ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

(Approved by AICTE, New Delhi. Affiliated to Anna University, Chennai)

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ANGUCHETTYPALAYAM, PANRUTI – 607 106.

ME3391 ENGINEERING THERMODYNAMICS

PREPARED BY

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DEPARTMENT OF MECHANICAL ENGINEERING

ME3391 Engineering Thermodynamics

Part- A

1. **Define the terms equilibrium path and process**

   Path: The series of states passed through by the system during a change from one equilibrium state to another. Process: When the path followed by system during change from one equilibrium state to another is completely specified (initial and final conditions, interactions with surroundings) it is called process.

2. **Write the steady flow energy equation for a turbine**

 $$W = h_1 - h_2$$

3. **State Carnot theorem**

   Carnot's theorem states that: Heat engines that are working between two heat reservoirs are less efficient than the Carnot heat engine that is operating between the same reservoirs. Irrespective of the operation details, every Carnot engine is efficient between two heat reservoirs.

4. **Define entropy.**

   Entropy is defined as a measure of randomness or disorder of a system. This concept was introduced by a German physicist named Rudolf Clausius in the year 1850.

5. **Draw the T-S diagram of a reheat cycle.**

   T-s and h-s Diagrams of Reheat Cycle:
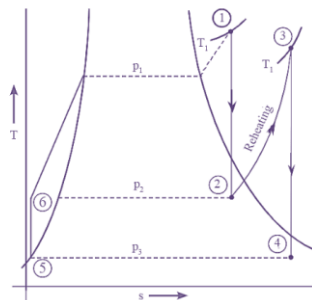
6. **Define dryness and wetness fraction.**

   Dry or saturated steam does not contain any water droplets and you produce it by heating water in a closed chamber. Wet or unsaturated steam does contain water droplets.

7. **Write down clausius clapeyron equation.(*)**

   The differential equation relating pressure of a substance to temperature in a system in which two phases of the substance are in equilibrium. where T is temperature in °C and vapor pressure is in kPa. Also called Clapeyron equation, Clapeyron–Clausius equation.)

8. **Write down first and second Tds equation.**

$TdS = T(\partial P \partial T)VdV + CVdT$.
This is the first of the TdS equations.

9. **Should the automobile radiator be analysed as a closed system or as an open system?**
If we consider radiator as a system, the mass is crossing the boundary of the system (radiator) and going into the air. In open system mass can cross the boundaries but in closed system there is no transfer of mass. Thus, the radiator should be analyzed as open system.

10. **What are intensive and extensive properties?**
An intensive property is one that does not depend on the mass of the substance or system. An extensive property of a system depends on the system size or the amount of matter in the system.

11. **A reversible heat engine operates between a source $800^{0}C$ and a sink at $30^{0}C$. What is the least rate of heat rejection per kW network output of the engine?**

Concept:

Reversible heat engine cycle will reject least rate of heat (QL) per kW net output (W) of engine.

For reversible heat engine,

$\eta = \frac{W}{Q_H} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$

Calculation:

Given $T_H = 800°C = 1073$ K, $T_L = 30°C = 303$ K, W = 1 kW,

$\frac{W}{Q_H} = 1 - \frac{T_L}{T_H} \Rightarrow \frac{1}{Q_H} = 1 - \frac{303}{1073}$

$\Rightarrow Q_H = 1.39$ kW

$\Rightarrow Q_L = Q_H - W = 1.39 - 1 = 0.39$ kW ≈ 0.4 kW

12. **Define irreversibility**
Thermodynamic irreversibility-refers to physical process that will be thermodynamically irreversible when the total entropy that is the sum of system and its reservoir becomes positive.

13. **What are compressed solid and compressed liquid?**
The solid is not compressible because as the pressure is increased, the atomic orbitals tend to overlap and due to Pauli Exclusion Principle a large repulsive force comes into play. Compressed liquid (subcooled liquid): A substance that it is not about to vaporize. • Saturated liquid: A liquid that is about to vaporize. At 1 atm and 20°C, water exists in the liquid phase (compressed liquid). At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize (saturated liquid).

14. List the methods for improving the performance of the Rankine cycle?
i)Rankine cycle with reheat
ii) Rankine cycle with regenerative

15. What is joule- Thomson coefficient? Why is it zero for an ideal gas?
As there are no intermolecular attractive forces in an ideal gas so Joule-Thomson coefficient for an ideal gas is zero as ideal will show neither heating nor cooling during J.T. effect so $\mu=\delta T/\delta P=0$.

16. What is the law of corresponding states?
According to van der Waals, the theorem of corresponding states (or principle/law of corresponding states) indicates that all fluids, when compared at the same reduced temperature and reduced pressure, have approximately the same compressibility factor and all deviate from ideal gas behavior to about the same degree.

17. State Amagat's law.
Amagat's law of partial volumes states that the total volume of a gas mixture is equal to the sum of the partial volumes each gas would occupy if it existed alone at the temperature and pressure of the mixture

18. State the zeroth law of thermodynamics
The zeroth law of thermodynamics states that if two bodies are each in thermal equilibrium with some third body, then they are also in equilibrium with each other.

19. Define entropy of a pure substance.
In the context of a pure substance, entropy can be understood as a measure of the amount of thermal energy that is unavailable for doing useful work. For a pure substance, the entropy can be expressed as a function of temperature and pressure, and is typically denoted by the symbol S.

20. Write a short note on Mollier chart.
The Mollier diagram is a graph used in thermodynamics to visualize the relationships between temperature, pressure, specific volume, enthalpy, and entropy of a substance. It's also known as the enthalpy-entropy chart.

21. List the advantages in superheating steam.
- ✓ High temperatures at normal pressure: meaning you can use simple piping.
- ✓ Extremely high thermal conductivity compared to hot air because of the high capacity per unit volume.
- ✓ Low oxygen conditions: preventing oxidation and lowering the possibility of fires or explosions.

22. State the assumptions made in deriving ideal gas equation using the kinetic theory gases.

The kinetic theory of gases assumptions: All gases are made up of molecules that are constantly and persistently moving in random directions. The separation between the molecules is much greater than the size of the molecules.

23. Differentiate between path function and point function.

A property whose value doesn't depend on the path taken to reach that specific value is known as a state function or point function. In contrast, those functions which depend on the path from two points are known as path functions.

24. What is the work transfer in free expansion process? And why?

In a free expansion, gas is allowed to expand into a vacuum. This happens quickly, so there is no heat transferred. No work is done, because the gas does not displace anything. According to the First Law, this means that: ΔE int $= 0$.

25. Compare source with sink.

Reservoir that supplies energy in the form of heat is called a source and one that absorbs energy in the form of heat is called a sink. For example, atmospheric air is a source for heat pumps and a sink for air conditioners.

26. What happens to energy, entropy and energy of an isolated system? Why?

The second law of thermodynamics states that the entropy of an isolated system never decreases, because isolated systems always evolve toward thermodynamic equilibrium, a state with maximum entropy.

27. What is degree of superheat?

It is the phenomenon in which a liquid is heated to a temperature higher than its boiling point, without boiling.

28. What is carnot vapour cycle? Plot the same on T-s diagram.

The Carnot cycle consists of the following four processes: A reversible isothermal gas expansion process. In this process, the ideal gas in the system absorbs q in amount heat from a heat source at a high temperature Thigh, expands and does work on surroundings. A reversible adiabatic gas expansion process.
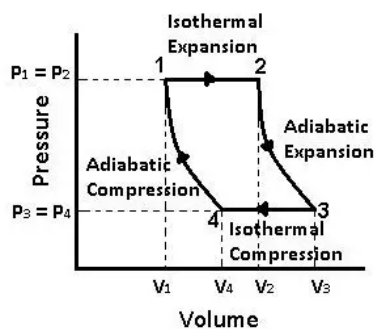
29. Define compressibility factor.

The ratio of a gas's molar volume to that of an ideal gas at constant temperature and pressure is known as the compressibility factor (Z), sometimes known as the compression factor. The compressibility factor for an ideal gas is unity, which is typically written as $Z = PV / RT$

30. What is the significance of Clasius-Clapeyron equation?

The Clausius Clapeyron equation predicts the rate at which vapour pressure increases per unit increase in temperature for a substance's vapour pressure (P) and temperature (T).

31. State Dalton's law of partial pressure.

According to Dalton's law of partial pressures, the total pressure by a mixture of gases is equal to the sum of the partial pressures of each of the constituent gases. The partial pressure is defined as the pressure each gas would exert if it alone occupied the volume of the mixture at the same temperature.

32. What is meant by control volume and control surface?

A control volume is a fixed region in space chosen for the thermodynamic study of mass and energy balances for flowing systems. The boundary of a control volume may be a real or an imaginary envelope. The control surface is the boundary of the control volume.

33. Define heat reservoir and source.

A heat reservoir is a body of uniform temperature throughout, the mass of which is sufficiently large that its temperature is unchanged by the absorption or ejection of heat.

34. What is Helmholtz free energy function?

Helmholtz free energy is a concept in thermodynamics where the work of a closed system with constant temperature and volume is measured using thermodynamic potential. It may be described as the following equation: $F = U -TS$.

35. What is critical condition of steam?

The critical pressure and critical temperature of water and steam are 22.12 MPa and 647.14 K, respectively. Any boiler that operates below the critical point is called a subcritical boiler, and one that operates above the critical point is known as a supercritical boiler.

36. What do you understand by heat rate?

The heat rate is defined as the total amount of energy required to produce one kilowatt-hour (kWh) of electricity by an electric generator or power plant. It is the input rate required for generating unit power. The heat rate can also be described as the ratio of thermal inputs to electrical output.

37. State the principle of corresponding states.

The principle of Corresponding States (PCS) was stated by van der Waals and reads: "Substances behave alike at the same reduced states. Substances at same reduced states are at corresponding states." That is, "Substances at corresponding states behave alike."

38. Identify the application of Clasius-Clapeyron equation?

It is often used to calculate vapor pressure of a liquid. The equation expresses this in a more convenient form just in terms of the latent heat, for moderate temperatures and pressures.

39. What is meant by partial volume?

Partial molar volume is an important thermodynamic property that gives insights into molecular size and intermolecular interactions in solution. Theoretical frameworks for determining the partial molar volume (V°) of a solvated molecule generally apply Scaled Particle Theory or Kirkwood–Buff theory.

40. State the first law for a closed system undergoing a process and a cycle.

According to first law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the network transfer. The cyclic integral of heat transfer is equal to cyclic integral of work transfer

41. Why does free expansion have zero work transfer?

In free expansion, no external pressure is supplied to the gas. In absence of external pressure, gas expands by its own. Thus, due to zero external pressure and heat transfer, work done is zero.

42. What is triple point? For a pure substance, how many degrees of freedom are there at triple point.

The states where three phases coexist are called triple points. Most pure substances have a triple point in which solid, liquid, and vapor phases coexist, but other triple points involving any three phases for example, polymorphic solids and 4He can be formed.
Hence degree of freedom will be Zero at triple point for pure substance.

43. A vessel of 2m^3 contains a wet steam of quality 0.8 at 210^{0}C. Determine the mass of liquid and vapour present in the vessel.

Once you have these values, you can calculate the mass of the liquid (m_{liquid}) and mass of the vapor (m_{vapor}) using the following formulas:

$$m_{liquid} = (1-x) \cdot V \cdot \rho_{liquid}$$

$$m_{vapor} = x \cdot V \cdot \rho_{vapor}$$

Where:

- x is the quality of the wet steam,
- V is the volume of the vessel,
- ρ_{liquid} is the density of the liquid phase,
- ρ_{vapor} is the density of the vapor phase.

44. Is iced water a pure substance? Why?

Yes, iced water (ice) is a pure substance. A pure substance is a substance that is composed of only one type of particle, and its composition is uniform throughout. In the case of iced water, it is primarily composed of water molecules arranged in a crystalline structure.

45. What is the effect of reheat on (a) the network output, (b) the cycle efficiency and (c) steam rate of a steam power plant ?

Reheating in a steam power plant has positive effects on the network output, cycle efficiency, and steam rate. It allows for more work to be extracted from the steam, improves the efficiency of the cycle, and reduces the amount of steam needed to produce a given amount of work. However, it's important to note that the design and operation of a power plant involve trade-offs, and the benefits of reheating must be balanced against the additional complexity and cost associated with the reheating process.

46. What are reduced properties? Give their significance.

Reduced properties are a set of dimensionless thermodynamic properties used to characterize the behavior of a substance in a standardized and general way. These properties are obtained by dividing the actual thermodynamic properties of a substance by the corresponding properties at a reference state. The reference state is often the critical point of the substance.

The reduced properties are typically defined as follows:

1. **Reduced Temperature (T_r):**

$$T_r = \frac{T}{T_c}$$

where T is the absolute temperature and T_c is the critical temperature.

2. **Reduced Pressure (P_r):**

$$P_r = \frac{P}{P_c}$$

where P is the pressure and P_c is the critical pressure.

3. **Reduced Volume (V_r):**

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

where V is the specific volume and V_c is the specific volume at the critical point.

4. **Reduced Enthalpy (H_r):**

$$H_r = \frac{H - H_c}{R \cdot T_c}$$

where H is the enthalpy, H_c is the enthalpy at the critical point, R is the specific gas constant, and T_c is the critical temperature.

47. What is the importance of Joule-Thomson coefficient?

The Joule-Thomson coefficient, often denoted as μ or μ_{JT}, is a thermodynamic property that describes the change in temperature of a gas or fluid when it undergoes a throttling process. The Joule-Thomson effect is the phenomenon where a real gas experiences a temperature change upon expansion through a valve or porous plug while being kept insulated (adiabatic process).

48. State and prove the amagat's law of partial volume.

Amagat's law of partial volumes states that "the volume occupied by a mixture of non-reacting gases at a given temperature and pressure is equal to the sum of the volumes that each gas would occupy if it alone occupied the entire container at the same temperature and pressure."

Mathematically, Amagat's law can be expressed as:

$$V = \sum_{i=1}^{n} V_i$$

Where:

- V is the total volume of the gas mixture,
- V_i is the volume of the individual gas component i in the mixture,
- n is the number of gas components in the mixture.

49. Write down the equation for first law for a steady flow process.

The first law of thermodynamics, also known as the energy balance equation, for a steady flow process can be expressed as:

$$\Delta H = Q - W$$

where:

- ΔH is the change in enthalpy of the system,
- Q is the heat added to the system,
- W is the work done by the system.

For a steady flow process, the equation is often written in terms of mass flow rates and specific enthalpies. The equation becomes:

$$\dot{H}_{i}n - \dot{H}_{o}ut = \dot{Q} - \dot{W}$$

where:

- $\dot{H}_{i}n$ and $\dot{H}_{o}ut$ are the specific enthalpies of the incoming and outgoing streams, respectively,
- $\dot{Q}$ is the rate of heat transfer to the system,
- $\dot{W}$ is the rate of work done by the system.

50. **Give the energy equation applicable for an adiabatic nozzle and an adiabatic turbine.**

Adiabatic Nozzle:

For an adiabatic nozzle, the process is typically assumed to be adiabatic (no heat transfer) and reversible (isentropic). In an adiabatic nozzle, the enthalpy remains constant, so the change in enthalpy (ΔH) is zero. Therefore, the energy equation simplifies to:

$$0 = Q - W$$

Since the process is adiabatic ($Q = 0$), the equation further simplifies to:

$$0 = -W$$

This implies that in an adiabatic nozzle, the work done is solely in the form of a decrease in enthalpy, and there is no heat exchange.

Adiabatic Turbine:

Similar to the adiabatic nozzle, the adiabatic turbine process is assumed to be adiabatic and reversible. For an adiabatic turbine, the work done is typically in the form of an increase in enthalpy. Therefore, the energy equation can be written as:

$$\Delta H = -W$$

51. **What is PMM2?**

Perpetual motion machine of the second kind (PMM2): A fictitious machine that produces net-work in a complete cycle by exchanging heat with only one reservoir is called the PMM2

52. **What do you understand by high grade energy and low grade energy?**

Energy in forms having high availability is called high-grade energy. Low-grade energy is the energy which only a small fraction can be converted to applied work. An example of high-grade energy is the energy stored in fossil fuels and electricity.

53. **Define Degree of saturation.**

The degree of saturation is defined as the ratio of actual humidity ratio to the humidity ratio of a saturated mixture at the same temperature and pressure.

