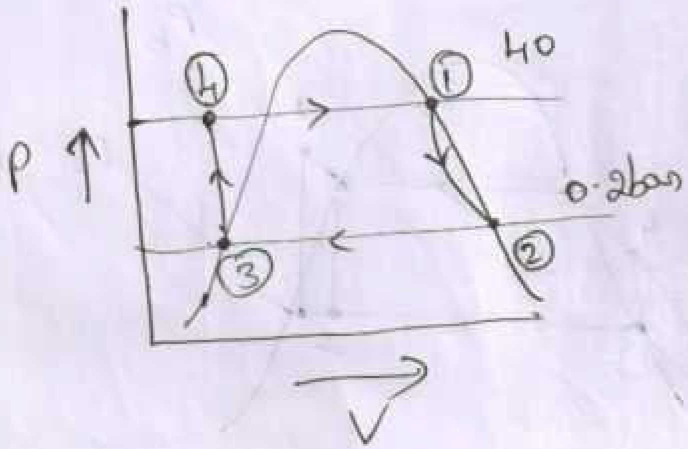
$$= vf_2 (P_1 - P_2)$$

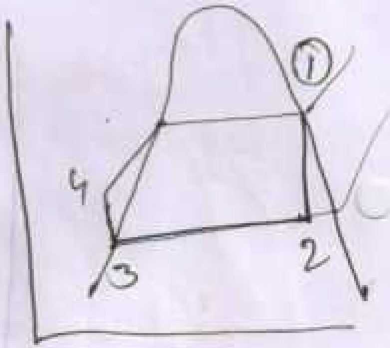
$$= 0.001017$$

$\times$ kN/

A Rankine cycle works between 40 bar

Given Data:



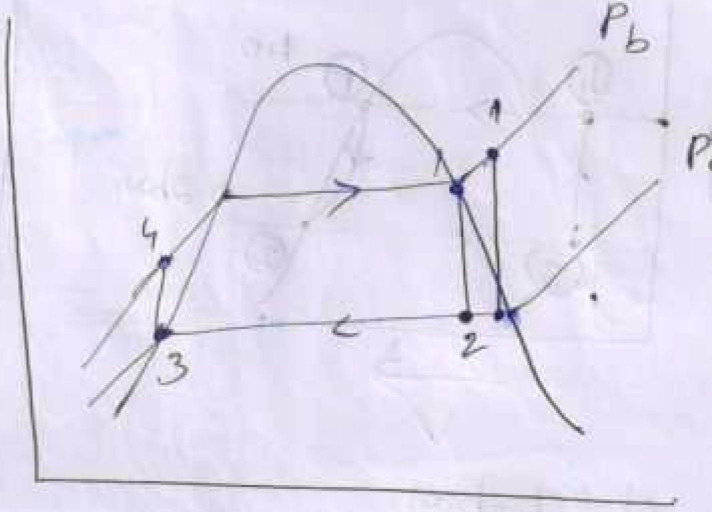


At 40 bar

$h_1 = h_g = 2800 \text{ kJ/kg}$

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

$$= 1 - \frac{(h_2 - h_3)}{(h_1 - h_4)}$$



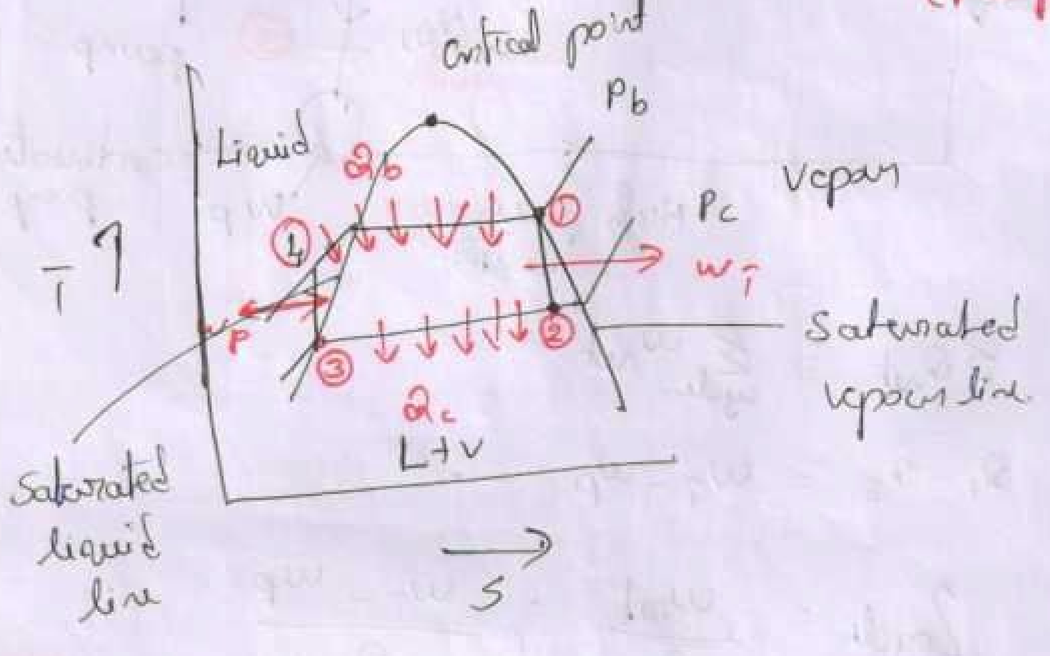
$h_1 = ?\ (f)$

④ - ① → Reversible constant pressure heating process. (Boiler)

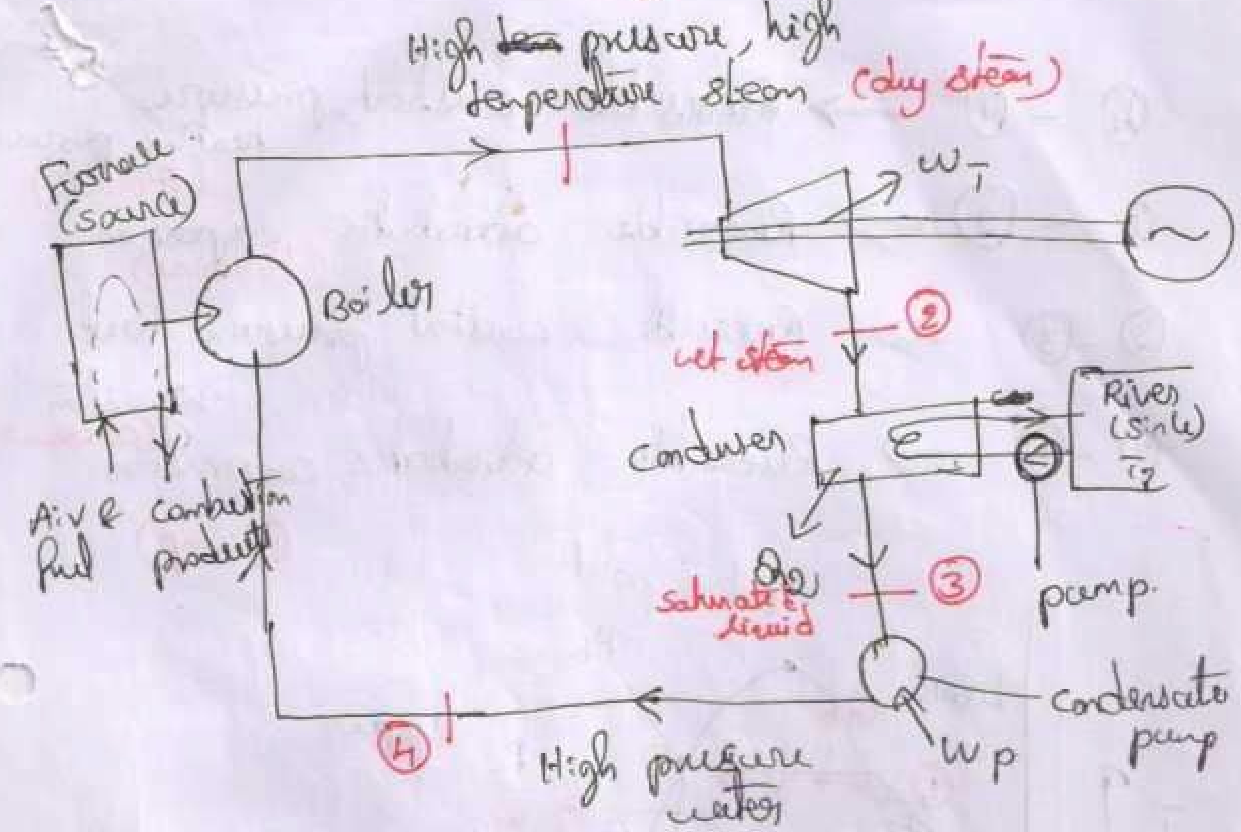
① - ② → Reversible adiabatic expansion (turbine)

② - ③ → Reversible constant pressure heat rejection (condensor.

③ - ④ → Reversible adiabatic compression (Pump)



UNIT – III



$$\sum Q_{net} = \sum_{cycle} W_{net}$$

$$Q_1 - Q_2 = W_T - W_P$$

$$\eta_{cycle} = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1}$$

① change in internal energy

$$\Delta u = U_2 - U_1 = m c_v (T_2 - T_1)$$

$$= 10 \times 0.6898 (323 - 298)$$

$$= 172.45 \text{ kJ}$$

② change in enthalpy

$$\Delta H = m c_p (T_2 - T_1)$$

$$= 10 \times 0.9216 (323 - 298)$$

$$= 230.4 \text{ kJ}$$

③ change in entropy

$$\Delta S = m c_v \ln \left(\frac{T_2}{T_1}\right) + m R \ln \left(\frac{V_2}{V_1}\right)$$

Given Data:

$m = 10 kg$

$C_{V_{N_2}} = 0.745 \ kJ/kg.K$ $\quad C_{V_{CO_2}} = 0.653 \ kJ/kg.K$

$C_{P_{N_2}} = 1.041 \ kJ/kg.K$ $\quad C_{P_{CO_2}} = 0.842 \ kJ/kg.K$

$T_1 = 25°C + 273 = 298 K$ $\quad T_2 = 50 + 273 = 323 K.$

To find:

For the mixture

$$C_p = \frac{m_{N_2} C_{P_{N_2}} + m_{CO_2} * C_{P_{CO_2}}}{m_{N_2} + m_{CO_2}}$$

$$= \frac{(4 \times 1.041) + (6 \times 0.842)}{10}$$

volume of N_2 (V_{N_2}) $= \dfrac{n_{N_2} \bar{R} T_{N_2}}{P_{N_2}}$

$= 2.32 m^3$

volume of mixture (V_m) $= V_{O_2} + V_{N_2}$

$= 8.02 m^3$

pressure of mixture (P_m) $= \dfrac{N_m \bar{R} T_m}{V_m}$

$= 114.5 kPa$

⑤ A perfect gas mixture consists of 4kg of N_2 and 6kg of CO_2 at a pressure of 4bar and a temperature of 25°c

For N_2: $C_v = 0.745$ kJ/kg.k and $C_p = 1.041$ kJ/kg.k

$$T_m = \frac{m_{O_2} c_{v_{O_2}} T_{O_2} + m_{N_2} + c_{v_{N_2}} + T_{N_2}}{m_{O_2} c_{vO_2} + m_{N_2} c_{v_{N_2}}}$$

$$= \frac{(7 \times 0.658 \times 313) + (4 \times 0.743 \times 293)}{(7 \times 0.658) + (4 \times 0.743)}$$

$$= 305.16 k$$

molecular weight of O_2, $\mu_2 = 2 \times 16 = 32 kg/kg\text{-}mol$

molecular weight of N_2, $\mu_{N_2} = 28 kg/kg\text{-}mol$

$$n_{O_2} = \frac{m_{O_2}}{\mu_{O_2}} = \frac{7}{32} = 0.219 \ kg.mol$$

$$n_{N_2} = \frac{m_{N_2}}{\mu_{N_2}} = 4/28 = 0.142 \ kg.mol.$$

(4) An insulated rigid tank is divided into two compartments by a partition. One compartment contains 7 kg of oxygen gas at 40°c and 100kpa, and the other compartment contains 4 kg of nitrogen gas at 20°c and 150 kpa. Now the partition is removed, and the two gases are allowed to mix.

Determine

1. The mixture temperature
2. The mixture pressure after equilibrium has been established

$$\left[\begin{array}{l} C_v, N_2 = 0.743 \ kJ/kg \cdot k \\ C_v, O_2 = 0.658 \ kJ/kg \cdot k. \end{array}\right]$$

Given Data:

$m_{O_2} = 7kg$

number of moles of mixture

$$n_{mix} = \frac{Vp}{\bar{R}T}$$

$$= \frac{0.5 \times 1000}{8.314 \times 293}$$

$$\boxed{n_{mix} = 0.205 \text{ kmol.}}$$

(iv) mass of mixture molecular $\left(\because n_{mix} = \frac{m_m}{M_m} \right)$

$$m_m = n_{mix} \times M_m$$

$$= 0.205 \times 38.4$$

$$= 7.881 \text{ kg}$$

(iii) mass percentage $mf_{(i)} = \frac{x_i \times M_i}{M_m}$

$mf_{N_2} = 0.2 \times 28$

③ A closed vessel has a capacity of $0.5 m^3$. It contains 20% of N_2 and 20% O_2 60% CO_2 by volume at 20°c and 1 MPa. Calculate the molecular mass, gas constant, mass percentage and mass of mixture.

$$\mu_{N_2} = 28 \ kg/k.mole.$$

$$\mu_{CO_2} = 44 \ kg/k.mole$$

$$\mu_{O_2} = 32 \ kg/k.mole.$$

(i)

(ii)

$$R_{N_2} = \frac{8.314}{28} = 0.296 \ kJ/kg.k.$$

$$R_{CO_2} = \frac{8.314}{44} = 0.189 \ kJ/kg.k.$$

$$P_{CO_2} = \frac{m_{CO_2} R_{CO_2} T_m}{V_m}$$

$$= \frac{0.5 \times 0.189 \times 293}{0.2}$$

$$= 138.44 \ kN/m^2$$

Total pressure = 22.588 bar.

molar mass of mixture

$$\mu_m = \frac{m_m}{\cancel{\ }\, n_m} = \frac{\text{mass of mixture}}{\text{mole number of mixture}}$$

mass of mixture = 4+1+0.5 = 5.5 kg

number of mole $\boxed{n_{N_2} = \frac{m_{N_2}}{\mu_{N_2}}} = 4/28$

$= 0.1428$ kmol.

(2) A tank contains $0.2 m^3$ of gas mixture composed of 4 kg of nitrogen, 1 kg of oxygen and 0.5 kg of CO_2. If the temp is $20°C$. Determine the total pressure, gas constant and molar mass of the mixture.