54. **State Gibbs-Dalton's law.**

The Gibbs-Dalton ideal gas mixture law presumes that no molecular interactions take place between the components of the mixture, because each component is presumed to behave as though the other components were not present

55. **What are reduced properties?**

Reduced properties are used to define corresponding states. Reduced properties provide a measure of the "departure" of the conditions of the substance from its own critical conditions and are defined as follows: Pr=P/Pc

56. Write down the two Tds equations.
Also, in a constant pressure process, TdS = dH so that
T($\partial S \partial T$)P=($\partial H \partial T$)P=CP. TdS=−T($\partial V \partial T$)PdP+CPdT.
This is the second of the TdS equations. dS=($\partial S \partial P$)VdP+($\partial S \partial V$)PdV.

57. What is meant by intensive property in thermodynamics? Give two examples.

An intensive property is one that does not depend on the mass of the substance or system. Temperature (T), pressure (P) and density (r) are examples of intensive properties.

58. State the significance of Zeroth law of thermodynamics.
The zeroth law of thermodynamics is important for the mathematical formulation of thermodynamics or, more precisely, to state the mathematical definition of temperature. This law is mostly used to compare the temperatures of different objects.

59. A reversible heat engine is operated with an efficiency of 25%. If it is operated as reversible refrigerator between the same temperature limits, what is its COP?

The efficiency (η) of a heat engine is defined as the ratio of the useful work output (W_out) to the heat input (Q_in). For a reversible heat engine, the efficiency is given by:

$$\eta = \frac{W_{out}}{Q_{in}}$$

The Coefficient of Performance (COP) for a refrigerator is defined as the ratio of the heat extracted from the refrigerated space (Q_c) to the work input (W_in):

$$COP_{ref} = \frac{Q_c}{W_{in}}$$

For a reversible heat engine operating between the same temperature limits as a reversible refrigerator, the relationship between their efficiencies is given by:

$$COP_{ref} = \frac{1}{\eta - 1}$$

Given that the efficiency (η) of the reversible heat engine is 25%, or 0.25, we can substitute this value into the formula for COP:

$$COP_{ref} = \frac{1}{0.25 - 1}$$

Simplifying this expression:

$$COP_{ref} = \frac{1}{-0.75}$$

60. How does entropy of isolated system change? Why?

The second law of thermodynamics states that the entropy of an isolated system never decreases, because isolated systems always evolve toward thermodynamic equilibrium, a state with maximum entropy.

61. What is critical condition in phase change in thermodynamics?

In thermodynamics, the critical point (or critical state) is a specific set of conditions at which a substance undergoes a phase transition. The critical point is typically associated with the phase transition between the liquid and gas phases of a substance. The critical point is characterized by several important properties:

Critical Temperature (Tc): The highest temperature at which a distinct liquid and gas phase can coexist. Above this temperature, there is no clear distinction between the liquid and gas phases.

Critical Pressure (Pc): The pressure at the critical temperature where the transition between the liquid and gas phases occurs without a change in temperature.

Critical Density (ρc): The density of the substance at the critical point.

Critical Volume (Vc): The volume occupied by one mole of substance at the critical point.

62. What is the effect of reheating on network and efficiency of Rankine cycle?

Reheating is a technique used in steam power plants to improve the performance of the Rankine cycle. In a conventional Rankine cycle, steam is generated in the boiler at high pressure and then expanded through a turbine to produce work. The steam is then condensed back into liquid form in a condenser, and the cycle repeats

1.   Increased Network Output:
2.   Increased Thermal Efficiency:
3.   Reduction of Moisture Content:

63. What are the two distinct features of real gas?

Real gases deviate from ideal gas behavior under certain conditions, and two distinct features of real gases are commonly observed:

1. **Deviation from Ideal Gas Law:** Real gases do not always obey the ideal gas law under all conditions. The ideal gas law, $PV = nRT$, assumes that gas particles have no volume (point particles) and experience no attractive or repulsive forces. In reality, gas particles have finite volumes, and intermolecular forces (Van der Waals forces) come into play, especially at higher pressures and lower temperatures. As a result, real gases deviate from ideal behavior, and corrections or modifications to the ideal gas law are needed to account for these deviations.

2. **Compressibility Factor (Z):** The compressibility factor (Z) is a measure of how real gases deviate from ideal behavior. It is defined as the ratio of the molar volume of a real gas to the molar volume predicted by the ideal gas law at the same temperature and pressure:
   $$Z = \frac{V_{\text{real}}}{V_{\text{ideal}}}$$
   - If $Z = 1$, the gas behaves ideally.
   - If $Z < 1$, the gas exhibits negative deviation, suggesting that the gas particles experience attractive forces, causing the volume to be smaller than predicted by the ideal gas law.
   - If $Z > 1$, the gas exhibits positive deviation, indicating that the gas particles experience repulsive forces, causing the volume to be larger than predicted by the ideal gas law.

The compressibility factor is particularly useful in understanding and characterizing the behavior of real gases in various conditions.

64. What is the compressibility factor of Vander Walls' gas at critical point?

The compressibility factor (Z) of a gas at its critical point is a dimensionless quantity that characterizes the behavior of the gas near the critical point. For a Van der Waals gas, the expression for the compressibility factor at the critical point is known.

The Van der Waals equation of state for a real gas is given by:

$$\left(P + a\frac{n^2}{V^2}\right)(V - nb) = nRT$$

where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- T is the temperature,
- a and b are Van der Waals constants.

65. How does gas constant depend on molecular mass of the gas?

The gas constant, often denoted by R, is a fundamental constant in thermodynamics that relates the energy of a system to its temperature and pressure. The ideal gas law is expressed as $PV = nRT$, where R is the gas constant. The gas constant is related to the molecular mass of the gas through the following relationship:

$$R = \frac{R_u}{M}$$

where:

- R is the specific gas constant (per unit mass),
- R_u is the universal gas constant (a constant for all gases),
- M is the molar mass of the gas.

The universal gas constant (R_u) is the same for all gases and is approximately $8.314 \text{ J}/(\text{mol}\cdotp\text{K})$ or $0.0821 \text{ L}\cdotp\text{atm}/(\text{mol}\cdotp\text{K})$ in the commonly used units.

The specific gas constant (R) is the gas constant per unit mass. It is obtained by dividing the universal gas constant (R_u) by the molar mass (M) of the gas. The specific gas constant is particularly useful when dealing with the behavior of gases on a per-mass basis.

66. What is equation of state? Write equation of state for ideal gas.

An equation of state is a mathematical relationship that describes the thermodynamic state of a system, typically relating properties such as pressure, volume, and temperature. Different equations of state are used to model the behavior of substances under various conditions.

The equation of state for an ideal gas is known as the Ideal Gas Law. It is given by:

$PV=nRT$

where:

- P is the pressure of the gas,
- V is the volume of the gas,
- n is the number of moles of the gas,
- R is the gas constant (universal gas constant),
- T is the temperature of the gas in kelvins.

67. Define Kelvin planck statement of second law of thermodynamics

- The Kelvin-Planck statement of the second law of thermodynamics is one of the forms used to express the principles of the second law. It is named after Lord Kelvin and Max Planck. The statement is typically formulated as follows:
- "No process is possible in which the sole result is the absorption of heat from a reservoir and its complete conversion into work."

68. Prove COPHP = COPR + 1.

Coefficient of performance of Heat Pump $(COP)_H = \dfrac{Q_1}{W}$

$$Q_1 = W + Q_2 \quad \Rightarrow \quad W = Q_1 - Q_2$$

$$\therefore (COP)_H = \frac{Q_1}{Q_1 - Q_2} \quad \ldots\ldots\ldots(1)$$

Coefficient of performance of Refrigerator $(COP)_R = \dfrac{Q_2}{W}$

$Q_1 = W + Q_2 \quad \Rightarrow \quad W = Q_1 - Q_2$

$\therefore \quad (COP)_R = \dfrac{Q_2}{Q_1 - Q_2}$ ....(2)

From [(1) − (2)] we get :-

$(COP)_H - (COP)_R = \dfrac{Q_1}{Q_1 - Q_2} - \dfrac{Q_2}{Q_1 - Q_2} = 1$

∴ (COP)$_H$ = 1 + (COP)$_R$

69. What is available energy?

Available energy, also known as exergy, is a concept in thermodynamics that represents the maximum useful work that can be obtained from a system as it comes into equilibrium with its surroundings. Unlike total energy, which includes both useful and unusable components, available energy specifically refers to the portion of energy that can be converted into useful work. It is a measure of the potential to do work.

70. Define the second law efficiency for a work producing device.

The second law efficiency, also known as the thermal efficiency or exergetic efficiency, for a work-producing device is a measure of how effectively the device converts available energy (exergy) into useful work. Unlike traditional thermal efficiency, which is based on the first law of thermodynamics and considers only energy conservation, the second law efficiency takes into account the quality of energy and the irreversibilities in the system.

The second law efficiency (η_{II}) is defined as the ratio of the actual work output (W_{actual}) to the maximum possible work output (W_{max}) or available work (exergy):

$$\eta_{II} = \frac{W_{actual}}{W_{max}}$$

The maximum possible work output is determined by the available energy (exergy) of the system, and it is given by:

$$W_{max} = \text{Exergy}_{in} - \text{Exergy}_{out}$$

where:

- Exergy_{in} is the exergy of the energy input to the system,
- Exergy_{out} is the exergy of the energy rejected by the system.

71. A saturated steam has entropy of 6.76kJ/kg.K. what are its pressure, temperature and specific volume?

The given entropy value (6.76 kJ/kg·K) corresponds to saturated steam, we can use steam tables to find the corresponding pressure, temperature, and specific volume.

QUESTION 7

Determine the entropy (kJ/kg-K) of water at P = 2.49 bar and T = 93.6°C based on the saturated liquid approximation.
Note: Give your answer to four decimal places.

Properties of Saturated Water: Temperature Table

Temp	Pres	Specific Volume m3/kg		Sp. Internal Energy kJ/kg		Specific Enthalpy kJ/kg			Specific Entropy kJ/kg-K		Temp
°C	bar	vf x 10³	vg	uf	ug	hf	hfg	hg	sf	sg	°C
50	0.12350	1.0121	12.031	209.47	2443.0	209.48	2382.1	2591.6	0.7039	8.0755	50
60	0.19941	1.0170	7.670	251.61	2456.2	251.63	2357.5	2609.1	0.8323	7.9087	60
70	0.31189	1.0227	5.042	293.65	2469.1	293.69	2332.7	2626.3	0.9567	7.7545	70
80	0.47391	1.0289	3.407	335.60	2481.7	335.65	2307.5	2643.2	1.0772	7.6114	80
90	0.70141	1.0359	2.360	377.49	2494.1	377.56	2282.1	2659.6	1.1941	7.4782	90
100	1.0135	1.0434	1.673	419.39	2506.0	419.50	2256.1	2675.6	1.3080	7.3540	100
120	1.9854	1.0604	0.892	503.47	2528.8	503.68	2202.2	2705.8	1.5275	7.1288	120
140	3.6130	1.0800	0.509	588.34	2549.6	588.73	2144.7	2733.4	1.7380	6.9291	140
160	6.1785	1.1022	0.307	674.39	2567.9	675.07	2082.6	2757.6	1.9414	6.7494	160
180	10.022	1.1275	0.194	761.80	2583.2	762.93	2014.8	2777.7	2.1387	6.5849	180
200	15.539	1.1564	0.127	850.66	2594.8	852.46	1940.3	2792.7	2.3307	6.4314	200
220	23.179	1.1897	0.086	941.12	2601.9	943.88	1857.8	2801.7	2.5181	6.2852	220
240	33.443	1.2287	0.060	1033.58	2603.5	1037.69	1765.6	2803.3	2.7021	6.1429	240
260	46.887	1.2753	0.042	1128.80	2598.5	1134.78	1661.6	2796.4	2.8844	6.0010	260
280	64.118	1.3323	0.030	1227.96	2585.5	1236.50	1542.4	2778.9	3.0676	5.8561	280

72. Consider a gas mixture that consists of 3kg of O2, 5kg of N2 and 12 kg of CH4. Determine the mass fraction of each component.

Concept:

$$\text{Mass fraction of } O_2 = \frac{3}{3+5+12} = \frac{3}{20}$$

$$\therefore \text{ Mass fraction of } O_2 = 0.15$$

$$\text{Mole fraction of } O_2 = \frac{\frac{3}{32}}{\frac{3}{32}+\frac{5}{28}+\frac{12}{16}}$$

$$\text{Mole fraction of } O_2 = \frac{0.09375}{0.09375+0.1785+0.75}$$

$$\therefore \text{ Mole fraction of } O_2 = 0.0917$$

Part- B&C

1. **90 kJ of heat are supplied to a system at a constant volume. The system rejects 95 kJ of heat at constant pressure and 18 kJ of work is done on it. The system is brought to original state by adiabatic process. Determine: (i) The adiabatic work; (ii) The values of internal energy at all end states if initial value is 105 kJ.**

Given data:
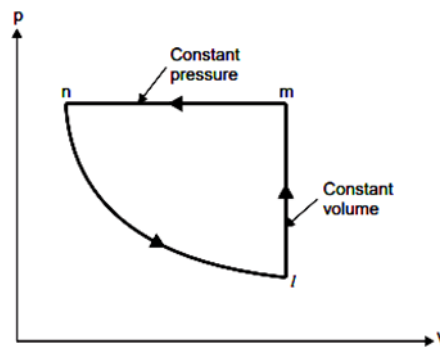
Heat supplied at constant volume = 90 kJ

Heat rejected at constant pressure = $-$ 95 kJ

Work done on the system = $-$ 18 kJ

Initial value of internal energy, U_l = 105 kJ

Process l–m (constant volume) :

$W_{l-m} = 0$

$Q_{l-m} = 90 = U_m - U_l$

$\therefore U_m = U_l + 90 = 105 + 90$

$= 195$ kJ

Process m–n (constant pressure) :

$Q_{m-n} = (U_n - U_m) + W_{m-n}$

$- 95 = (U_n - U_m) - 18$

$\therefore U_n - U_m = - 77$ kJ

$U_n = 195 - 77 = 118$ kJ

$Q_{n-l} = 0$ being adiabatic process

$\therefore \qquad \oint \delta Q = 90 - 95 = -5 \text{ kJ}$

and $\qquad \oint \delta W = -18 + W_{n-l} = -5$

$\therefore \qquad W_{n-l} = -5 + 18 = 13 \text{ kJ}$

Hence, $\quad W_{n-l} = 13 \text{ kJ} \; ; \; U_l = 105 \text{ kJ} \; ; \; U_m$

$= 195 \text{ kJ} \; ; \; U_n = 118 \text{ kJ}.$

2. The air is expanded at constant pressure to 0.09 m3 a polytrophic process with n=1.5 is then carried out, followed by a constant temperature process which completes the cycle. All the process are reversible. Sketch the cycle on pressure-volume diagram and find the heat received and heat rejected in the cycle. Take R=0.287 KJ/KgK, Cr = 0.713 KJ/KgK.

Given: P_11=7 bar,
T_1=206°C,
V_1=0.03m3,
V_2=0.09m3,

n=1.5
To find mass of the air we will use the relation,

Given: P_1=7 bar, T_1=206°C, V_1=0.03m^3, V_2=0.09m^3, n=1.5

To find mass of the air we will use the relation,

$$P_1V_1 = mRT_1 \quad m=\frac{(P_1V_1)}{(RT_1)}=\frac{(7\times10^5\times0.03)}{(287\times479)}=0.1527\text{Kg}$$

From

$$P_2V_2 = mRT_2 \quad T_2=\frac{(P_2V_2)}{mR}=\frac{(7\times10^5\times0.09)}{(0.1527\times287)}=1437.53\text{K}$$

Also

$$P_2V_2^{1}.4 = P_3V_3^{1}.4$$

And

$$\frac{T_2}{T_3}=\frac{P_2}{P_3}^{\frac{1.4-1}{1.4}}$$

But T_3=T_1 as 1 and 3 are on an isothermal line.

$$\frac{1437.53}{479}=\frac{7}{P_3}^{\frac{0.4}{1.4}}$$

p_3=0.581 bar

Now,

$$p_3V_3=mRT_3$$

$$0.581\times10^5\times V_3=0.1527\times287\times479$$

$$V_3 = 0.3613m^3$$

i) The heat received in the cycle:

Applying firs law to the constant pressure process 1-2,

Q=ΔU+W

W=$\int_1^2 pdV$

=p$(V_2 - V_1)$

=7×10^5 (0.09-0.03)

=42000J or 42 KJ

Q=mC_v $(T_2 - T_1)$+42

=0.1527×0.713(1437.53-479)+42

=146.36KJ

i.e., Heat received= 146.36kJ

Applying first law to reversible polytropic process 2-3

Q=ΔU+W

But W=$\frac{p_2 V_2 - p_1 V_1}{(n-1)}$

=mR$\frac{(T_2 - T_3)}{(n-1)}$

=$\frac{(0.1527 \times 287 \times (1437.53 - 479))}{(1.4-1)}$

=105.01KJ

$$Q = mC_v(T_3 - T_2)$$

=0.1527×0.713×(479-1437.53)+105.01

=0.6499KJ

Therefore total heat received in the cycle=146.36+0.6499=147KJ **ii) The heat rejected in the cycle:**

applying first law to reversible isothermal process 3-1 Q=ΔU+W

W=$p_3 V_3$ log_e $\frac{V_1}{V_3}$

=0.581×0.3613 log_e $\frac{0.03}{0.3613}$

=-0.52 KJ

$$Q=mC_v(T_1 - T_3) + W$$

=0-0.52

=-0.52KJ

Hence heat rejected in the cycle = 0.52KJ

3. A Piston –cylinder device contains 0.15kg of air initially at 2 MPa and 3500C. The air is first expended isothermally to 500KPa, then compressed polytropically with a polytropic exponent of 1.2 to the initial pressure and finally compressed at the constant pressure to the initial state .Determine the boundary work for each process and the network of the cycle.