Solution

Gas constant of N_2

$$R_{N_2} = \frac{8.314}{28} = \frac{\bar{R}}{\mu_i}$$

$$= 0.296 \text{ kJ/kg·K}$$

$$R_{O_2} = \frac{8.314}{32} = 0.2598 \text{ kJ/kg·K}$$

$R_{CO_2} = 8.314$

$$R = \frac{2.5 \times 0.29694 + 4.5 \times 0.188}{7}$$

$$\boxed{R = 0.2275 \ \text{kJ/kg.k}}$$

(4) Partial pressures and partial volume

$$P_{N_2} = x_{N_2} \times P = 0.46603 \times 400$$

$$= 186.432 \ \text{kpa.}$$

$$P_{CO_2} = x_{CO_2} \times P = 0.53389 \times 400$$

$$= 213.556 \ \text{kpa.}$$

Partial volume

$$PV = mRT$$

$$V_{N_2} = \frac{m_{N_2} \times R_{N_2} \times T}{}$$

(5) Density & volume

$$x_{CO_2} = \frac{\frac{4.5}{44}}{\frac{2.5}{28} + \frac{4.5}{44}} = 0.533$$

② **Equivalent molecular weight [M]**

$$M = x_1 M_1 + x_2 M_2 \ldots x_n \cdot M_n.$$

$$= x_{N_2} M_{N_2} + x_{CO_2} + M_{CO_2}$$

$$= (0.466 \times 28) + (0.533 \times 44)$$

$$\boxed{M = 36.54 \text{ kJ/kg mol}}$$

③ **Equivalent gas constant [R]**

$$m = m_{N_2} + m_{CO_2} = 2.5 + 4.5$$

① A mixture of ideal gases consists of 2.5 kg of N_2 and 4.5 kg of CO_2 at a pressure of 4 bar and a temperature of 25°C. Determine

1. Mole fraction of each constituent.
2. Equivalent molecular weight of mixture.
3. Equivalent gas constant of the mixture.
4. Partial pressure and partial volume.
5. volume and density of the mixture.

Given Data:

$m_{N_2} = 2.5\,kg \quad m_{N_2} = 4.5\,kg$

$P = 4\,bar = 400\,kpa$

Avagadro's law:

Equal volume of diffrent perfect gases at the same temperature and pressure contain equal number of molecule.

characteristic gas equation

General gas equation for ideal gas

$$\frac{pv}{T} = c$$

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

$$pv = RT$$

$$\boxed{pv = MRT}$$

Properties of Perfect

charle's law:

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

$V \propto T$

$\frac{V}{T} = c$ as long as pressure is constant

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

$P \propto T$

$\frac{P}{T} = c$ as long as pressure is constant.

charle's law:

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

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$\frac{V}{T} = c$ as long as pressure is constant

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

$P \propto T$

$\frac{P}{T} = c$ as long as pressure is constal.

Dividing by ∂T

$$\left(\frac{\partial h}{\partial p}\right)\left(\frac{\partial p}{\partial T}\right)_h + \left(\frac{\partial h}{\partial T}\right)_p = 0$$

$$\left(\frac{\partial h}{\partial p}\right)_T\left(\frac{\partial p}{\partial T}\right)_h = -\left(\frac{\partial h}{\partial T}\right)_p$$

$$\left(\frac{\partial h}{\partial p}\right)_T\left(\frac{1}{\mu}\right) = -\left(\frac{\partial h}{\partial T}\right)_p$$

$$\left(\frac{\partial h}{\partial T}\right)_p = \frac{-1}{\mu}\left(\frac{\partial h}{\partial p}\right)_T$$

$$\boxed{c_p = \left(\frac{\partial h}{\partial T}\right)_p = \frac{-1}{\mu}\left(\frac{\partial h}{\partial p}\right)_T}$$

Differentiating this equation with respect to pressure at constant enthalpy

$\because h = c$

$dh = 0$

$$\left(\frac{\partial T}{\partial P}\right)_h = 0 + \frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]$$

$$\mu = \left(\frac{\partial T}{\partial P}\right)_h = \frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]$$

Joule Thomson coefficient for ideal gas.

Constant temperature coefficient

$h = f(P, T)$

Case (ii) when μ is zero, the temp of the gas remains constant with throttling.

The temperature at which $\mu = 0$ is called inversion temperature for a given pressure.

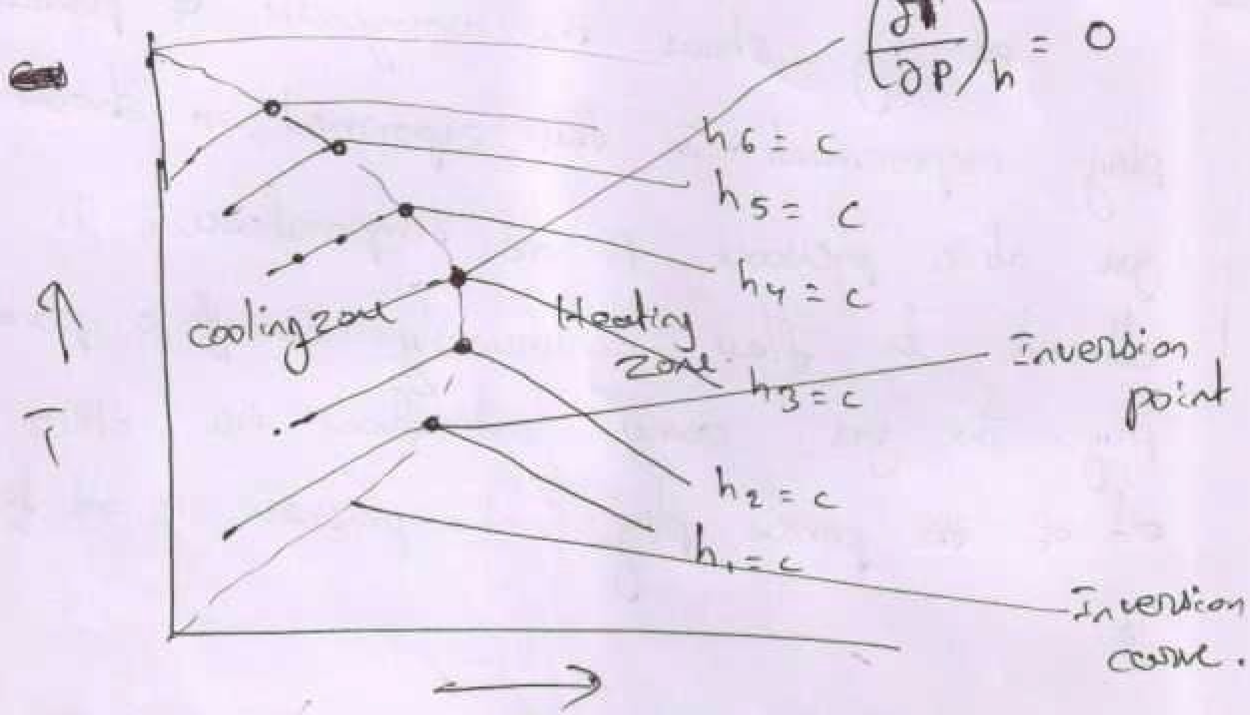
Inversion curve:

The maximum point on each curve is called inversion point and the locus of the inversion point is called inversion curve.

change in enthalpy $dh = \left[C_p dT - T\left(\frac{\partial v}{\partial T}\right)_p dp\right] + v\,dp$

$$dh - v\,dp = C_p\,dT - T\left(\frac{\partial v}{\partial T}\right)_p dp$$

$$\mu = \left(\frac{\partial T}{\partial P}\right)_h$$



Case: (i)

$$\mu = \left(\frac{\partial T}{\partial P}\right)$$

pressure & temperature changes are negative

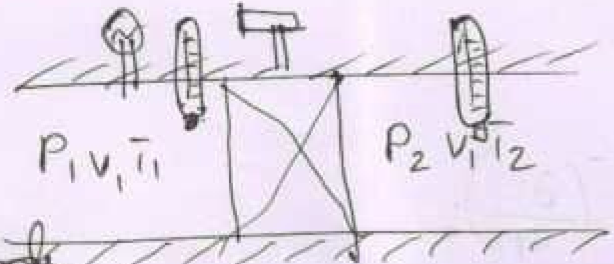


fig shows the arrangement of porous plug experiment. In this experiment, a stream of gas at a pressure P_1 and temperature T_1 is allowed to flow continuously through a porous plug. The gas comes out from the other end of the porous plug at a pressure P_2 and temperature T_2.

From SFEE

$$g\cancel{z_1} + \cancel{\frac{v_1^2}{2}} + h_1 + \cancel{Q} = g\cancel{z_2} + \cancel{\frac{v_2^2}{2}} + h_2 + \cancel{W}$$

$$\boxed{h_1 = h_2}$$

Joule - Thomson co-efficient:

It is defined as the change in temperature with change in pressure keeping the enthalpy remains constant. It is denoted by (μ).

$$\mu = \left(\frac{\partial T}{\partial P}\right)_h \longrightarrow (1)$$

Throttling process:

It is defined as the fluid expansion through a minute orifice (or) slightly opened valve. During the throttling process, pressure and velocity are reduced. But there is no heat transfer and no work done by the system. In this process,

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

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

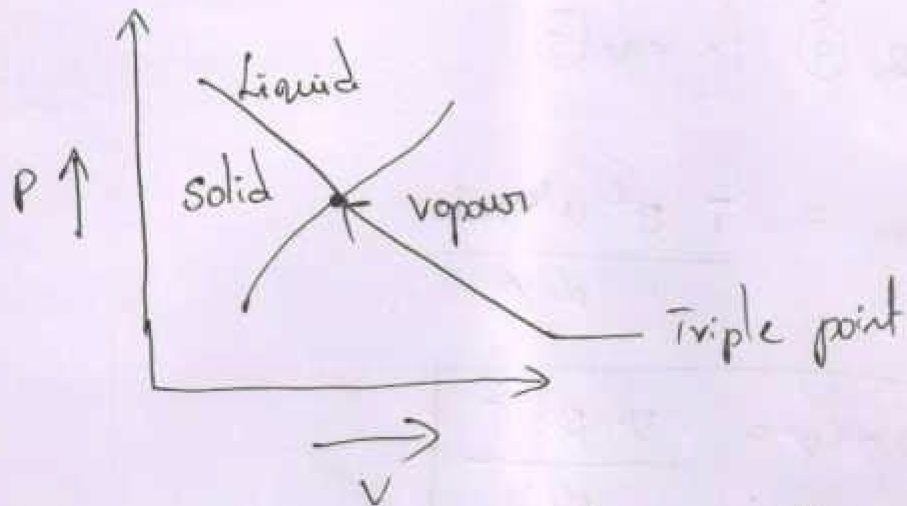
$$\left[s_g - s_f\right] = \frac{dp}{dT}\left[v_g - v_f\right]$$

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f} = \frac{s_{fg}}{v_{fg}} \longrightarrow (5)$$

from second law of thermodynamics

<u>wkT</u>

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



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

$$ds = \left(\frac{\partial s}{\partial v}\right)_T dv \quad \left[\because \ dT = 0\right] \longrightarrow (2)$$

From maxwell equation

Sub (8) & (9) in eq (7)

$$c_p - c_v = \frac{T \beta^2 v^{\cancel{2}} . 1}{\alpha \cancel{v}}$$

$$\boxed{c_p - c_v = \frac{v \beta^2 T}{\alpha}}$$

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 phases involved. This equation provides a basis for calculation ... it gives from the above, we conclude

$$C_p - C_v = T\left(\frac{\partial p}{\partial T}\right)_v \cdot \left(\frac{\partial u}{\partial T}\right)_p \rightarrow (5)$$

<u>we know that</u>

$$\left(\frac{\partial p}{\partial v}\right)_T \cdot \left(\frac{\partial v}{\partial T}\right)_p \cdot \left(\frac{\partial T}{\partial p}\right)_v = -1$$

$$\left(\frac{\partial p}{\partial T}\right)_v \cdot \left(\frac{\partial T}{\partial u}\right)_p \cdot \left(\frac{\partial u}{\partial p}\right)_T = -1$$

$$\left(\frac{\partial p}{\partial T}\right)_v = -\left(\frac{\partial v}{\partial T}\right)_p \cdot \left(\frac{\partial p}{\partial u}\right)_T \rightarrow (6)$$

Sub eq (6) in (5)

$$C_p - C_v = -T\left(\frac{\partial v}{\partial T}\right) \cdot \left(\frac{\partial p}{\partial u}\right)_T \cdot \left(\frac{\partial v}{\partial T}\right)_p$$

$$\left(\frac{\partial p}{\partial T}\right)_v dv + \left(\frac{\partial v}{\partial T}\right)_p dp = \frac{C_p}{T}\, dT - \frac{C_v}{T}\, dT$$

$$T\left[\left(\frac{\partial p}{\partial T}\right)_v dv + \left(\frac{\partial v}{\partial T}\right)_p dp\right] = (C_p - C_v)\, dT$$

$$\left[\frac{T\left(\frac{\partial p}{\partial T}\right)_v}{C_p - C_v}\right] dv + \left[\frac{T\left(\frac{\partial v}{\partial T}\right)_p}{C_p - C_v}\right] dp = dT \longrightarrow (3)$$

choose a function

$$T = T(v, p)$$

$$dT = \left(\frac{\partial T}{\partial v}\right)_p dv + \left(\frac{\partial T}{\partial p}\right)_v dp \longrightarrow (4)$$

coefficient of eq (3) & (4)

According to maxwell equation

$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P \longrightarrow (2)$$

from the enthalpy changes

$$c_p = T\left(\frac{\partial s}{\partial T}\right)_P \longrightarrow (3)$$

substitute (2) & (3) in eq (1)

$$\boxed{ds = \frac{c_p}{T}\,dT - \left(\frac{\partial v}{\partial T}\right)_P dP}$$

Generalised relations for specific heat cp & cv

we know that

Entropy changes : (ds)

Case (i)

Take a function $S = s(T, v)$

$$ds = \left(\frac{\partial s}{\partial T}\right)_v dT + \left(\frac{\partial s}{\partial v}\right)_T dv \longrightarrow ①$$

According to maxwell relation

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v \longrightarrow ②$$

From the internal energy changes equation

$$C_v = T\left(\frac{\partial s}{\partial T}\right)_v$$

$$\frac{C_v}{T} = \left(\frac{\partial s}{\partial T}\right)_v \longrightarrow ③$$

Now compare the co-efficient of eq ③ & ⑥

$$c_p = T\left(\frac{\partial s}{\partial T}\right)_p$$

$$\left(\frac{\partial h}{\partial p}\right)_T = \left(\frac{\partial s}{\partial p} + v\right) \longrightarrow ⑦$$

According to maxwell relations w.r.t T

$$\left(\frac{\partial s}{\partial p}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_p \longrightarrow ⑧$$