1. If air properties are calculated at $300\ K$, then from Table A-2a

$$R = 0.287\ kJ/kg \cdot K$$

$$k = 1.4$$

2. If air properties are calculated at $350\ K$, then from Table A-2b

$$R = c_p - c_v = 1.008 - 0.721 = 0.287\ kJ/kg \cdot K$$

$$k = 1.398$$

Since there is very little difference, I will proceed with case 1.

Isothermal Expansion

$$V_1 = \frac{mRT}{P_1} = \frac{(0.15\ kg)(0.287\ kJ/kg \cdot K)(350 + 273.15)\ K}{2000\ kPa \times \dfrac{1\ kJ}{1\ kPa \cdot m^3}} = 0.01341\ m^3 \quad \boxed{\text{1 mark}}$$

$$V_2 = \frac{mRT}{P_2} = \frac{(0.15\ kg)(0.287\ kJ/kg \cdot K)(350 + 273.15)\ K}{500\ kPa \times \dfrac{1\ kJ}{1\ kPa \cdot m^3}} = 0.05365\ m^3 \quad \boxed{\text{1 mark}}$$

The work for an isothermal process is given as

$$W_{1-2} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) = (2000\ kPa)(0.01341\ m^3)\left(\frac{1\ kJ}{1\ kPa \cdot m^3}\right) \ln\left(\frac{0.05365}{0.01341}\right)$$

$$= 37.2\ kJ \Leftarrow \qquad \boxed{\text{2 marks}}$$

Polytropic Compression

We know for a polytropic process that $Pv^n = constant$, which for a constant mass also implies that $PV^n = constant$.

$$P_2V_2^n = P_3V_3^n \longrightarrow (500 \, kPa)(0.05365 \, m^3)^{1.2} = (2000 \, kPa)V_3^{1.2}$$

or

$$V_3 = 0.0169 \, m^3$$

$$W_{2-3} = \frac{P_3V_3 - P_2V_2}{1-n} = \frac{(2000 \, kPa)(0.0169 \, m^3) - (500 \, kPa)(0.05364 \, m^3)}{1 - 1.2} \left(\frac{1 \, kJ}{1 \, kPa \cdot m^3}\right)$$

$$= -34.9 \, kJ \Leftarrow$$

Constant Pressure Compression

The work at constant pressure is known as PdV work, therefore

$$W_{3-1} = P_3(V_1 - V_3) = (2000 \, kPa)(0.01341 \, m^3 - 0.0169 \, m^3) \left(\frac{1 \, kJ}{1 \, kPa \cdot m^3}\right)$$

$$= -6.98 \, kJ \Leftarrow$$

Net Work

$$W_{net} = W_{1-2} + W_{2-3} + W_{3-1} = 37.2 + (-34.9) + (-6.98) = -4.68 \, kJ \Leftarrow$$

4. A Piston –cylinder device contains 0.15kg of air initially at 2 MPa and 350⁰C. The air is first expended isothermally to 500KPa, then compressed poly tropically with a polytropic exponent of 1.2 to the initial pressure and finally compressed at the constant pressure to the initial state .Determine the boundary work for each process and the network of the cycle.

Given data:

m =0.15kg

p_1 =2MPa =2000KPa = p_3

T_1 =350⁰C =270+350 =623 ⁏K =T_2

P2 =500KPa

n =1.2

Process 1-2 is isothermal (Expansion)

Process 2-3 is polytropic (Compression)
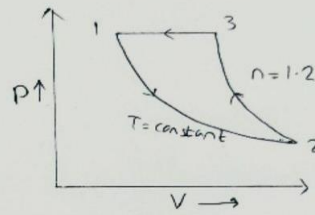
Process 3-1 is constant pressure (Compression)

Given Data: $M = 0.15 \text{ kg}$
$P_1 = P_3 = 2 \text{ MPa}$
$T_1 = 350°C$
$P_2 = 500 \text{ kPa}$
$n = 1.2$

Solution

For the isothermal expansion process the work could be defined as the following

$$W_{iso} = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$V_1 = \frac{mRT}{P_1} = \frac{0.15 \times 0.287 \times 623}{2000} = 0.01341 \text{ m}^3$$

$$V_2 = \frac{mRT}{P_2} = \frac{0.15 \times 0.287 \times 623}{500} = 0.05364 \text{ m}^3$$

$$W_{iso} = 2000 \times 0.01341 \times \ln\frac{0.05364}{0.01341} = 37.18 \text{ KJ}$$

For the polytropic compression process the work could be defined as the following

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

$P_2V_2^{1.2} = P_3V_3^{1.2}$
$500 \times (0.05364)^{1.2} = 2000 \times V_3^{1.2}$
$V_3 = 0.0169 \text{ m}^3$

$$W_{poly} = \frac{(2000 \times 0.0169) - (500 \times 0.05364)}{1-1.2} = -34.9 \text{ KJ}$$

For constant pressure process the work could be defined as the following

$$W_{cp} = P_3(V_1 - V_3)$$

$$W_{cp} = 2000 \times (0.01341 - 0.0169) = -6.98 \text{ KJ}$$

The net work for the cycle could be defined as the following

$$W_{net} = W_{iso} + W_{poly} + W_{cp}$$

$$W_{net} = 37.18 + (-34.9) + (-6.98) = -4.7 \text{ KJ}$$

5.Derive the expression for workdone for constant volume and polytropic process.

Constant volume process

W = 0 for Isochoric Process, It is true. In the Isochoric process, the volume remains constant. if the volume is constant, we can say no work has been done on the system. There is no expansion or compression of the gas

Polytropic process

$$W = \int_1^2 p dV$$

$$pV^n = const = C$$

$$W = \int_1^2 \frac{C}{V^n} dV$$

$$W = \left[\frac{C \cdot V^{1-n}}{1-n} \right]_1^2$$

$$W = \frac{C \cdot V_2^{1-n}}{1-n} - \frac{C \cdot V_1^{1-n}}{1-n}$$

multiply with $\frac{-1}{-1}$

$$W = \frac{-C \cdot V_2^{1-n}}{n-1} + \frac{C \cdot V_1^{1-n}}{n-1}$$

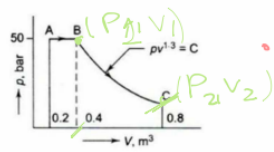$$W = \frac{C \cdot V_1^{1-n}}{n-1} - \frac{C \cdot V_2^{1-n}}{n-1}$$

replace with $C V_i^{-n} = p_i$

$$W = \frac{p_1 \cdot V_1 - p_2 \cdot V_2}{n-1}$$

6. Determine the total work done by a gas system following an expansion process as shown in Figure.
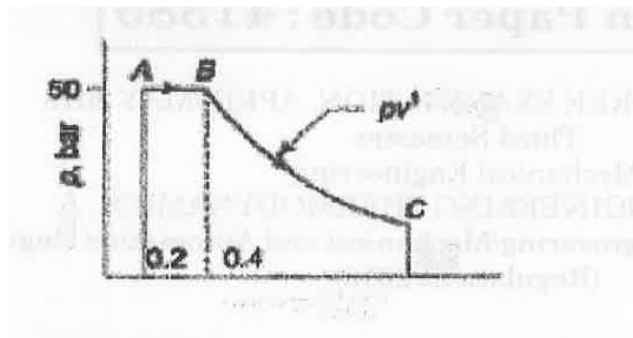
5. Determine the total work done by a gas system following an expansion process as shown in Figure.
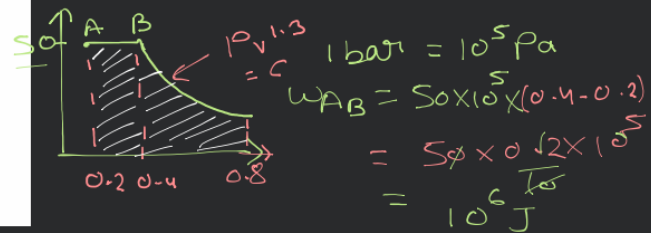
$$P_1 V_1^{1.3} = P_2 V_2^{1.3}$$
$$\Rightarrow 50(0.4)^{1.3} = P_2(0.8)^{1.3}$$
$$\Rightarrow P_2 = 50\left[\frac{1}{2^{1.3}}\right]$$
$$\boxed{P_2 = 20.306}$$

$$\boxed{PV^n = k}$$

$1 \text{ bar} = 10^5 \text{ Pa}$

$$W_{AB} = 50 \times 10^5 \times (0.4 - 0.2)$$
$$= 50 \times 0.2 \times 10^5$$
$$= 10^6 \text{ J}$$

$$W = \frac{nR\Delta T}{1-n}$$

$$W = \frac{P_2 V_2 - P_1 V_1}{1-n}$$
$$= \frac{(20.306 \times 0.8 - 50 \times 0.4) \times 10^5}{-0.3}$$
$$= \frac{[16.2448 - 20]}{-0.3} \times 10^5$$
$$= 12.51 \times 10^5$$
$$= 1.251 \times 10^6$$

$W_{AB} + W_{BC}$

$$W_T = W_{AB} + W_{BC}$$
$$= 10^6 [1 + 1.251]$$
$$\boxed{W = 2.251 \times 10^6 \text{ J}}$$

7. Prove energy as a property of a system

The concept of energy as a property of a system is fundamental in thermodynamics. Energy is considered a state function, which means its value depends only on the current state of the system and not on the path the system took to reach that state. The idea that energy is a property of a system is supported by the first law of thermodynamics, also known as the law of energy conservation.

The first law of thermodynamics is expressed mathematically as:

$$\Delta U = Q - W$$

where:

- ΔU is the change in internal energy of the system,
- Q is the heat added to the system,
- W is the work done by the system on its surroundings.

Now, let's consider a closed system, meaning it does not exchange matter with its surroundings. For a closed system, the first law can be written as:

$$\Delta U = Q - W$$

If we rearrange this equation, we get:

$$Q = \Delta U + W$$

This equation shows that the heat added to the system (Q) is equal to the change in internal energy (ΔU) plus the work done by the system (W). This equation reinforces the concept that energy is conserved in a closed system. Any heat added to the system contributes to a change in internal energy and/or work done.

8. Prove Carnot theorem

The Carnot theorem is a fundamental principle in thermodynamics that describes the maximum possible efficiency of a heat engine operating between two reservoirs at different temperatures. The Carnot theorem is based on the Carnot cycle, an idealized thermodynamic cycle that serves as a benchmark for the maximum efficiency achievable by any heat engine.

The Carnot theorem states that:

"No heat engine operating between two reservoirs at different temperatures can be more efficient than a Carnot engine operating between the same two temperatures."

To prove the Carnot theorem, let's consider the Carnot cycle and the efficiency of a Carnot engine. The Carnot cycle consists of two isothermal processes (constant temperature) and two adiabatic processes (no heat exchange). The efficiency (Carnot engine operating between two reservoirs at temperatures T_H (hot reservoir) and T_C (cold reservoir) is given by:

$\eta_{\text{Carnot}} = 1 - T_H / T_C$

Now, let's assume there is another heat engine (not Carnot) operating between the same two temperatures. According to the Carnot theorem:

Actual $\leq$ Carnot $\eta_{\text{actual}} \leq \eta_{\text{Carnot}}$

9. Derive first Tds and second Tds equation

The equations Tds and Td^2s are related to the change in entropy (ds) with respect to temperature (T) for a substance. Let's derive both the first-order (Tds) and second-order (Td^2s) expressions.

Derivation of Tds:

The fundamental relation in thermodynamics is given by the Gibbs equation:

$$dh = Tds + vdp$$

where:

- h is the enthalpy,
- T is the temperature,
- s is the entropy,
- v is the specific volume, and
- p is the pressure.

Rearranging the terms to isolate Tds, we get:

$$Tds = dh - vdp$$

This is the first-order differential expression Tds.

10. Derive clausius clapeyron equation.

The Clausius–Clapeyron equation is a thermodynamic equation that describes the relationship between the vapor pressure of a substance at two different temperatures and the enthalpy of vaporization. It is particularly useful for predicting how the vapor pressure of a substance changes with temperature.

The Clausius–Clapeyron equation is given by:

$$\frac{dP}{dT} = \frac{\Delta H_{vap}}{T \Delta V}$$

where:

- $\frac{dP}{dT}$ is the rate of change of vapor pressure with respect to temperature,
- ΔH_{vap} is the enthalpy of vaporization,
- T is the absolute temperature (in Kelvin),
- ΔV is the change in molar volume during vaporization.

Derivation:

Starting with the definition of Gibbs free energy (G):

$$G = H - TS$$

where:

- H is the enthalpy,
- T is the absolute temperature,
- S is the entropy.

For a phase change at constant temperature and pressure (such as vaporization), the change in Gibbs free energy is given by:

$$\Delta G = \Delta H - T \Delta S$$

For a reversible phase change, ΔG is zero, and we have:

$$\Delta H = T\Delta S$$

Now, considering the definition of entropy change (ΔS) as the ratio of heat transfer (q) to temperature (T):

$$\Delta S = \frac{q}{T}$$

Substituting this into the expression for ΔH:

$$\Delta H = T\frac{q}{T}$$

Simplifying:

$$\Delta H = q$$

This is the heat transfer at constant temperature and pressure, which is the enthalpy of vaporization (ΔH_{vap}).

Now, consider the definition of vapor pressure (P):

$$\frac{dP}{dT} = \frac{\Delta H_{vap}}{T\Delta V}$$

This derivation is based on certain assumptions, such as the process being reversible, and it assumes ideal behavior of the substance. T ↓ Clausius–Clapeyron equation is particularly useful for understanding how vapor pressure varies with temperature for a substance undergoing phase

11. Joule Thomson coefficient? Why is it zero for an ideal gas?

The Joule-Thomson coefficient (μ) is a measure of how the temperature of a gas changes when it undergoes throttling or expansion without exchange of heat with its surroundings. It is defined as the change in temperature with respect to pressure at constant enthalpy. Mathematically, it is expressed as:

compression of a gas without exchanging heat with its surroundings. It is defined mathematically as:

$$\mu = \left(\frac{\partial T}{\partial P}\right)_H$$

where T is the temperature, P is the pressure, and the subscript H indicates that the process is occurring at constant enthalpy.

For an ideal gas, the Joule-Thomson coefficient is zero. This result can be derived from the ideal gas law and the definition of enthalpy.

Starting with the ideal gas law:

$$PV = nRT$$

Now, differentiate both sides of the equation with respect to enthalpy (H) at constant moles (n):

$$\frac{\partial(PV)}{\partial H} = R\frac{\partial T}{\partial H}$$

Recall that $H = U + PV$, where U is the internal energy. So, $PV = H - U$.

$$\frac{\partial(H-U)}{\partial H} = R\frac{\partial T}{\partial H}$$

$$1 - \frac{\partial U}{\partial H} = R\frac{\partial T}{\partial H}$$

Now, for an ideal gas, the internal energy is only a function of temperature, not enthalpy ($\partial U/\partial H = 0$). Therefore:

$$1 = R\frac{\partial T}{\partial H}$$

$$\frac{\partial T}{\partial H} = \frac{1}{R}$$

Since R is a positive constant, the Joule-Thomson coefficient (μ) for an ideal gas is indeed zero. This means that an ideal gas does not experience a change in temperature when it undergoes a Joule-Thomson expansion or compression. In other words, there is no heating or cooling associated with the expansion or compression of an ideal gas under these conditions.

12. How do you minimize the energy consumed by your domestic refrigerator?

Minimizing the energy consumed by your domestic refrigerator can lead to both cost savings and reduced environmental impact. Here are some tips to help you improve the energy efficiency of your refrigerator:

1. **Temperature Settings:**
   - Set the refrigerator temperature to the recommended level, typically between 37°F (3°C) and 40°F (4°C).
   - Set the freezer temperature to around 0°F (-18°C).
2. **Door Seals:**
   - Ensure that the door seals are tight and in good condition. Replace them if needed.
   - Make sure the doors close properly to avoid unnecessary energy loss.
3. **Location:**
   - Place the refrigerator away from heat sources such as ovens, stoves, and direct sunlight.
   - Leave some space behind and on the sides of the refrigerator for proper ventilation.
4. **Defrosting:**
   - Regularly defrost manual-defrost freezers to maintain efficient operation.
   - Keep the freezer compartment free from excessive ice buildup.
5. **Organize the Interior:**
   - Keep the refrigerator and freezer compartments organized to allow proper air circulation.
   - Avoid overcrowding, as this can obstruct airflow and reduce efficiency.
6. **Cleaning:**
   - Clean the condenser coils at least twice a year to remove dust and debris.
   - Vacuum or brush the coils to improve heat exchange efficiency.
7. **Efficient Use:**
   - Minimize the frequency and duration of door openings.
   - Allow hot foods to cool down before placing them in the refrigerator.
8. **Energy-Efficient Models:**
   - If possible, consider upgrading to an Energy Star certified refrigerator, which meets higher energy efficiency standards.
9. **Smart Features:**
   - Some newer models come with energy-saving features such as inverter compressors and smart controls. Consider these options when purchasing a new refrigerator.
10. **Temperature Monitoring:**
- Use a refrigerator thermometer to ensure that the temperature settings are accurate and consistent.
11. **Turn Off Unnecessary Features:**
- If your refrigerator has features like ice makers or water dispensers that you don't use, consider turning them off to save energy.

By implementing these measures, you can reduce the energy consumption of your domestic refrigerator while maintaining its functionality and

13. What are the desirable characteristics of a working fluid most suitable for vapour cycles?

The choice of a working fluid is crucial in the design and operation of vapor cycles, such as Rankine and refrigeration cycles. The desirable characteristics of a working fluid for vapor cycles include:

1. **High Latent Heat of Vaporization (Enthalpy of Vaporization):**
   - A high latent heat of vaporization allows the working fluid to absorb a significant amount of heat during vaporization, contributing to efficient heat transfer in the cycle.

2. **Low Critical Temperature:**
   - A low critical temperature is desirable to avoid the need for high-temperature materials and equipment. It also allows for operation at higher pressures without reaching the critical point.

3. **Adequate Critical Pressure:**
   - A working fluid with a critical pressure that is neither too high nor too low is preferable. This helps in achieving reasonable pressures in the cycle without requiring excessively robust or expensive equipment.

4. **Low Triple Point Temperature:**
   - The triple point is the unique temperature and pressure at which all three phases (solid, liquid, and vapor) coexist in equilibrium. A lower triple point temperature allows for a wider range of operating conditions.

5. **Non-toxic and Non-flammable:**
   - For safety reasons, it is essential for the working fluid to be non-toxic and non-flammable, especially in applications where leaks or accidents could pose risks to human health or safety.

6. **Chemical Stability:**
   - The working fluid should be chemically stable and not react with system components or lubricants, ensuring the longevity of the equipment.

7. **Low Cost and Availability:**
   - Ideally, the working fluid should be economically viable and readily available, minimizing operational costs and facilitating maintenance.

8. **High Specific Volume in Vapor Phase:**
   - A high specific volume in the vapor phase allows for a larger volume change during vaporization, reducing the volume flow rate and the size of associated components like turbines and condensers.

9. **Low Viscosity:**
   - Low viscosity promotes fluid flow and reduces pumping power requirements.

10. **Compatibility with Materials:**
    - The working fluid should be compatible with the materials used in the system to prevent corrosion or other forms of degradation.

11. **Environmentally Friendly:**
    - Increasing emphasis is placed on environmentally friendly working fluids, such as those with low global warming potential (GWP) and ozone depletion potential (ODP).

12. **Ease of Condensation:**
    - The working fluid should have a condensation temperature that matches the available cooling medium, allowing for efficient heat rejection.

Different applications and operating conditions may prioritize these characteristics differently, and the choice of a working fluid depends on the specific requirements of the system. Common working fluids include water, ammonia, hydrocarbons, and refrigerant compounds like HFCs (hydrofluorocarbons) and natural refrigerants.

14. why is Carnot cycle not practicable for a steam power plant

While the Carnot cycle is a theoretical construct that establishes an upper limit on the efficiency of heat engines, it is not practical for actual steam power plants due to several reasons:

1. **Idealization of Processes:**
   - The Carnot cycle assumes all processes to be reversible, which means they can be reversed without causing any change in the system or its surroundings. Achieving reversibility in real-world processes is practically impossible due to factors like friction, irreversibilities in heat transfer, and other inherent losses.

2. **Constant Heat Source and Heat Sink Temperatures:**
   - The Carnot cycle assumes that heat is exchanged isothermally (at constant temperature) with a high-temperature reservoir and a low-temperature reservoir. In real steam power plants, achieving constant temperature heat addition and rejection is challenging, especially when dealing with boilers and condensers.

3. **Impossible in the Real World:**
   - The Carnot cycle implies a perfectly efficient and reversible engine, which is not achievable in the real world. Real engines have inherent irreversibilities and inefficiencies.

4. **Large Size of Equipment:**
   - The Carnot cycle implies large equipment size, particularly large condensers and boilers. This is not practical for real-world applications where space and cost considerations are crucial.

5. **Long Expansion and Compression Processes:**
   - The isentropic expansion and compression processes in the Carnot cycle are assumed to be infinitely slow. In real engines, the time taken for these processes is finite, and achieving very slow processes is impractical.

6. **Complexity and Cost:**
   - Achieving the conditions necessary for a Carnot cycle in a real-world steam power plant would require complex engineering solutions, making the system expensive and challenging to implement.

7. **Adiabatic Processes:**
   - The Carnot cycle requires adiabatic (no heat transfer) processes during expansion and compression. Achieving perfect adiabatic conditions is difficult in practice due to heat losses.

Despite these limitations, the Carnot cycle is valuable as a theoretical benchmark for the maximum possible efficiency of heat engines operating between two temperature reservoirs. Real-world power plants, including steam power plants, aim to approach the efficiency limits set by the Carnot cycle by minimizing irreversibilities and optimizing processes. The Rankine cycle is a more practical model for steam power plants and is widely used in engineering applications.

15. Derive the entropy equation.

The entropy equation can be derived from the definition of entropy as a state function that represents the amount of thermal energy not available to do work in a system. The change in entropy (dS) is related to heat transfer (dq) at constant temperature. The entropy change for a reversible process is given by:

$$dS = \frac{dq_{rev}}{T}$$

For an infinitesimally small change in entropy, we can write this equation as:

$$\Delta S = \frac{\Delta q_{rev}}{T}$$

Now, let's consider a reversible process in a closed system. The change in internal energy (dU) is equal to the heat added (dq_{rev}) minus the work done (dw_{rev}) on the system:

$$dU = dq_{rev} - dw_{rev}$$

Rearranging this equation, we get:

$$dq_{rev} = dU + dw_{rev}$$

16. A fluid system, contained in a piston and cylinder machine, passes through a complete cycle of four processes. The sum of all heat transferred during a cycle is – 340 kJ. The system completes 200 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)
1-2	0	4340	--
2-3	42000	0	--
3-4	-4200	--	-73200
4-1	--	--	--

Sum of all heat transferred during the cycle
$$= -340 \text{ kJ}.$$
Number of cycles completed by the system
$$= 200 \text{ cycles/min}.$$

Process 1-2:
$$Q = \Delta E + W$$
$$0 = \Delta E + 4340$$
$$\therefore \quad \Delta E = -4340 \text{ kJ/min}$$

Process 2-3:
$$Q = \Delta E + W$$
$$42000 = \Delta E + 0$$
$$\Delta E = 42000 \text{ kJ/min}$$

Process 3-4:
$$Q = \Delta E + W$$
$$-4200 = -73200 + W$$
$$\therefore \quad W = 69000 \text{ kJ/min}$$

Process 4-1:
$$\sum_{cycle} Q = -340 \text{ kJ}$$

The system completes 200 cycles/min

$$\therefore \quad Q_{1-2} = Q_{2-3} + Q_{3-4} + Q_{4-1} = -340 \times 200$$
$$= -68000 \text{ kJ/min}$$
$$0 + 42000 + (-4200) + Q_{4-1} = -68000.$$
$$Q_{4-1} = -105800 \text{ kJ/min}$$

Now, $\int dE = 0$, since cycle integral of any property is zero

$$\Delta E_{1-2} + \Delta E_{2-3} + \Delta E_{3-4} + \Delta E_{4-1} = 0$$

$$-4340 + 42000 + (-73200) + \Delta E_{4-1} = 0$$

$$\therefore \Delta E_{4-1} = 35540 \; kJ/min$$

$$\therefore W_{4-1} = Q_{4-1} - \Delta E_{4-1} = -105800 - 35540$$

$$= -141340 \; kJ/min$$

The completed table is given below:

Process	Q (kJ/min)	W(kJ/min)	ΔE (kJ/min)
1-2	0	4340	-4340
2-3	42000	0	42000
3-4	-4200	69000	-73200
4-1	-105800	-141340	35540

Since $\quad \Sigma Q = \Sigma W$
$\qquad\quad$ cycle $\quad$ cycle

Rate of work output $= -68000 \; kJ/min$

$$= \frac{-68000}{60} \; kJ/s \; or \; kW$$

$$= 1133.33 \; kW \; (\wedge$$

17. A mass of 15 kg of air in a piston-cylinder device is heated from 25 to 77 by passing through a resistance heater inside the cylinder. the pressure inside the cylinder is held constant at 300 kPa during the process, and a heat loss of 60kJ occurs. determine the electric energy supplied, in kWh.
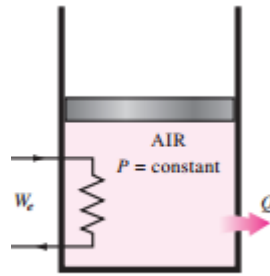
FIGURE P4–65

$$\Delta H = m \cdot c_p \cdot (T_2 - T_1)$$

$$\Delta H = 15 \text{ kg} \cdot 1.005 \frac{\text{kJ}}{\text{kg K}} \cdot (77°C - 25°C)$$

$$\Delta H = 784 \text{ kJ}$$

The **energy supplied** W is then:

$$W = \Delta H + Q$$
$$W = 784 \text{ kJ} + 60 \text{ kJ}$$
$$W = 844 \text{ kJ} \cdot \frac{1 \text{ kWh}}{3600 \text{ kJ}}$$
$$W = \boxed{0.234 \text{ kWh}}$$

18. **In the compression stroke of an internal combustion engine the heat rejected to the cooling water is 35kJ/kg and the work input is 100kJ/kg. find the change in specific internal energy of the working fluid.'**

Heat rejected to the cooling water, Q = – 50 kJ/kg (–ve sign since heat is rejected) Work input,
 W = – 100 kJ/kg (–ve sign since work is supplied to the system) Using the relation, Q = (u2 – u1) + W
 – 50 = (u2 – u1) – 100 or
 u2 – u1 = – 50 + 100 = 50 kJ/kg
 Hence, gain in internal energy = 50 kJ/kg.

19. **An adiabatic air compressor compresses 10 L/s of air at 120 kPa and 20 deg centigrade. determine the work required by the compressor, in kJ/kg and the power required to drive the air compressor, in kW**

- **Pressure, P** = 120 kPa
- **Temperature, T** = 20°C or, 293 k
- **Flow rate** = 10 L/s or, 0.01 m³/s
- **Gas constant, R** = 0.287 kJ/(kg.K)

As we know,

➜ $Density = \frac{P}{RT}$

$$= \frac{120}{0.287 \times 293}$$

$$= 1.43 \ kg/m^3$$

and,

➜ $Mass = \frac{Density}{Flow \ rate}$

$$= \frac{1.43}{0.01}$$

$$= 0.0143 \ kg/s$$

hence,

The **work** will be:

➜ $w = C_p(T_1 - T_2)$

By substituting the values,

$$= 1.005(300 - 20)$$

$$= 281.4 \ KJ/kg$$

and,

The **power** be:

➜ $P = mw$

$$= 0.0143 \times 281.4$$

$$= 4 \ kw$$

20. A reversible heat engine operates between two reservoirs at temperatures 700°C and 50°C. The engine drives a reversible refrigerator which operates between reservoirs at temperatures of 50°C and – 25°C. The heat transfer to the engine is 2500 kJ and the network output of the combined engine refrigerator plant is 400 kJ. **(i)** Determine the heat transfer to the refrigerant and the net heat transfer to the reservoir at 50°C; if efficiency of the 45% actual heat engine cycle.
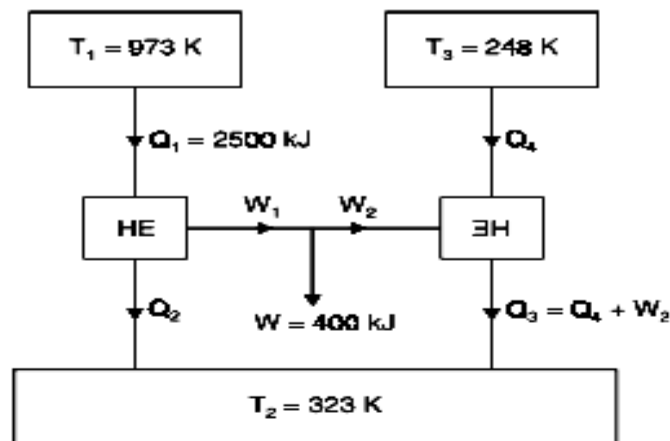
Temperature, $T_1 = 700 + 273 = 973$ K

Temperature, $T_2 = 50 + 273 = 323$ K

Temperature, $T_3 = -25 + 273 = 248$ K

The heat transfer to the heat engine, $Q_1 = 2500$ kJ

The network output of the combined engine refrigerator plant,

$W = W_1 - W_2 = 400$ kJ.

(I) Maximum efficiency of the heat engine cycle is given by

$$\eta_{max} = 1 - \frac{T_2}{T_1} = 1 - \frac{323}{973} = 0.668$$

Again, $\quad \dfrac{W_1}{Q_1} = 0.668$

∴ $\quad W_1 = 0.668 \times 2500 = 1670$ kJ

$(C.O.P.)_{max} = \dfrac{T_3}{T_2 - T_3} = \dfrac{248}{323 - 248} = 3.306$

Also, C.O.P. $= \dfrac{Q_4}{W_2} = 3.306$

Since, $W_1 - W_2 = W = 400$ kJ

$W_2 = W_1 - W = 1670 - 400 = 1270$ kJ

$\therefore Q_4 = 3.306 \times 1270 = 4198.6$ kJ

$Q_3 = Q_4 + W_2 = 4198.6 + 1270 = 5468.6$ kJ

$Q_2 = Q_1 - W_1 = 2500 - 1670 = 830$ kJ.

Heat rejection to the 50°C reservoir

$= Q_2 + Q_3 = 830 + 5468.6 = 6298.6$ kJ.

(II) Efficiency of actual heat engine cycle,

$\eta = 0.45\, \eta_{max} = 0.45 \times 0.668 = 0.3$

$\therefore W_1 = \eta \times Q_1 = 0.3 \times 2500 = 750$ kJ

$\therefore W_2 = 750 - 400 = 350$ kJ

C.O.P. of the actual refrigerator cycle,

C.O.P. $= Q_4/W_2 = 0.45 \times 3.306 = 1.48$

$\therefore Q_4 = 350 \times 1.48 = 518$ kJ.

$Q_3 = 518 + 350 = 868$ kJ

$Q_2 = 2500 - 750 = 1750$ kJ

Heat rejected to 50°C reservoir

$= Q_2 + Q_3 = 1750 + 868 = 2618$ kJ.