Sub ⑦ & ⑧ in eq ③

$$dh = c_p dT + \left[\left(\frac{\partial s}{\;}\right) + v\right] dp$$

Enthalpy changes : (dh)

Take a function $h = h(T, P)$

$$dh = \left(\frac{\partial h}{\partial T}\right)_P dT + \left(\frac{\partial h}{\partial P}\right)_T dP \longrightarrow (1)$$

specific heat at constant pressure

$$c_p = \left(\frac{\partial h}{\partial T}\right)_P \longrightarrow (2)$$

sub eq (2) in eq (1)

$$dh = c_p dT + \left(\frac{\partial h}{\partial P}\right)_T dp \longrightarrow (3)$$

choose a function

$$s = s(T, P)$$

$$= T\left(\frac{\partial s}{\partial T}\right)_v dT + \left[T\left(\frac{\partial s}{\partial v}\right)_T - P\right] dv \rightarrow (6)$$

Now compare the co-efficient of eq (3) & (6)

$$C_v = T\left(\frac{\partial s}{\partial T}\right)_v$$

$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial s}{\partial v}\right)_T - P \longrightarrow (7)$$

According to maxwell relations we know that

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v \longrightarrow (8)$$

Sub (7) & (8) in eq (3)

General relations of du, dh, ds and cp & cv

① Internal energy changes : (du)

Take a function $u = u(T, v)$

$$du = \left(\frac{\partial u}{\partial T}\right)_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv \longrightarrow ①$$

Specific heat at constant volume $C_v = \left(\frac{\partial u}{\partial T}\right)_v \longrightarrow ②$

Sub eq ② in eq ①

$$du = c_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv \longrightarrow ③$$

choose a fuction

$s = s(T, v)$

w.k.t $du = T\,ds - p\,dv \rightarrow (5)$

sub eq (4) in eq (5)

$$du = T\left\{\left(\frac{\partial s}{\partial T}\right)_v dT + T\left(\frac{\partial s}{\partial v}\right)_T dv - p\,dv\right.$$

$$= T\left(\frac{\partial s}{\partial T}\right)_v dT + \left[T\left(\frac{\partial s}{\partial v}\right)_T - p\right] dv \rightarrow (6)$$

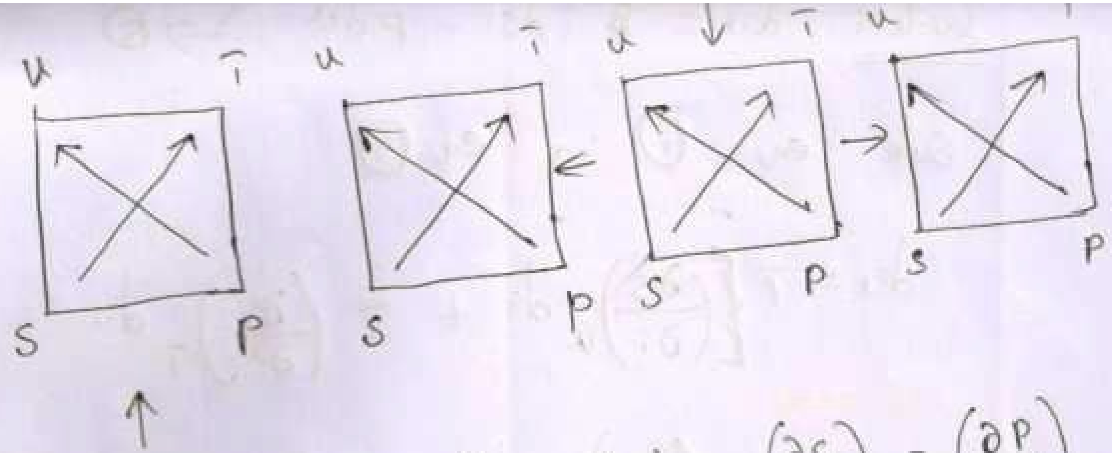
now compare the coefficient of eq (3) & (6)

$$C_v = T\left(\frac{\partial s}{\partial T}\right)_v$$

$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial s}{\partial v}\right)_T - p \rightarrow (7)$$

According to maxwell relations w.k.T

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial p}{\partial T}\right)_v \rightarrow (8)$$



$$\left(\frac{\partial v}{\partial s}\right)_P = \left(\frac{\partial T}{\partial P}\right)_S \qquad \left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P \qquad \left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v$$

$$\left(\frac{\partial T}{\partial v}\right)_S = -\left(\frac{\partial P}{\partial s}\right)_v$$

General relations of du, dh, ds and cp & cv (2)

Internal energy changes :(du)

Take a function $u = u(T, v)$

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

By Gibbs Function

$G = h - Ts$

$dg = dh - d(Ts)$

$dg = dh - Tds - sdT \longrightarrow ⑥$

substitute dh value in equation ⑥

$dg = \cancel{Tds} + vdp - \cancel{Tds} - sdT$

$dg = vdp - sdT \longrightarrow ⑦$

$du = Tds - pdv$

$dh = Tds + vdp$

$da = -pdv - sdT$

$dg = vdp - sdT$

$① \rightarrow \left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v \longrightarrow ⑧$

UNIT

Maxwell's Equations

Maxwell's equations relate entropy to the three directly measurable properties P, v and T for pure simple compressible substance.

From 1st law

$$Q = W + \Delta u$$

Rearranging the parameters

$$Q = \Delta u + W \qquad \left[\because ds = \frac{Q}{T} \right.$$

$$Tds = du + pdv \qquad \left. \because W = pdv \right]$$

$$du = Tds - pdv \longrightarrow (1)$$

$\longrightarrow (2)$

w.k.T

$$h = u + pv$$

$$dh = du + d(pv)$$

$$dh = du + pdv + vdp \longrightarrow (2)$$

$$dh = du + pdv \quad \text{eq } (3)$$

value in

UNIT - V

Psychrometry

→ Science which deals with the study of behaviour of moist air (mixture of dry air and water vapour) is known as psychrometry.

Psychrometric properties:

① Dry air:

Dry air is nothing but the air without moisture (or) water vapour. Dry air is considered to consist of 21% oxygen and 79% nitrogen by volume. 23% oxygen and 77% nitrogen by mass. Completely dry air does not exist in nature.

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 saturated 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. It is denoted by t_d.

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. It is denoted by t_w.

7) wet bulb depression (WBD):

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

$$WBD = DBT - WBT$$

The value of wet bulb depression is zero when the air becomes saturated.

⑧ Dew point depression (DPD):

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

$$DPD = DBT - DPT$$

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 and dew point temperature are all same.

⑩ Specific humidity (or) Humidity ratio (or) moisture content (ω)

It is the ratio of mass of water vapour present in a unit mass of dry air

$$\omega = \frac{\text{mass of water vapour}}{\text{mass of dry air}} = \frac{m_v}{m_a}$$

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

⑪ Relative humidity (ϕ):

It is defined as amount of moisture the air holds (m_v) relative to maximum amount of moisture the air can hold at the same temperature

$$\boxed{\phi = \frac{m_v}{m_g}} \quad \boxed{\phi = \frac{\mu}{1-(1-\mu)\frac{P_s}{P_b}}}$$

③

12. Degree of saturation (or) percentage of (or) saturation ratio

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

$$\boxed{\mu = \frac{P_v}{P_s}\left[\frac{P_b - P_s}{P_b - P_v}\right]}$$

(13) Total enthalpy of moist air

$H = c_p t_d + \omega h_g$

$c_p = 1.005$ kJ/kg.K

$h_g \rightarrow$ specific enthalpy of air corresponding to dBT

(14) Dalton's law of partial pressure

$P_b = P_a + P_v$

(15)

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

$P_{sw} \rightarrow$ saturation pressure corresponding wet bulb temperature

① The moist air is at 45°C dry bulb temperature and 30°C wet bulb temperature. Calculate

(i) vapour pressure (ii) Dew point temperature

(iii) specific ~~enthalpy~~ humidity (iv) Relative humidity

(v) Degree of saturation (vi) vapour density

(vii) Enthalpy of mixture.