21. **An air preheater is used to heat up the air used for combustion by cooling the outgoing products of combustion from a furnace. The rate of flow of the products is 10 kg/s, and the products are cooled from 300°C to 200°C, and for the products at this temperature cp = 1.09 kJ/kg K. The rate of air flow is 9 kg/s, the initial air temperature is 40°C, and for the air cp = 1.005 kJ/kg K. (a) What is the initial and final availability of the products? (b) What is the irreversibility for this process? (c) If the heat transfer from the products were to take place reversibly through heat engines, what would be the final temperature of the air?**

$$\dot{m}_g \, c_{pg} \, (573 - 473) = \dot{m}_a \, c_{pa} \, (T_f - 313)$$

$$10 \times 1.09 \, (573 - 473) = 9 \times 1.005 \, (T_f - 313)$$

$$T_f = 433.5 \text{ K}$$

(a) Initial availability of the product

$$= c_{pg} \left[(573 - 300) - 300 \ln \frac{573}{300} \right]$$

$$= 85.97 \text{ kJ/kg of product}$$

$$= c_{pg} \left[(473 - 300) - 300 \ln \frac{473}{300} \right]$$

$$= 39.68 \text{ kJ/kg of product}$$

$\therefore$ Loss of availability = 46.287 kJ/kg of product

Availability gain by air

$$= c_{pg} \left[(433.5 - 313) - 300 \ln \left(\frac{433.5}{313} \right) \right]$$

$$= 22.907 \text{ kJ/kg of air}$$

$(\Delta S)_{\text{Univ}} = 0$

$(\Delta S)_{\text{gas}} + (\Delta S)_{\text{air}} = 0$

$(\Delta S)_{\text{gas}} = -(\Delta S)_{\text{air}}$

$$\dot{m}_g \, c_{pg} \ln\left(\frac{T_f}{T_i}\right)$$

$$= \dot{m}_a \, c_{pa} \ln\left(\frac{T_f}{T_i}\right)$$

$$10 \times 1.09 \ln\left(\frac{473}{10 \times 1.09 \ln(473)\,573}\right)$$

$$= -9 \times 1.005 \times \ln\frac{T_f}{313}$$

$T_f = 394.4 = 399.4$ K

$\dot{Q}_1 = \dot{m}_g \, c_{pg}(T_i - T_f) = 1090$ kJ

$Q_2 = \dot{m}_a \, c_{pa}(394.4 - 313) = 736.263$ kJ

$\dot{W} = \dot{Q}_1 - Q_2 = 353.74$ kW output of engine.

22. A power cycle operating between two thermal reservoirs receives energy Qh by heat transfer from a hot reservoir at Th= 2000K and rejects energy Qc by heat transfer to a cold reservoir Tc=400K for each of the following cases determine whether the cycle operates reversibly operates irreversibility or is impossible. A) Qh= 1000kJ, ή =60% (reversible, irreversibly, impossible)

Qh=1000 kj, ή =60%

Qh=1000kj, Wcycle=850kj

Qc =200kj, Qh=1000kj

a) $Q_H = 1000$ kJ, $\eta=60\%$ (reversibly, irreversibly, ~~impossible~~)

$$\eta = 1 - \frac{Q_c}{Q_H} \Rightarrow 0.6 = 1 - \frac{Q_c}{1000} \Rightarrow Q_c = 400 \text{ kJ}$$

a) > 0

$$= -\frac{Q_H}{T_H} + \frac{Q_c}{T_c} = -\frac{1000}{2000} + \frac{400}{400} = -0.5 + 1 = 0.5$$

b) $Q_H = 1000$ kJ, $W_{cycle} = 850$ kJ   (reversibly, ⊙irreversibly⊙ impossible)

$$Q_H - Q_c = 850 \text{ kJ} \Rightarrow Q_c = 150 \text{ kJ}$$

$$-\frac{Q_H}{T_H} + \frac{Q_c}{T_c} = -\frac{1000}{2000} + \frac{150}{400} = -0.5 + 0.375$$

b) < 0

$$= -0.125$$

c) $Q_H = 1000$ kJ, $Q_c = 200$ kJ   (⊙reversibly⊙, irreversibly, impossible)

$$-\frac{Q_H}{T_H} + \frac{Q_c}{T_c} = -\frac{1000}{2000} + \frac{200}{400}$$

c) $= 0$

$$= -0.5 + 0.5$$

$$= 0$$

23. **A 50-kg block of cast iron at 500 K is thrown into a large lake which has a temperature at 285 K. The iron block eventually reaches thermal equilibrium with the lake water. Assuming an average specific heat of 0.45 kJ / (kgK) for the iron, determine (a) the entropy, change of the iron block (b) the entropy change of the lake water, and (c) the total entropy change for the process**

Specific heat of iron block:
$C_v = m \, c_v = 22.5$ kJ/K

Entropy of iron:
$S(T) = \int dS = \int 1/T \, C_v dT = C_v \ln T$

Entropy change of iron:
$\Delta S_i = C_v \ln(T_o/T) = -12.65$ kJ/K

Entropy change of water:
$\Delta S_w = \Delta Q/T_o = C_v(T/T_o - 1) = +16.97$ kJ/K

Total entropy change:
$\Delta S = \Delta S_I + \Delta S_w = +4.3$ kJ/K

24. Steam initially at 1.5Mpa, 573 K expands reversibly and adiabatically in a steam turbine to 313 K. determine the ideal work output of the turbine per kg of steam.

The ideal work output of a steam turbine can be determined using the first law of thermodynamics and the specific enthalpy and specific entropy values of the steam at the initial and final conditions.

The first law of thermodynamics states that the change in internal energy (dU) of a system is equal to the heat added to the system (Q) minus the work done by the system (W). For a reversible and adiabatic process, the heat added to the system is zero (Q = 0) and the change in internal energy is equal to the work done by the system (dU = W).

The specific enthalpy (h) and specific entropy (s) of steam can be found using thermodynamic tables. At 1.5 MPa and 300°C, the specific enthalpy of steam is 3485 kJ/kg and the specific entropy is 6.8 kJ/kg-K. At 40°C and 1.5 MPa, the specific enthalpy is 2789 kJ/kg and the specific entropy is 7.2 kJ/kg-K.

Therefore, the ideal work output of the turbine per kg of steam can be determined using the following equation:

$$W = H1 - H2 = 3485 - 2789 = 696KJ/KG$$

So the ideal work output of the turbine per kg of steam is 696 kJ/kg.

25. A rigid tank contains 2 k mol of N_2 and 6 kmol of CO_2 gases at 300 K and 15 Mpa. Estimate the volume of the tank on the basis of i) the ideal gas equation of state ii) compressibility factor's Amagat's law.

A rigid tank contains 2 kmol of N_2 and 6 kmol of CO_2 gases at 300 K and 15 MPa (Fig. 13–10). Estimate the volume of the tank on the basis of (a) the ideal-gas equation of state, (b) Kay's rule, (c) compressibility factors and Amagat's law, and (d) compressibility factors and Dalton's law.

> 2 kmol N_2
> 6 kmol CO_2
> 300 K
> 15 MPa
> $V_m = ?$

FIGURE 13–10

Schematic for Example 13–2.

Solution The composition of a mixture in a rigid tank is given. The volume of the tank is to be determined using four different approaches.

Assumptions Stated in each section.

Analysis (a) When the mixture is assumed to behave as an ideal gas, the volume of the mixture is easily determined from the ideal-gas relation for the mixture:

$$V_m = \frac{N_m R_u T_m}{P_m} = \frac{(8\,kmol)(8.314\,kPa \cdot m^3/kmol \cdot K)(300\,K)}{15{,}000\,kPa} = 1.330\,m^3$$

since

$$N_m = N_{N_2} + N_{CO_2} = 2 + 6 = 8\,kmol$$

(c) When Amagat's law is used in conjunction with compressibility factors, Z_m is determined from Eq. 13–10. But first we need to determine the Z of each component on the basis of Amagat's law:

$$N_2: \quad T_{R,N_2} = \frac{T_m}{T_{cr,N_2}} = \frac{300 \text{ K}}{126.2 \text{ K}} = 2.38$$

$$P_{R,N_2} = \frac{P_m}{P_{cr,N_2}} = \frac{15 \text{ MPa}}{3.39 \text{ MPa}} = 4.42$$

$$\left.\right\} \quad Z_{N_2} = 1.02 \qquad \text{(Fig. A–15b)}$$

$$CO_2: \quad T_{R,CO_2} = \frac{T_m}{T_{cr,CO_2}} = \frac{300 \text{ K}}{304.2 \text{ K}} = 0.99$$

$$P_{R,CO_2} = \frac{P_m}{P_{cr,CO_2}} = \frac{15 \text{ MPa}}{7.39 \text{ MPa}} = 2.03$$

$$\left.\right\} \quad Z_{CO_2} = 0.30 \qquad \text{(Fig. A–15b)}$$

Mixture: $\quad Z_m = \sum y_i Z_i = y_{N_2} Z_{N_2} + y_{CO_2} Z_{CO_2}$

$$= (0.25)(1.02) + (0.75)(0.30) = 0.48$$

Thus,

$$V_m = \frac{Z_m N_m R_u T_m}{P_m} = Z_m V_{ideal} = (0.48)(1.330 \text{ m}^3) = 0.638 \text{ m}^3$$

The compressibility factor in this case turned out to be almost the same as the one determined by using Kay's rule.

26. Two grams of a saturated liquid are converted to a saturated vapor by being heated in a weighted piston-cylinder device arranged to maintain the pressure at 200 kPa. During the phase conversion, the volume of the system increases by 1000Cm3; 5 kJ of heat are required; and the temperature of the substance stays constant at 80∘C. Estimate the boiling temperature of this substance when its pressure is 180 kPa

To estimate the boiling temperature of the substance at a pressure of 180 kPa, we can use the Clausius-Clapeyron equation, which relates the vapor pressure of a substance at two different temperatures:

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

where:

- P_1 is the initial pressure (200 kPa),
- P_2 is the final pressure (180 kPa),
- ΔH_{vap} is the heat of vaporization,
- R is the gas constant,
- T_1 is the initial temperature (80°C + 273.15 K),
- T_2 is the final temperature (boiling temperature we want to find).

We can rearrange this equation to solve for T_2:

$$\frac{1}{T_2} = \frac{1}{T_1} - \frac{R}{\Delta H_{vap}}\ln\left(\frac{P_2}{P_1}\right)$$

Now, we need to find the heat of vaporization (ΔH_{vap}). The heat added during the phase change is given by:

$\downarrow$

$$Q = \Delta H_{vap}$$

Given that $Q = 5$ kJ, convert this to joules: $Q = 5$ kJ $\times 1000$ J/kJ.

Now, we can substitute the known values into the equation to find T_2. Make sure to use consistent units.

$$\frac{1}{T_2} = \frac{1}{T_1} - \frac{R}{\Delta H_{vap}}\ln\left(\frac{P_2}{P_1}\right)$$

$$T_2 = \frac{1}{\frac{1}{T_1} - \frac{R}{\Delta H_{vap}}\ln\left(\frac{P_2}{P_1}\right)}$$

Substitute the values and solve for T_2. Keep in mind that temperatures should be in Kelvin for this calculation.

27. A piston-cylinder device initially contains 1.5 kg of liquid water at 150 kPa and 20⁰C. The water is now heated at constant pressure by the addition of 4000 kJ of heat. Determine the entropy change of the water during this process.

State 1:
$$\left. \begin{array}{l} P_1 = 150 \text{ kPa} \\ T_1 = 20°C \end{array} \right\} \quad \begin{array}{l} s_1 \cong s_{f@\,20°C} = 0.2965 \text{ kJ/kg.K} \\ h_1 \cong h_{f@20°C} = 83.915 \text{ kJ/kg} \end{array}$$

At the final state, the pressure is still 150 kPa, but we need one more property to fix the state. This property is determined from the energy balance,

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$Q_{in} - W_b = \Delta U$$

$$Q_{in} = \Delta H = m(h_2 - h_1)$$

$$4000 \text{ kJ} = (1.5 \text{ kg})(h_2 - 83.915 \text{ kJ/kg})$$

$$h_2 = 2750.6 \text{ kJ/kg}$$

since $\Delta U + W_b = \Delta H$ for a constant-pressure quasi-equilibrium process. Then,

State 2:
$$\left. \begin{array}{l} P_2 = 150 \text{ kPa} \\ h_2 = 2750.6 \text{ kJ/kg} \end{array} \right\} \quad \begin{array}{l} s_2 = 7.3674 \text{ kJ/kg.K} \\ \text{(Table A-6 , interpolation)} \end{array}$$

Therefore, the entropy change of water during this process is

$$\Delta S = m(s_2 - s_1) = (1.5 \text{ kg})(7.3674 - 0.2965) \text{ kJ/kg.K}$$
$$= 10.61 \text{ kJ/K}$$
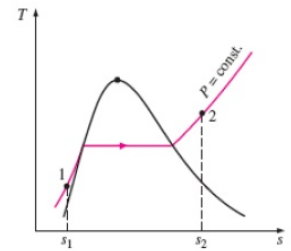
28. State first law of thermodynamics and list its limitations.

The first law establishes the relationship between work done and heat absorbed while doing that work. However, it fails to specify the direction of heat flow, which is a significant limitation of this law. Example- We cannot extract heat from a cube of ice by cooling it to low temperatures.

29. Derive steady flow energy equation per unit mass and show that shaft work Produced by a gas turbine is equal to the enthalpy drop across the gas turbine.

Steady Flow Energy Equation (S.F.E.E.)

$$m\left(h_1 + \frac{v_1^2}{2} + gz_1\right) + \dot{Q} = m\left(h_2 + \frac{v_2^2}{2} + gz_2\right) + \dot{W}$$

Now,

Boiler:

- $\dot{W}$ = 0, no work is done by the boiler,
- Change in kinetic and potential energy is neglected (ΔK.E = ΔP.E = 0)

$\therefore \dot{Q} = \dot{m}(h_2 - h_1)$

Nozzle:

- $\dot{Q}$ = 0, as the nozzle is perfectly insulated.
- $\dot{W}$ = 0, no work is done by the nozzle, $v_1 <<< v_2$ and potential energy change is neglected

$\therefore v_2 = \sqrt{2(h_1 - h_2)}$

Turbine:

- Q = 0, for the adiabatic or perfectly insulated turbine,
- Change in kinetic and potential energy is neglected

$\therefore \dot{W} = \dot{m}(h_1 - h_2)$

Compressor:

- $\dot{Q}$ = 0, for the adiabatic or perfectly insulated turbine,
- Change in kinetic and potential energy is neglected (ΔK.E = ΔP.E = 0)

$\therefore \dot{W} = \dot{m}(h_2 - h_1)$

Points to remember:

Device	S.F.E.E
Nozzle	$v_2 = \sqrt{2\,(h_1 - h_2)}$
Turbine	$\dot{W} = \dot{m}(h_1 - h_2)$
Compressor	$\dot{W} = \dot{m}(h_2 - h_1)$
Boiler	$Q = \dot{m}(h_2 - h_1)$

30. **A blower handles 1 kg/s of air at 293 K and consumes a power of 15kW. The inlet and outlet velocities of the air are 100 m/s and 150 m/s respectively. Find the exit air temperature and the pressure ratio, assuming adiabatic conditions. Take C_p = 1.005kJ/kg.**

$t_1 = 20°C$
$V_1 = 100$ m/s

$V_2 = 150$ m/s
$t_2 = ?$

$\dfrac{dW}{dt} = -15$ kN
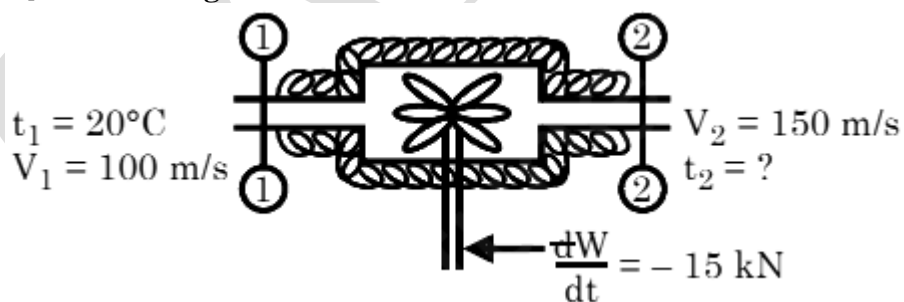
$$w_1\left(h_1 + \frac{V_1^2}{2000} + \frac{gZ_1}{1000}\right) + \frac{dQ}{dt} = w_2\left(h_2 + \frac{V_2^2}{2000} + \frac{gZ_2}{1000}\right) + \frac{dW}{dt}$$

Here $w_1 = w_2 = 1\ kg/s$; $Z_1 = Z_2$; $\dfrac{dQ}{dt} = 0$.

$$\therefore\quad h_1 + \frac{100^2}{2000} + 0 = h_2 + \frac{150^2}{2000} - 15$$

$$\therefore\quad h_2 - h_1 = \left(15 + \frac{100^2}{2000} - \frac{150^2}{2000}\right)$$

or $C_p\left(t_2 - t_1\right) = 8.75$

or $t_2 = 20 + \dfrac{8.75}{1.005} = 28.7^\circ C$

31. State and derive Clausius inequality.

The **Inequality of Clausius.** — If an actual irreversible change be represented by the path i, Fig. 20 (assuming it to be possible to give such a representation), a correct value of the change cannot be obtained from the integral $\int_{T_1}^{T_2} \frac{dQ_i}{T}$ taken along the path i. For as we have seen

$$S_2 - S_1 = \int_{T_1}^{T_2} \frac{dQ_i}{T} + \Sigma,$$

where Σ is the increase of entropy due to the internal irreversible changes. For the actual irreversible change we have, therefore,

$$S_2 - S_1 > \int_{T_1}^{T_2} \frac{dQ}{T}.$$
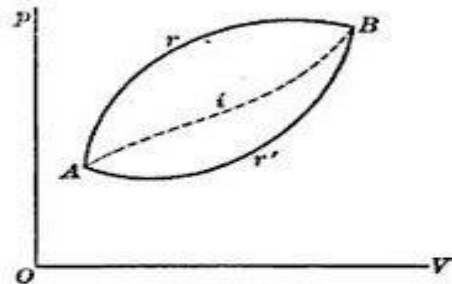

Fig. 20.

This is the inequality of Clausius.

32. A reversible engine operates between a source at 972°C and two sinks, one at 127°C and another at 27°C. The energy rejected is same at both the sinks. Compute the engine efficiency. Also calculate the power and rate of heat supply if the rate of heat rejected to each sink is 100 kW.

The efficiency (η) of a reversible engine operating between a high-temperature reservoir (source) and two low-temperature reservoirs (sinks) can be determined using the Carnot efficiency formula:

$\eta = 1 - T_H/T_C$

where:

- T_C is the absolute temperature of the colder sink,

- T_H is the absolute temperature of the hotter source.

Given:

- Source temperature (T_H) = 972°C
- Colder sink temperature (T_C) = 127°C
- Hotter sink temperature ($'T_{H'}$) = 27°C

Convert temperatures to Kelvin: $T_H = 972 + 273.15$

$T_C = 127 + 273.15 =$

$T_{H'} = 27 + 273.15 =$

Calculate the Carnot efficiency for each sink: $\eta_C = 1 - T_H T_C$

$\eta_{C'} = 1 - T_H T_{H'}$

The total energy rejected (Q_C) is the sum of the energy rejected to each sink.

$Q_C = Q_{C1} + Q_{C2}$

For each sink: $Q_C = \dot{Q}_C$

The power ($\dot{W}$) of the engine is given by: $\dot{W} = \eta \cdot \dot{Q}_H$

The rate of heat supply ($\dot{Q}_H$) is equal to the sum of the rate of heat rejected to each sink.

$\dot{Q}_H = \dot{Q}_{C1} + \dot{Q}_{C2}$

33. Draw the Carnot cycle on p-V and T-s diagram and derive the efficiency of Carnot cycle based on T-s diagram.
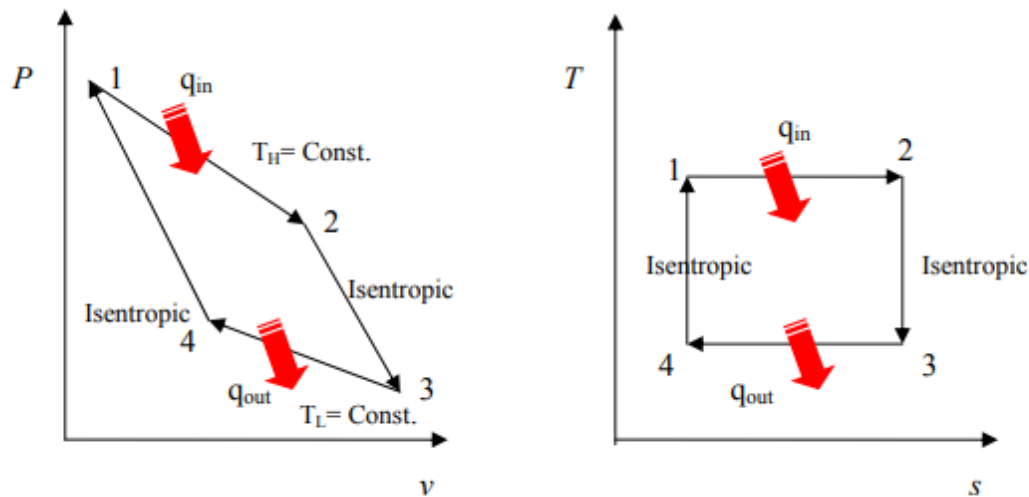
Fig. 2-2: P-v and T-s diagrams for the Carnot cycle (in a cylinder-piston).

Process 1-2, isothermal heat transfer (heat supply): heat is supplied at constant temperature T_H

Process 2-3, isentropic expansion (work output): air expands isentropically from the high pressure and temperature to the low pressure and temperature

Process 3-4, isothermal heat transfer (condenser or heat rejection): heat is rejected at constant temperature T_L

Process 4-1, isentropic compression (work in): the air compresses isentropically to the high pressure and temperature.

Thermal efficiency of the Carnot cycle can be calculated from:

$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H}$$

34.

Air flows through an adiabatic compressor at 2 kg/s. The inlet conditions are 1 bar and 310 K and the exit conditions are 7 bar and 560 K. Compute the net rate of availability transfer and the irreversibility. Take $T_0 = 298$ K.

(Ans. 481.1 kW and 21.2 kW)

Mass flow rate $(\dot{m}) = 2$ kg/s

$p_i = 1$ bar $= 100$ kPa $\qquad\qquad$ $p_f = 7$ bar $= 700$ kPa $\qquad\qquad$ $T_0 = 298$ K

$T_i = 310$ K $\qquad\qquad\qquad\qquad$ $T_f = 560$ K

Calculated data:

$$\dot{V}_i = \frac{\dot{m}\,RT_i}{p_i} = 1.7794 \text{ m}^3/\text{s} \qquad \dot{V}_f = \frac{\dot{m}\,RT_f}{p_f} = 0.4592 \text{ m}^3/\text{s}$$

Availability increase rate of air $= B_2 - B_1$

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

$$= \dot{m}\,c_P(T_2 - T_1) - T_0\left\{m c_P \ln\frac{V_2}{V_1} + m c_v \ln\frac{p_2}{p_1}\right\}$$

$$= \dot{m}\left[c_P(T_2 - T_1) - T_0\left\{c_P \ln\frac{V_2}{V_1} + c_v \ln\frac{p_2}{p_1}\right\}\right]$$

$$= 2[251.25 - 10.682] \text{ kW}$$
$$= 481.14 \text{ kW}$$

Actual work required$= \dot{m}(h_2 - h_1)$

$$W = 2 \times 251.25 \text{ kW} = 502.5 \text{ kW}$$

$\therefore$ $\quad$ Irreversibility $= W_{act.} - W_{min.}$
$$= (502.5 - 481.14) \text{ kW}$$
$$= 21.36 \text{ kW}$$

35. Explain the use of Throttling Calorimeter to determine dryness fraction Steam flows through a small turbine at the rate of 500 kg/h entering at 15 bar, 300°C and leaving gat 0.1 bar with 4% moisture. The steam enters at 80 m/s at a point 2 m above the discharge and leaves at 40 m/s. compute the shaft power assuming that the device is adiabatic but considering kinetic and potential energy changes. Calculate the areas of the inlet and discharge tubes.

1. **Throttling Process:**
   - The steam is initially at a higher pressure and temperature.
   - It passes through a throttle valve, leading to a rapid drop in pressure.
   - Due to the sudden drop in pressure, the steam undergoes adiabatic expansion, and its temperature decreases.
2. **Calorimeter:**
   - A calorimeter is attached downstream to measure the temperature of the steam after throttling.
   - The calorimeter is designed to absorb any moisture in the steam, leaving only dry steam for temperature measurement.
3. **Dryness Fraction Calculation:**
   - By measuring the temperature of the steam after throttling and comparing it with the saturation temperature corresponding to the final pressure, the dryness fraction can be determined using steam tables.

Now, let's apply this principle to the given scenario of a steam turbine:

Given data:

- Inlet conditions: $P_1 = 15$ bar, $T_1 = 300°C$
- Outlet conditions: $P_2 = 0.1$ bar, $x_2 = 0.04$ (4% moisture content)

Assuming adiabatic conditions, the work done by the steam in the turbine is given by the change in enthalpy. The kinetic and potential energy changes also need to be considered.

1. **Calculate Enthalpies:**
$$h_1 = h_{g_1} + x_1 h_{f_1}$$
$$h_2 = h_{g_2} + x_2 h_{f_2}$$
Use steam tables to find the enthalpies at the given conditions.

2. **Calculate Work Done:**
$$W = h_1 - h_2$$

3. **Consider Kinetic and Potential Energy Changes:**
$$W_{\text{kinetic}} = \tfrac{1}{2} \cdot (V_2^2 - V_1^2)$$
$$W_{\text{potential}} = g \cdot (z_2 - z_1)$$

4. **Calculate Total Shaft Power:**
$$\text{Shaft Power} = W + W_{\text{kinetic}} + W_{\text{potential}}$$

5. **Calculate Tube Areas:**
   - The areas of the inlet and discharge tubes can be calculated using the mass flow rate and velocity.

$$A_1 = \frac{\dot{m}}{\rho_1 \cdot V_1}$$
$$A_2 = \frac{\dot{m}}{\rho_2 \cdot V_2}$$

where $\dot{m}$ is the mass flow rate, ρ is the density, and V is the velocity.
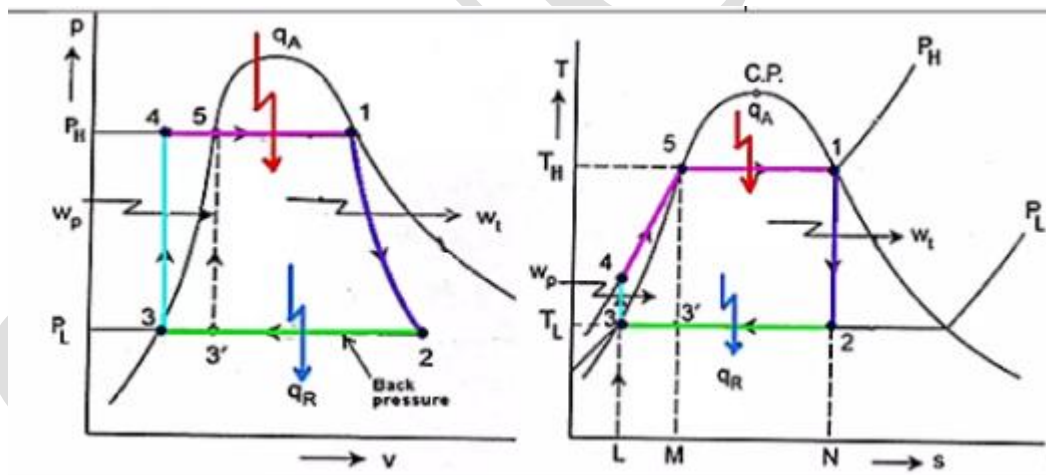
36. Draw Rankine Cycle on T-s and H-s diagram with steam at superheated condition at the entry of turbine and explain the effect of super-heated steam on network and efficiency, compared to saturated steam based Rankine cycle.
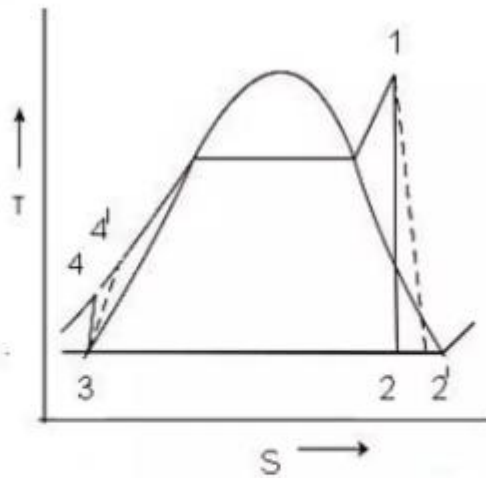
$$\eta(Turbine/Rankin) = \frac{Actual\ Turbine\ Work}{Ideal\ Turbine\ Work} = \frac{(h1-h2')}{(h1-h2)}$$

$$\eta(Pump/Rankin) = \frac{Ideal\ Pump\ Work}{Actual\ Pump\ work\ Work} = \frac{(h4-h3)}{(h4'-h3)}$$

$$\text{Thermal efficiency (Rankine)} = \frac{Net\ Work}{Heat\ added} = \frac{Turbine\ Work - Compression\ or\ Pumping\ Work}{Heat\ added}$$

$$\therefore \text{Thermal efficiency } \eta(Rankine) = \frac{W_T - W_C}{Q_S}$$

Turbine Work $W_T = (h1 - h2)$

Compressor or Pumping work $W_C = (h4 - h3)$

Heat added $Q_S = (h1 - h4) = T1(S1 - S4)$

Heat rejected $Q_R = (h2 - h3) = T3(S2 - S3)$

$$\therefore \eta(Rankine) = \frac{(h1 - h2) - (h4 - h3)}{(h1 - h4)}$$

Rearranging $(h1 - h4)$ **as** $(h1 - h3) - (h4 - h3)$ **we get**

$$\therefore \eta(Rankine) = \frac{(h1 - h2) - (h4 - h3)}{(h1 - h3) - (h4 - h3)} = \frac{(h1 - h2) - W_P}{(h1 - h3) - W_P}$$

In a Rankine cycle the pump work may be neglected as it is very small compared with other

Superheated Rankine cycle : The average temperature at which heat is added to the steam can be increased without increasing the boiler pressure by superheating the steam to high temperatures. Thus, efficiency increases.