Given Data:

$t_d = 45°c$

$t_w = 30°c$

Assume $P_b = 1$ bar

Solution

① Vapour pressure $(P_v) = P_{sw} - \frac{(P_b - P_{sw})(t_d - t_w)}{1527.4 - 1.3 t_w}$

$P_{sw} \rightarrow$ saturation pressure corresponding to WBT (30°c) from steam table.

$$\boxed{P_{sw} = 0.04242 \text{ bar}}$$

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

$$\boxed{P_v = 0.03277 \text{ bar}}$$

② Dew point temperature (t_{dp})

$t_{dp} \rightarrow$ Temperature corresponding to vapour pressure $P_v = 0.03277$ bar.

$$\boxed{t_{dp} = 25.26°c}$$

③ Specific humidity (ω)

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

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

$$\omega = 0.02107 \text{ /kg of dry air.}$$

④ Relative humidity:

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

$P_s \rightarrow$ ~~sat~~ pressure corresponding to ~~d~~ DB

(45°C) $P_s = 0.09582$ bar

$$\phi = \frac{0.03277}{0.09582} = 0.342$$

$$\boxed{\phi = 34.2\%}$$

Ⓒ

⑤ Saturation ratio (or) Degree of Saturation.

$$\mu = \frac{P_v}{P_s}\left[\frac{P_b - P_s}{P_b - P_v}\right]$$

$$= \frac{0.03277}{0.09582}\left[\frac{1 - 0.09582}{1 - 0.03277}\right]$$

$$\boxed{\mu = 0.3197}$$

(6) Vapour density (ρ_v)

$$\rho_v = \frac{1}{v_g}$$

$v_g \rightarrow$ specific volume corresponding to DBT 45°c

$$v_g = 15.276 \text{ m}^3/\text{kg}$$

$$\rho_v = \frac{1}{15.276} = 0.06546 \text{ kg/m}^3 \text{ of saturated steam.}$$

Vapour density at 34.2%

$$\rho_v = 0.06546 \times 0.342$$

$$\boxed{\rho_v = 0.0224 \text{ kg/m}^3}$$

(7) Enthalpy of mixture:

kJ/kg.K × K ✱ kJ/kg

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

$$= (1.005 \times 318) + (0.0210 \times 8583.3)$$

$$= 373.83 \text{ kJ/kg}$$

② Atmospheric air at 1.0132 bar has 20°C dry bulb temperature and 65% RH. Find the humidity ratio, wet bulb temperature, dew point temperature, degree of saturation, enthalpy of the mixture, density of air and density of air and density of vapour in the mixture.

Given Data:

$P_b = 1.0132$ bar

$DBT = 20°C \quad RH = 65\% = 0.65$

Solution

$$\text{Relative humidity}(\phi) = \frac{P_v}{P_s}$$

$P_s \rightarrow$ saturation pressure corresponding to DBT (20°C)

$P_s = 0.02337$ bar

$$\phi = \frac{P_v}{P_s} \Rightarrow P_v = 0.65 \times 0.02337$$

$$\boxed{P_v = 0.0151 \text{ bar}}$$

WKT

$P_b = P_a + P_v$

$P_a = P_b - P_v = 1.0132 - 0.0151$

$$\boxed{P_a = 0.998 \text{ bar}}$$

Specific volume $(v_a) = \frac{R_a T_a}{P_a}$

$R_a = 0.287$ kJ/kg K $\qquad R_a = 0.287$ kJ/kg.K.

$T_a = t_d + 273 = \underline{293K}$

$\frac{\frac{kJ}{kg.K} \times K}{kN \times} \quad \frac{kN.m}{kg} \times \frac{m^2}{kN}$

$$v_a = \frac{0.287 \times 293}{0.998 \times 100} = \frac{84.09}{99.8} = 0.842 m^3/kg.$$

(2) Dew point temperature

$P_v = 0.0151$ bar

$t_{dp} = 13°c$

(3) Specific humidity (ω)

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

$= 0.00941$ kg/kg of dry air.

(4) Degree of saturation

$$\mu = \frac{P_v}{P_s} \left[\frac{P_b - P_s}{P_b - P_v}\right]$$

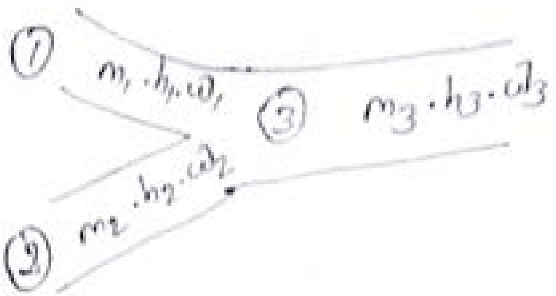
$$= \frac{0.0151}{0.08337} \left[\frac{1.0132 - 0.08337}{1.0132 - 0.0151}\right]$$

$$\boxed{\mu = 0.64}$$

Psychrometric Process:

1. Sensible heating (or) cooling
2. Heating & humidification
3. cooling & dehumidification
4. Adiabatic mixing of air streams.
5. Evaporative cooling.

(4) Adiabatic mixing of air streams



mass balance for dry air: $m_1 + m_2 = m_3 \rightarrow (1)$

mass balance for water vapour $m_1 \omega_1 + m_2 \omega_2 = m_3 \omega_3 \rightarrow (2)$

Energy balance $m_1 h_1 + m_2 h_2 = m_3 h_3 \rightarrow (3)$

Substituting the value of m_3 in eq (3)

$$m_1 h_1 + m_2 h_2 = (m_1 + m_2) h_3$$

$$m_1 h_1 + m_2 h_2 = m_1 h_3 + m_2 h_3$$

$$m_1(h_1 - h_3) = m_2(h_3 - h_2)$$

$$\boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}} \longrightarrow (4)$$

Substituting the value of m_3 in eq (3)

$$m_1\omega_1 + m_2\omega_2 = (m_1 + m_2)\omega_3$$

$$m_1\omega_1 + m_2\omega_2 = m_1\omega_3 + m_2\omega_3$$

$$m_1(\omega_1 - \omega_3) = m_2(\omega_3 - \omega_2)$$

$$\boxed{\frac{m_1}{m_2} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_3}} \longrightarrow (5)$$

from eq (4) & (5)

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_3}$$

(1) Two streams of moist air, one having flow rate of 3kg/s at 30°C and 30% relative humidity, other having flow rate of 2kg/s at 35°C and 65% relative humidity get mixed adiabatically. Determine specific humidity and partial pressure of water vapour after mixing. Take C_p stream = 1.86 kJ/kg.k.