37. **Steam enters the turbine at 3 MPa and 400°C and is condensed at 10 KPa. Some quantity of steam leaves the turbine at 0.6 MPa and enters open feed water heater. Compute the fraction of the steam extracted per kg of steam and cycle thermal efficiency.**

A steam power plant based on ideal regenerative Rankine cycle. Steam enters the turbine at 400°C and 3 MPa state while the condenser pressure is 10 kPa. Find cycle efficiency and mass fraction of steam extracted at 0.6 MPa for open type feed water heater.
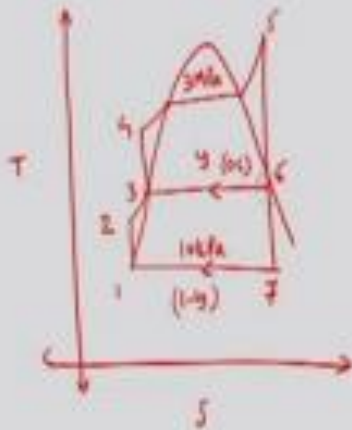
given $P_4 = P_5 = 3 MPa$ $P_2 = P_3 = P_6 = 0.6 MPa$ $P_1 = P_7 = 10 kPa$

$T_5 = 400°C$

$h_1 = 191.83 \, kJ/kg$, $v_1 = 0.001010 \, m^3/kg$,

$\Delta h|_{P_1} = w_{P_1} = v_1(P_2 - P_1) = 0.001010 (600 - 10) = 0.5959 \, kJ/kg$

$h_3 = 670.56 \, kJ/kg$, $v_3 = 0.001101 \, m^3/kg$

$w_{P_2} = v_3 \cdot (P_4 - P_3) = 0.001101 (3000 - 600) = 2.6424 \, kJ/kg$

$h_2 = h_1 + \Delta h|_{P_1} = 191.83 + 0.5959 = 192.43 \, kJ/kg$

$h_4 = h_3 + w_{P_2} = 670.56 + 2.6424 = 673.2 \, kJ/kg$

$h_5 = 3230.9 \, kJ/kg$ $S_5 = 6.9212 \, kJ/kgK$

$S_5 = S_6 \longrightarrow h_6 = 2829.63 \, kJ/kg$ $T_6 = 190.97°C$

$y = \dfrac{h_3 - h_2}{h_6 - h_2} = \dfrac{670.56 - 192.43}{2829.63 - 192.43} = 0.181$

$S_6 = S_7 = S_f + x_7 S_{fg} \longrightarrow x_7 = (S_7 - S_1)/S_{fg}$

$x_7 = \dfrac{6.9212 - 0.6493}{8.1502 - 0.6493} = 0.836$

$h_7 = h_1 + x_7 \cdot h_{fg} = 191.83 + 0.836 \times (2547 - 191.83)$

$h_7 = 2192.22 \, kJ/kg$

$q_{in} = h_5 - h_4 = 3230.9 - 673.20$

$q_{in} = 2557.7 \, kJ/kg$

$q_{out} = (1-y) \cdot (h_2 - h_1)$

$q_{out} = (1 - 0.181)(2192.27 - 191.83)$

$q_{out} = 1638.36 \, kJ/kg$

$\eta = 1 - \dfrac{q_{out}}{q_{in}}$

$\eta = 1 - \dfrac{1638.36}{2557.7}$

$\underline{\eta = 35.9\%}$

38. Deduce the value of Van der Waals' constant in terms of critical properties.

Derivation of critical constants from the Van der Waals constants:

Van der Waals equation is,

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT \text{ for 1 mole}$$

From this equation, the values of critical constant $P_C V_C$ and T_C arc derived in terms of a and b the Van der Waals constants.

$$\left(P + \frac{an^2}{V^2}\right)(V - b) = RT \quad \text{..........(1)}$$

On expanding the equestion (1)

$$PV + \frac{a}{V} - Pb - \frac{ab}{V^2} - RT = 0 \quad \text{.........(2)}$$

Multiplying eqestion (2) by $\frac{V^2}{P}$,

$$\frac{V^2}{P}\left(PV + \frac{a}{V} - Pb - \frac{ab}{V^2} - RT\right) = 0$$

$$V^3 + \frac{aV}{P} - bV^2 - \frac{ab}{P} - \frac{RRV^2}{P} = 0 \quad \text{........(3)}$$

equation (3) is rearranged in the powers of V

equation (3) is rearranged in the powers of V

$$V^3 - \left[\frac{RT}{P} + b\right]V^2 + \frac{aV}{P} - \frac{ab}{P} = 0 \quad \text{.........(4)}$$

The above equation (4) is an cubic equation of V, which can have three roots. At the critical point. all the three values of V are equal to the critical volume V_C.

i.e. $V = V_C$.

$V - V_C = 0$ ....(5)

$(V - V_C)^3 = 0$ ....(6)

$(V^3 - 3V_C V^2 + 3V_C^3 V - V_C^3 = 0$ ....(7)

As equation (4) is identical with equation (7), comparing the 'V' terms in (4) and (7),

$$- 3V_C V^2 = -\left[\frac{RT_C}{P_C} + b\right]V^2 \quad \text{.......(8)}$$

$$3V_C = b + \frac{RT_C}{P_C} \quad \text{........(9)}$$

$$3V_C^2 = \frac{a}{P_C} \quad \text{........(10)}$$

$$V_C^3 = \frac{ab}{P_C} \quad \text{.....(11)}$$

Divide equation (11) by (10)

$$\frac{V_C^3}{3V_C^2} = \frac{\frac{ab}{P_C}}{\frac{a}{P_C}}$$

$$\frac{V_C}{3} = b$$

$$\therefore V_C = 3b \quad \text{.......(12)}$$

When equation (12) is substituted in (10)

$$3V_C^2 = \frac{a}{P_C}$$

$$P_C = \frac{a}{3V_C^2} = \frac{a}{3(3b)^2} = \frac{a}{3 \times 9b^2} = \frac{a}{27b^2}$$

$$\therefore P_C = \frac{a}{27b^2} \quad \text{.......(13)}$$

substituting the values of V_C and P_C in equation (9)

$$3V_C = b + \frac{RT_C}{P_C}$$

$$3 \times 3b = b + \frac{RT_C}{\frac{a}{27b^2}}$$

$$9b - b = \frac{RT_C}{a} \times 27b^2$$

$$8b = \frac{T_C \cdot R27b^2}{a}$$

$$\therefore T_C = \frac{8ab}{27Rb^2} = \frac{8a}{27RB}$$

$$T_C = \frac{8a}{27RB} \quad \text{....... (14)}$$

Critical constant a and b can be calculated using Van der Waals Constant as follows:
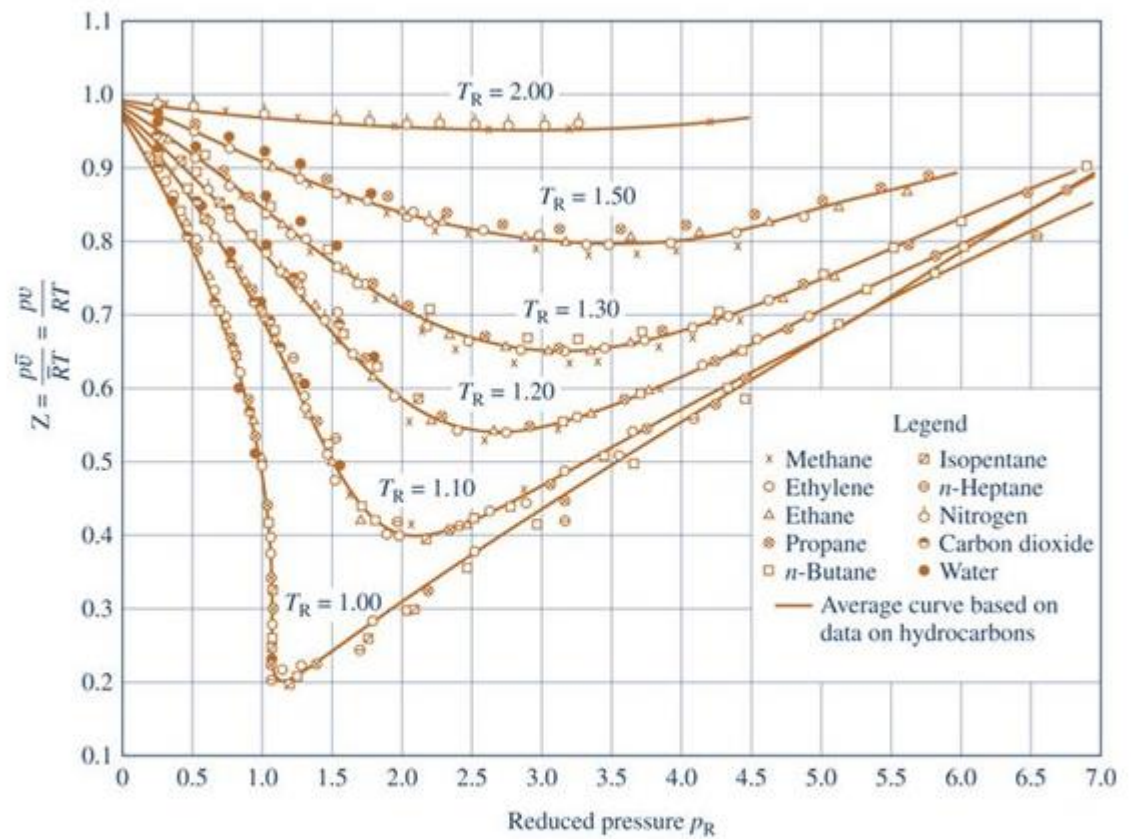
$$a = 3V_C^2 P_C$$

$$b = \frac{V_C}{3} \quad \text{.......(15)}$$

39. Explain reduced properties and their uses in generalised compressibility chart. List the advantages of generalized compressibility chart.

The generalized compressibility chart shows the p-v-T relation for gases.

Schematics

Axes

In the chart, the compressibility factor, Z, is plotted versus the reduced pressure, pR, and reduced temperature TR.

$$Z = \frac{p\bar{v}}{\bar{R}T} \qquad p_R = p/p_c \qquad T_R = T/T_c$$

$\bar{R}$ is the **universal gas constant**

$$\bar{R} = \begin{cases} 8.314 \text{ kJ/kmol·K} \\ 1.986 \text{ Btu/lbmol·°R} \\ 1545 \text{ ft·lbf/lbmol·°R} \end{cases} \qquad \textbf{(Eq. 3.22)}$$

Compressibility factor

An alternative form is given by

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

where

$$R = \frac{\bar{R}}{M}$$

Reduced pressure

The symbols pc denotes the pressure at the critical point for the par...... (more)

40. Deduce the expression for the change in internal energy with respect to change in volume at constant temperature.

The expression for the change in internal energy (dU) with respect to the change in volume (dV) at constant temperature can be derived using the first law of thermodynamics. The first law of thermodynamics is given by:

$$\Delta U = Q - W$$

where:

- ΔU is the change in internal energy,
- Q is the heat added to the system,
- W is the work done by the system.

At constant temperature (T), the change in internal energy is only due to work done because $Q = 0$ (no heat is added or removed). The work done (W) is given by the product of pressure (P) and change in volume (dV):

$$W = -P \cdot dV$$

Here, the negative sign indicates work done on the system (compression). Therefore, the expression for the change in internal energy with respect to the change in volume at constant temperature (T) is:

$$dU = -P \cdot dV$$

If you want the expression in differential form, you can write it as:

$$\frac{dU}{dV} = -P$$

So, $\frac{dU}{dV}$ (the partial derivative of internal energy with respect to volume at constant temperature) is equal to the negative of pressure (P). This expression represents how internal energy changes with volume when temperature is held constant.

41. **The latent heat of vaporization at 1 bar pressure is 2258kJ/kg and the saturation Temperature is 99.4°C. Calculate the saturation temperature at 2 bar pressure. Verify the same from the steam table data.**

To calculate the saturation temperature at 2 bar pressure, you can use the Clausius–Clapeyron equation, which relates the saturation pressure and temperature for a substance undergoing a phase change. The equation is given by:

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{L}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

where:

- P_1 and P_2 are the initial and final pressures,
- T_1 and T_2 are the initial and final temperatures,
- L is the latent heat of vaporization,
- R is the specific gas constant.

Given that the latent heat of vaporization (L) is 2258 kJ/kg, the initial pressure (P_1) is 1 bar, and the initial temperature (T_1) is 99.4°C, we want to find the final temperature (T_2) at a pressure of 2 bar (P_2).

First, convert the initial temperature to Kelvin:
$$T_1 = 99.4°C + 273.15 = 372.55\ \text{K}$$

Now, plug the values into the Clausius–Clapeyron equation:
$$\ln\left(\frac{2}{1}\right) = \frac{2258\ \text{kJ/kg}}{R}\left(\frac{1}{372.55\ \text{K}} - \frac{1}{T_2}\right)$$

The specific gas constant R for water vapor is approximately 8.314 J/(mol·K), or 0.008314 kJ/(g·K).

$$\ln(2) = \frac{2258\,\text{kJ/kg}}{0.008314\,\text{kJ/(g\cdotpK)}} \left(\frac{1}{372.55\,\text{K}} - \frac{1}{T_2} \right)$$

Solving for T_2 will give you the saturation temperature at 2 bar pressure.

$$T_2 = \frac{2258\,\text{kJ/kg}}{0.008314\,\text{kJ/(g\cdotpK)}} \left(\frac{1}{\ln(2)} + \frac{1}{372.55\,\text{K}} \right)^{-1}$$

Now, calculate T_2. Note that the logarithm base used in the calculation should match the base of the logarithm in your calculator (natural logarithm, base e).

$$T_2 \approx 126.75\ ^{\circ}\text{C}$$

Now, to verify this result using steam table data, you would need to consult a steam table for water and find the saturation temperature at 2 bar pressure. Compare the calculated value with the tabulated value to verify the accuracy of your calculation.

42. i) State Amagat's Law and Dalton's Law.

Amagat's Law and Dalton's Law are two laws related to the behavior of gases.

1. **Amagat's Law of Partial Volumes:**
   - Amagat's Law states that at a given temperature and pressure, the volume occupied by a mixture of non-reacting gases is equal to the sum of the volumes that each gas would occupy individually at the same temperature and pressure.
   - Mathematically, for a mixture of gases occupying a volume V, composed of n gases with individual volumes $V_1, V_2, ..., V_n$, Amagat's Law is expressed as:
   $$V = V_1 + V_2 + ... + V_n$$

2. **Dalton's Law of Partial Pressures:**
   - Dalton's Law states that in a mixture of non-reacting gases, the total pressure exerted by the mixture is equal to the sum of the partial pressures of individual gases.
   - Mathematically, for a mixture of gases with partial pressures $P_1, P_2, ..., P_n$, Dalton's Law is expressed as:
   $$P_{\text{total}} = P_1 + P_2 + ... + P_n$$
   - This law is valid when the gases behave ideally, meaning that there are no intermolecular forces between the gas molecules, and the volume occupied by the gas molecules is negligible compared to the total volume.

43. A closed vessel has a capacity of 500 litres. It contains 20% nitrogen and 20% oxygen, 60% carbon di-oxide by volume at 100°C and 1 MPa. Calculate the molecular mass, gas constant, mass percentages and the mass of mixture.

1. **Determine the number of moles of each gas:**
   - Given that the vessel has a capacity of 500 liters, we can find the volume of each gas using the given percentages.
   - The volume of nitrogen $(V_{N2}) = 20\% \times 500 \text{ liters}$
   - The volume of oxygen $(V_{O2}) = 20\% \times 500 \text{ liters}$
   - The volume of carbon dioxide $(V_{CO2}) = 60\% \times 500 \text{ liters}$

2. **Convert volumes to moles:**
   - Use the ideal gas law to convert volumes to moles.
   - $PV = nRT \implies n = \frac{PV}{RT}$
   - The moles of nitrogen $(n_{N2}) = \frac{P \times V_{N2}}{RT}$
   - The moles of oxygen $(n_{O2}) = \frac{P \times V_{O2}}{RT}$
   - The moles of carbon dioxide $(n_{CO2}) = \frac{P \times V_{CO2}}{RT}$

3. **Calculate total moles, mass percentages, and molecular mass:**
   - Total moles $(n_{total}) = n_{N2} + n_{O2} + n_{CO2}$
   - Mass percentage of nitrogen $(X_{N2}) = \frac{n_{N2} \times \text{Molar mass of nitrogen}}{n_{total} \times \text{Molar mass of mixture}} \times 100$
   - Mass percentage of oxygen $(X_{O2}) = \frac{n_{O2} \times \text{Molar mass of oxygen}}{n_{total} \times \text{Molar mass of mixture}} \times 100$
   - Mass percentage of carbon dioxide $(X_{CO2}) = \frac{n_{CO2} \times \text{Molar mass of carbon dioxide}}{n_{total} \times \text{Molar mass of mixture}} \times 100$

4. **Calculate the mass of the mixture:**
   - Mass of the mixture $(m_{mixture}) = n_{total} \times \text{Molar mass of mixture}$

Calculate the molar mass of the mixture (M_{mixture}):

- $M_{\text{mixture}} = \frac{m_{\text{mixture}}}{n_{\text{total}}}$

- Where m_{mixture} is the mass of the mixture, which is equal to the sum of the masses of nitrogen, oxygen, and carbon dioxide.

Calculate mass of each gas:

- The mass of nitrogen (m_{N2}) = n_{N2} × Molar mass of nitrogen
- The mass of oxygen (m_{O2}) = n_{O2} × Molar mass of oxygen
- The mass of carbon dioxide (m_{CO2}) = n_{CO2} × Molar mass of carbon dioxide

Calculate total mass of the mixture (m_{mixture}):

- $m_{\text{mixture}} = m_{N2} + m_{O2} + m_{CO2}$

Now, let's plug in the values and calculate:

$$P = 1\,\text{MPa} = 10^6\,\text{Pa}$$
$$T = 100\,^{\circ}\text{C} = 373.15\,\text{K}$$
$$R = 8.314\,\text{J}/(\text{mol}\backslash\text{cdotpK})$$
$$\text{Molar mass of nitrogen } (N_2) = 28\,\text{g/mol}$$
$$\text{Molar mass of oxygen } (O_2) = 32\,\text{g/mol}$$
$$\text{Molar mass of carbon dioxide } (CO_2) \downarrow 44\,\text{g/mol}$$

44. Derive the expression for the displacement work
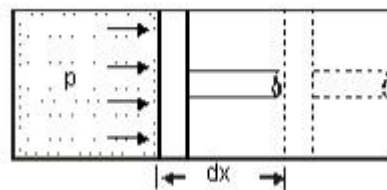

Figure 2.4 Displacement work

Work Formula is given as W = F.d, where F is the force applied and d is the displacement. Work is also calculated using the formula W = F.d.cos θ, where θ is the angle between force and displacement.