Given Data:

$\dot{m}_1 = 3 kg/s$ $\dot{m}_2 = 2 kg/s$

$td_1 = 30^\circ c$ $td_2 = 35^\circ c$

$R.H = 30\%$ $RH = 65\%$

solution

For adiabatic mixing

$$\frac{\dot{m}_1}{\dot{m}_2} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_3}$$

from psychrometric chart $td_1 = 30^\circ C$ & $RH = 3$

$$\omega_1 = 0.008$$

$td_2 = 35^\circ c$ & $RH = 65\%$

$$\omega_2 = 0.024$$

$$\frac{3}{2} = \frac{\omega_3 - 0.024}{0.008 - \omega_3}$$

$$1.5(0.008 - \omega_3) = \omega_3 - 0.024$$

$$0.012 - 1.5\omega_3 = \omega_3 - 0.024$$

$$0.012 + 0.024 = \omega_3 + 1.5\omega_3$$

$$0.036 = 2.5\omega_3$$

$$\boxed{\omega_3 = 0.0144 \text{ kg/kg of dry air}}$$

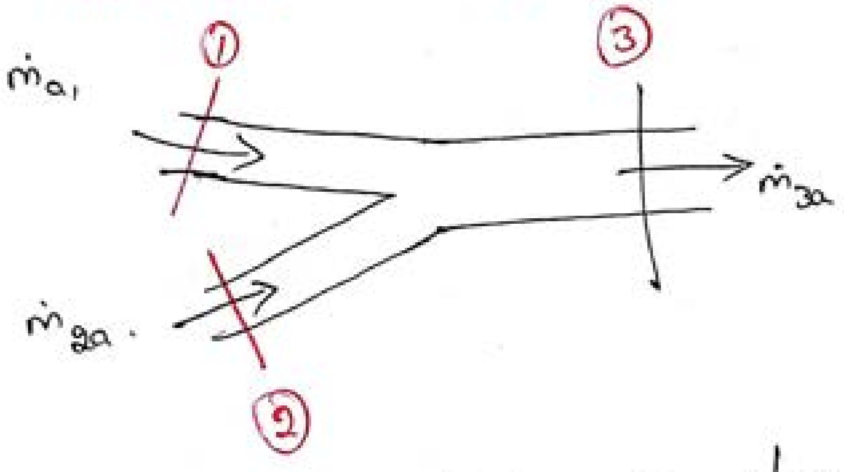
from psychrometric chart

for $\omega_3 = 0.0144$

$P_v = 2.15$ kPa.

$$\boxed{P_v = 0.0215 \text{ bar}}$$

② Saturated air at 20°C at a rate of $70 \, m^3/min$ is mixed adiabatically with the outside air at 35°C and 50% relative humidity at a rate $30 \, m^3/min$. Assuming that the mixing process occurs at a pressure of 1 atm, . Determine the specific humidity, the relative humidity, the relative humidity, the dry bulb temperature, and the volume flow rate of the mixture.



For mixing of two air streams:

$$\dot{m}_{a1} + \dot{m}_{a2} = \dot{m}_{a3}$$

$$\frac{\dot{m}_{a1}}{\dot{m}_{a2}} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_3} = \frac{h_3 - h_2}{h_1 - h_3}$$

psychrometric chart $\quad td_1 = 20^\circ c$; $v = 0.85\ m^3/$

m^3/min

$$\dot{m}_{a1} = \frac{\dot{V}}{v} = \frac{70\ m^3/min}{0.85\ m^3/kg}$$

$$\dot{m}_{a1} = 82.35\ kg/min$$

$td_2 = 35^\circ c$; $RH = 50\%$

$$v = 0.89\ m^3/kg \quad ; \dot{V} = 30$$

$$\dot{m}_{a2} = \frac{30}{0.89} = 33.5\ kg/min$$

$\omega_1 = 0.015\ kg/kg$ of dry air.

$\omega_2 = 0.018\ kg/kg$ of dry air

$h_1 = 57.5\ kJ/kg$; $h_2 = 81\ kJ/kg$.

$$\therefore \frac{82.35}{33.5} = \frac{\omega_3 - 0.018}{0.015 - \omega_3}$$

$$\boxed{\omega_3 = 0.0158\ kg/kg \text{ of dry air.}}$$

$$\frac{82.35}{33.5} = \frac{h_3 - 81}{57.5 - h_3}$$

$2.45(57.5 - h_3) = h_3 - 81$

$141.34 - 2.45h_3 = h_3 - 81 \Rightarrow 222.34 = 3.45h_3$

$\boxed{h_3 = 64.5}$

From psychrometric chart

$h_3 = 64.5$ kJ/kg ; $\omega_3 = 0.0158$

$\phi_3 = 80\%$

$t_{dp_3} = 24°C$

$v_3 = 0.865$

$\dot{m}_{a_1} + \dot{m}_{a_2} = \dot{m}_{a3}$

$82.5 + 33.5 = 115.85$ kg/min.

$\dot{V}_3 = \dot{m}_{a_3} \times v_3$

$= 115.85 \times 0.865$

$\boxed{\dot{V}_3 = 100 m^3/min.}$

$\dot{V}_1 + \dot{V}_2 = V_3$

to design an air conditi...

① A mixture of ideal gases consists of 2.5 kg of N_2 and 4.5 kg of CO_2 at a pressure of 4 bar and a temperature of 25°C. Determine

1. Mole fraction of each constituent.
2. Equivalent molecular weight of mixture.
3. Equivalent gas constant of the mixture.
4. Partial pressure and partial volume.
5. volume and density of the mixture.

Given Data:

$m_{N_2} = 2.5\,kg \quad M_{N_2} = 4.5\,kg.$

$P = 4\,bar = 400\,kpa$

$T = 25 + 273 = 298\,k.$

Solution

$\boxed{\text{Mole fraction } x_i = \frac{n_i}{\sum n_i}} = \frac{\text{mole numb}}{\text{total}}$

$$x_{N_2} = \frac{n_{N_2}}{\sum n_{N_2 m}} = \frac{\frac{2.5}{28}}{\frac{2.5}{28} + \frac{4.5}{44}}$$

$$= \underline{\underline{0.466}}$$

130

$$x_{CO_2} = \frac{\frac{4.5}{44}}{\frac{2.5}{28} + \frac{4.5}{44}} = 0.533$$

② Equivalent Molecular weight (μ)

$$\mu = x_1 \mu_1 + x_2 \mu_2 \dots x_n \cdot \mu_n.$$

$$= x_{N_2} \mu_{N_2} + x_{CO_2} + \mu_{CO_2}$$

$$= (0.466 \times 28) + (0.533 \times 44)$$

$$\boxed{\mu = 36.54 \text{ kJ/kg mol}}$$

③ Equivalent gas constant (R)

$$m = m_{N_2} + m_{CO_2} = 2.5 + 4.5$$

$$= 7 \text{kg}$$

$$R = \frac{m_{N_2} \times R_{N_2} + m_{CO_2} \times R_{CO_2}}{m}$$

$$R_{N_2} = \left(\frac{\bar{R}}{\mu_{N_2}}\right) = \frac{8.3143}{28} = 0.29694$$

$$R_{CO_2} = \left(\frac{\bar{R}}{\mu_{CO_2}}\right) = \frac{8.3143}{44} = 0.188$$

$$R = \frac{2.5 \times 0.29694 + 4.5 \times 0.188}{7}$$

$$\boxed{R = 0.2275 \text{ kJ/kg.k}}$$

④ Partial pressures and partial volume

$p_{N_2} = x_{N_2} \times P = 0.46603 \times 400$

$= 186.432 \text{ kpa.}$

$P_{CO_2} = x_{CO_2} \times P = 0.53389 \times 400$

$= 213.556 \text{ kpa.}$

Partial volume

$pv = mRT$

$$V_{N_2} = \frac{m_{N_2} \times R_{N_2} \times T}{P}$$

$$= \frac{2.5 \times 0.29694 \times 298}{400}$$

$$\boxed{V_{N_2} = 0.553 m^3}$$

$$V_{CO_2} = \frac{m_{CO_2} \times R_{CO_2} \times T}{P}$$

$$= \frac{4.5 \times 0.18896 \times 298}{400} = 0.633 m^3$$

⑤ Density & volume

$V = V_{N_2} + V_{CO_2}$

$= 1.186 m^3$

(or)

$PV = mRT$

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

$= 1.1865$

$\rho = m/v$

$= \frac{7}{1.1865}$

$= 5.894 \text{ kg/m}^3$

A tank contains $0.2 m^3$ of gas mixture composed of 4 kg of nitrogen, 1 kg of oxygen and 0.5 kg of CO_2. If the temp is $20°C$. Determine the total pressure, gas constant and molar mass of the mixture.

Solution

Gas constant of N_2

$$R_{N_2} = \frac{8.314}{28} = \frac{\bar{R}}{\mu_i}$$

$$= 0.296 \text{ kJ/kg·K}$$

$$R_{O_2} = \frac{8.314}{32} = 0.2598 \text{ kJ/kg·K}$$

$$R_{CO_2} = \frac{8.314}{44} = 0.189 \text{ kJ/kg·K}$$

$$P_{N_2} = \frac{m_{N_2} R_{N_2} T_m}{V_m}$$

$$= \frac{4 \times 0.296 \times 293}{0.2}$$

$$= 1734.56 \text{ kN/m}^2$$

$$P_{O_2} = \frac{m_{O_2} R_{O_2} T_m}{V_m}$$

$$= \frac{1 \times 0.2598 \times 293}{0.2} = 387.102 \text{ kN/m}^2$$

$$P_{CO_2} = \frac{m_{CO_2} R_{CO_2} T_m}{V_m}$$

$$= \frac{0.5 \times 0.189 \times 293}{0.2}$$

$$= 138.44 \ kN/m^2$$

Total pressure = 22.588 bar.

molar mass of mixture

$$\mu_m = \frac{m_m}{n_m} = \frac{\text{mass of mixture}}{\text{mole number of mixture}}$$

mass of mixture = 4 + 1 + 0.5 = 5.5 kg

number of mole $\boxed{n_{N_2} = \frac{m_{N_2}}{\mu_{N_2}}} = 4/28$

$= 0.1428$ kmol.

$$n_{O_2} = \frac{m_{O_2}}{\mu_{O_2}} = 1/32$$

$= 0.03125$ kmol.

$$n_{CO_2} = \frac{m_{CO_2}}{\mu_{CO_2}} = \frac{0.5}{44}$$

$= 0.01136$ kmol.

$$n_m = \Sigma n_i = n_{N_2} + n_{O_2} + n_{CO_2}$$

$= 0.1854$ kmol.

59 $\boxed{\mu_m = \frac{m_m}{n_m}} = \frac{5.5}{0.1854} = 29.6$ kg/kmol.

(3) A closed vessel has a capacity of 0.5 m^3. It contain 20% of N_2 and 20% O_2 60% CO_2 by volume at 20°C and 1 MPa. Calculate the molecular mass, gas constant, mass percentage and mass of mixture.

$\mu_{N_2} = 28$ kg/k.mole.

$\mu_{CO_2} = 44$ kg/k. mole.

$\mu_{O_2} = 32$ kg/k. mole. (1)

(ii)

$R_{N_2} = \frac{8.314}{28} = 0.296$ kJ/kg.k.

$R_{CO_2} = \frac{8.314}{44} = 0.189$ kJ/kg.k.

$R_{O_2} = \frac{8.314}{32} = 0.259$ kJ/kg.k. (3)

(i) molecular mass $\mu_m = \Sigma x_i \mu_i$

$= (0.2 \times 28) + (0.2 \times 32) + (0.6 \times 44)$

$= 38.4$ kg/mol. (2)

35

number of moles of mixture

$$n_{mix} = \frac{VP}{RT}$$

$$= \frac{0.5 \times 1000}{8.314 \times 293}$$

$$\boxed{n_{mix} = 0.205 \text{ kmol.}}$$

(ii) mass of mixture molar mass $\left(\because n_{mix} = \frac{m}{\mu_m} \right.$

$$m_m = n_{mix} \times \mu_m$$

$$= 0.205 \times 38.4$$

$$= 7.881 \text{ kg}$$

(iii) mass percentage $mf_{(i)} = \frac{x_i \times \mu_i}{\mu_m}$

$$mf_{N_2} = \frac{0.2 \times 28}{\mu_m} = 0.1458$$
$$= 14.58\%$$

mf_i, $\frac{x_i \mu_i}{\mu_m}$

$$mf_{O_2} = \frac{0.2 \times 32}{\mu_m} = 0.166$$
$$= 16.66\%$$

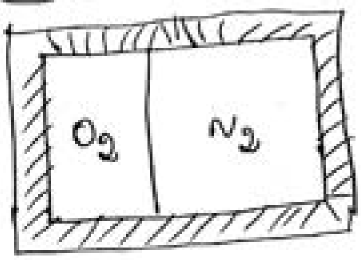
$$mf_{CO_2} = \frac{0.6 \times 44}{38.4} = 0.6875$$
$$= 68.75\%$$

(4) An insulated rigid tank is divided into two compartments by a partition. One compartment contains 7 kg of oxygen gas at 40°c and 100kpa, and the other compartment contains 4 kg of nitrogen gas at 20°c and 150 kpa. Now the partition is removed, and the two gases are allowed to mix. Determine

1. The mixture temperature
2. The mixture pressure after equilibrium has been established

$$\left[\begin{aligned} c_{v,N_2} &= 0.743\ kJ/kg\cdot k \\ c_{v,O_2} &= 0.658\ kJ/kg\cdot k. \end{aligned}\right]$$

Given Data:



$m_{O_2} = 7kg$

$T_{O_2} = 40°C = 273+40$
$= 313k$

$P_{O_2} = 100kpa$

$m_{N_2} = 4kg$ $\quad T_{N_2} = 20°c = 293k$

$P_{N_2} = 150kPa$

To find

$T_m = ?$

$P_m = ?$

$$T_m = \frac{m_{O_2} c_{v_{O_2}} T_{O_2} + m_{N_2} + c_{vN_2} + T_{N_2}}{m_{O_2} c_{vO_2} + m_{N_2} c_{vN_2}}$$

$$= \frac{(7 \times 0.658 \times 313) + (4 \times 0.743 \times 293)}{(7 \times 0.658) + (4 \times 0.743)}$$

$$= 305.16 k$$

molecular weight of O_2, $\mu_2 = 2 \times 16 = 32 kg/kg.mol$

molecular weight of N_2, $\mu_{N_2} = 28 kg/kg.mol$

$$n_{O_2} = \frac{m_{O_2}}{\mu_{O_2}} = \frac{7}{32} = 0.219 \ kg.mol$$

$$n_{N_2} = \frac{m_{N_2}}{\mu_{N_2}} = 4/28 = 0.142 \ kg.mol$$

$$n_m = n_{O_2} + n_{N_2}$$

$$= 0.219 + 0.142 = 0.362 \ kg.mol$$

volume of oxygen $V_{O_2} = \frac{N_{O_2} \bar{R} T_{O_2}}{P_{O_2}}$

$$V_{O_2} = \frac{0.219 \times 8.314 \times 313}{100}$$

$$= 5.7 m^3$$