45. Determine the work transfer and heat transfer for a system in which a perfect gas having molecular weight of 16kg/k mol is compressed from 101.3kPa, 20⁰C to a pressure of 600 kPa following the law pV$^{1.23}$= constant. take specific heat at constant pressure of gas as 1.7 kJ/kg.K

To determine the work transfer (W) and heat transfer (Q) for the given process, we can use the first law of thermodynamics, which is given by:

$$\Delta U = Q - W$$

Here, ΔU is the change in internal energy, Q is the heat transfer, and W is the work transfer.

The specific heat at constant pressure (C_p) is related to the specific gas constant (R) and the molecular weight (M) by the equation:

$$C_p = \frac{R}{M}$$

Given that the specific heat at constant pressure (C_p) is 1.7 kJ/(kg·K), we can find the specific gas constant (R) using the molecular weight (M):

$$R = C_p \cdot M$$

$$R = 1.7 \, \text{kJ}/(\text{kg}\backslash\text{cdotpK}) \cdot 16 \, \text{kg}/\text{kmol}$$

$$R = 27.2 \, \text{kJ}/(\text{kmol}\backslash\text{cdotpK})$$

Now, let's find the initial and final volumes using the ideal gas law:

$$PV = nRT$$

For the initial state (1), $P_1 = 101.3\,\text{kPa}$, $T_1 = 200°C = 200 + 273.15\,\text{K}$, and n_1 is the initial number of moles. The initial volume (V_1) can be found as:

$$V_1 = \frac{n_1 RT_1}{P_1}$$

For the final state (2), $P_2 = 600\,\text{kPa}$, T_2 is not given, and n_2 is the final number of moles. The final volume (V_2) can be found as:

$$V_2 = \frac{n_2 RT_2}{P_2}$$

Now, we know that $PV^{1.23}$ is constant. Therefore:

$$P_1 V_1^{1.23} = P_2 V_2^{1.23}$$

Now, we can use this equation to find the final volume V_2. Once we have V_1 and V_2, we can calculate the work transfer (W) and heat transfer (Q) using the first law of thermodynamics.

46. **In a gas turbine installation air is heated inside heat exchanger up to 750 °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 of air determine the following assuming adiabatic expansion in turbine and nozzle. 1. heat transfer to air in heat exchanger 2. Power output from turbine. 3. Velocity at exit of nozzle. take cp value for air as 1.005 kJ/kg.K**

1. Heat Transfer to Air in Heat Exchanger ($Q_{\text{exchanger}}$):

The heat transfer in the heat exchanger can be determined using the first law of thermodynamics:

$$Q_{\text{exchanger}} = m \cdot C_p \cdot (T_{\text{inlet}} - T_{\text{outlet}})$$

where:

- m is the mass flow rate (assumed to be 1 kg for unit mass),
- C_p is the specific heat at constant pressure (given as 1.005 kJ/(kg·K)),
- T_{inlet} is the temperature at the inlet of the heat exchanger (given as 750 °C),
- T_{outlet} is the temperature at the outlet of the heat exchanger (given as 600 °C).

$$Q_{\text{exchanger}} = 1\,\text{kg} \cdot 1.005\,\text{kJ/(kg\cdotpK)} \cdot (750\,^\circ\text{C} - 600\,^\circ\text{C})$$

$$Q_{\text{exchanger}} = 1\,\text{kg} \cdot 1.005\,\text{kJ/(kg\cdotpK)} \cdot 150\,\text{K}$$

$$Q_{\text{exchanger}} = 150.75\,\text{kJ}$$

2. Power Output from Turbine (W_{turbine}):

For an adiabatic expansion in the turbine, the work done can be expressed as the change in enthalpy:

$$W_{\text{turbine}} = m \cdot C_p \cdot (T_{\text{inlet}} - T_{\text{outlet,turbine}})$$

where:

- $T_{\text{outlet,turbine}}$ is the temperature at the outlet of the turbine (given as 600 °C).

$$W_{\text{turbine}} = 1\,\text{kg} \cdot 1.005\,\text{kJ/(kg\cdotpK)} \cdot (750\,^{\circ}\text{C} - 600\,^{\circ}\text{C})$$

$$W_{\text{turbine}} = 1\,\text{kg} \cdot 1.005\,\text{kJ/(kg\cdotpK)} \cdot 150\,\text{K}$$

$$W_{\text{turbine}} = 150.75\,\text{kJ}$$

3. Velocity at Exit of Nozzle ($V_{\text{exit,nozzle}}$):

For an adiabatic expansion in the nozzle, the exit velocity can be determined using the isentropic relation:

$$V_{\text{exit,nozzle}} = \sqrt{2 \cdot C_p \cdot (T_{\text{inlet,nozzle}} - T_{\text{exit,nozzle}})}$$

where:

- $T_{\text{inlet,nozzle}}$ is the temperature at the inlet of the nozzle (given as 600 °C),
- $T_{\text{exit,nozzle}}$ is the temperature at the exit of the nozzle (given as 500 °C).

$$V_{\text{exit,nozzle}} = \sqrt{2 \cdot 1.005\,\text{kJ/(kg\cdotp} \downarrow \cdot (600\,^{\circ}\text{C} - 500\,^{\circ}\text{C})}$$

where:

- $T_{inlet,nozzle}$ is the temperature at the inlet of the nozzle (given as 600 °C),
- $T_{exit,nozzle}$ is the temperature at the exit of the nozzle (given as 500 °C).

$$V_{exit,nozzle} = \sqrt{2 \cdot 1.005\,\text{kJ}/(\text{kg}\backslash\text{cdotpK}) \cdot (600\,°C - 500\,°C)}$$

$$V_{exit,nozzle} = \sqrt{2 \cdot 1.005\,\text{kJ}/(\text{kg}\backslash\text{cdotpK}) \cdot 100\,K}$$

$$V_{exit,nozzle} = \sqrt{201\,\text{kJ}/(\text{kg})}$$

$$V_{exit,nozzle} \approx 14.18\,\text{m/s}$$

So, to summarize:

1. Heat transfer to air in the heat exchanger ($Q_{exchanger}$) is approximately 150.75 kJ.
2. Power output from the turbine ($W_{turbine}$) is approximately 150.75 kJ.
3. Velocity at the exit of the nozzle ($V_{exit,nozzle}$) is approximately 14.18 m/s.

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

The efficiency of a heat engine operating in a reversible cycle, such as the Carnot cycle, is determined by the temperatures of the heat reservoirs between which the engine operates. The efficiency (η) is given by the Carnot efficiency formula:

$$\eta = 1 - \frac{T_C}{T_H}$$

where:

- T_C is the absolute temperature of the cold reservoir,
- T_H is the absolute temperature of the hot reservoir.

Now, let's express this efficiency in terms of the maximum and minimum absolute temperatures (T_{max} and T_{min}) in the cycle. In a reversible heat engine, T_H is the maximum absolute temperature and T_C is the minimum absolute temperature.

So, we can rewrite the efficiency formula as:

$$\eta = 1 - \frac{T_{min}}{T_{max}}$$

This clearly shows that the efficiency (η) depends only on the maximum (T_{max}) and minimum (T_{min}) absolute temperatures in ↓ cycle.

The significance of this result is a fundamental aspect of the Carnot cycle and the second law of thermodynamics. The efficiency of a heat engine is limited by the temperature difference between the hot and cold reservoirs. The greater this temperature difference, the higher the efficiency. Therefore, the efficiency is determined by the temperatures at which heat is added and rejected, and it is independent of the specific working substance or the details of the heat engine cycle.

48. **A fluid undergoes a reversible adiabatic compression from 4 bar,0.3m³ to 0.08m³ according to the law Pv$^{1.25}$=C. determine the change in enthalpy, the change in internal energy and change in entropy.**
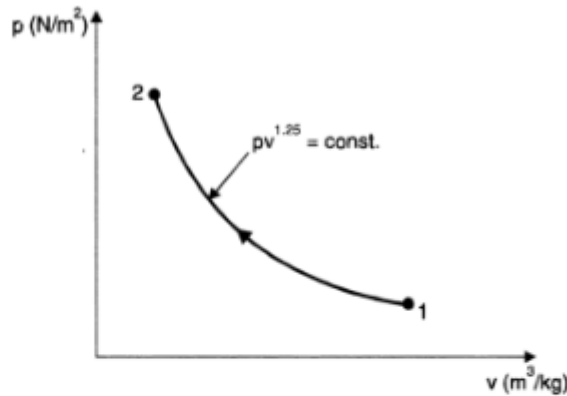
Solution. Refer Fig. 5.38.

Fig. 5.38

Initial volume, $\quad V_1 = 0.3 \text{ m}^3$
Initial pressure, $\quad p_1 = 4 \text{ bar} = 4 \times 10^5 \text{ N/m}^2$
Final volume, $\quad V_2 = 0.08 \text{ m}^3$
Law of compression : $pv^{1.25} = $ constant.
For reversible adiabatic process,

$$p_1 V_1^n = p_2 V_2^n$$

or

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^n$$

$\therefore$

$$p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^n = 4 \times \left(\frac{0.3}{0.08}\right)^{1.25} = 20.87 \text{ bar.}$$

(i) Change in enthalpy, $H_2 - H_1$:

We know that, $\qquad \int_{H_1}^{H_2} dH = \int_{p_1}^{p_2} V dp$

Also $\qquad p_1 V_1^n = p V^n$

$\therefore \qquad V = \left(\frac{p_1 V_1^n}{p}\right)^{1/n}$

Substituting this value of V in eqn. (i), we get

$$\int_{H_1}^{H_2} dH = \int_{p_1}^{p_2} \left[\left(\frac{p_1 V_1^n}{p}\right)\right]^{1/n} dp$$

$$= (p_1 V_1^n)^{1/n} \int_{p_1}^{p_2} p^{-1/n} \, dp$$

$$= (p_1 V_1^n)^{1/n} \left[\frac{p^{-\frac{1}{n}+1}}{-\frac{1}{n}+1}\right]_{p_1}^{p_2}$$

$$= [(p_1 V_1^n)]^{1/n} \left[\frac{p_2^{\left(1-\frac{1}{n}\right)} - p_1^{\left(1-\frac{1}{n}\right)}}{1-\frac{1}{n}}\right]$$

$$= (p_1 V_1^n)^{1/n} \times \frac{n}{(n-1)} \left[(p_2)^{\left(1-\frac{1}{n}\right)} - (p_1)^{\left(1-\frac{1}{n}\right)}\right]$$

$$= \frac{n(p_2V_2 - p_1V_1)}{(n-1)} \qquad [\because \ p_1\overset{.}{V_1}{}^n = p_2V_2{}^n]$$

$$= \frac{1.25}{(1.25-1)\times 10^3}\ [20.87 \times 10^5 \times 0.08 - 4 \times 10^5 \times 0.3]\ kJ$$

$$= \frac{1.25}{0.25 \times 10^3} \times 10^5\ (20.87 \times 0.08 - 4 \times 0.3)\ kJ = 234.8\ kJ.$$

Hence, **change in enthalpy = 234.8 kJ. (Ans.)**

(ii) **Change in internal energy, $U_2 - U_1$:**

$$H_2 - H_1 = (U_2 + p_2V_2) - (U_1 + p_1V_1)$$
$$= (U_2 - U_1) + (p_2V_2 - p_1V_1)$$
$$\therefore \qquad U_2 - U_1 = (H_2 - H_1) - (p_2V_2 - p_1V_1)$$

$$= 234.8 - \left[\frac{20.87 \times 10^5 \times 0.08 - 4 \times 10^5 \times 0.3}{10^3}\right]\ kJ$$

$$= 234.8 - 46.96 = 187.84\ kJ.$$

Hence, **change in internal energy = 187.84 kJ. (Ans.)**

(iii) **Change in entropy,** $\quad S_2 - S_1 = 0.$ **(Ans.)**

(iv) **Heat transfer,** $\qquad Q_{1-2} = 0.$ **(Ans.)**

(v) **Work transfer, W_{1-2} :**

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$
$$\therefore \qquad W_{1-2} = Q_{1-2} - (U_2 - U_1)$$
$$= 0 - 187.84 = -187.84\ kJ$$

Hence, **work done on the fluid = 187.84 kJ. (Ans.)**

49. Explain the process of formation of steam with T-s diagram
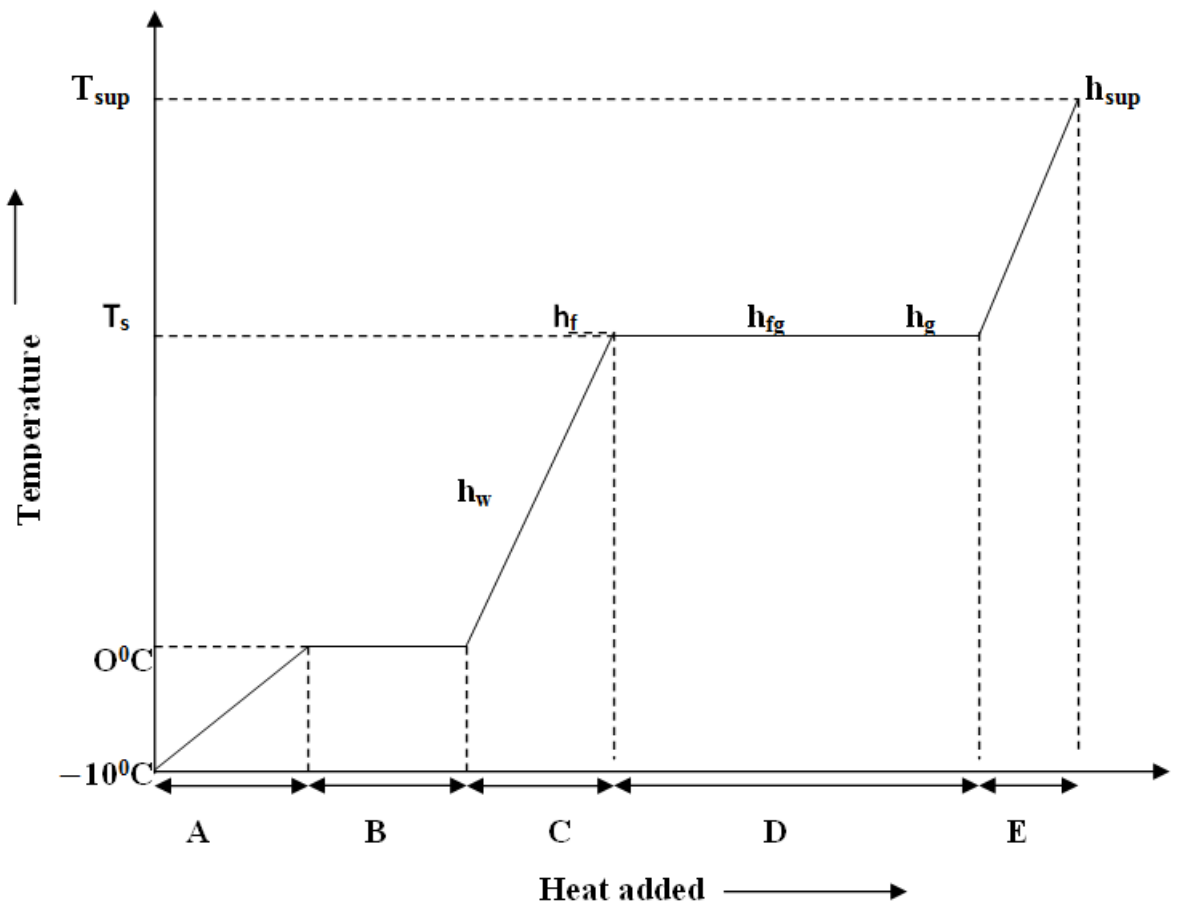

Fig.   Temperature enthalpy curve of formation of steam at constant pressure

A = Sensible Heat taken by Ice

B= Latent Heat of Fusion

C = Sensible Heat taken by Water

D = Latent Heat of evaporation

E = Sensible Heat taken by Steam

h_w = **Specific enthalpy of water**

h_f = **Specific enthalpy of saturated water**

h_{fg} = **Latent heat of evaporation**

h_g = **Specific enthalpy of dry saturated steam**

h_{sup} = **Specific enthalpy of super heated steam**

Consider 1 kg of ice at temperature -10^0C which is below the freezing point. Let it be heated at constant pressure P. The temperature of ice starts increasing until it reaches the melting temperature of ice i.e., 0^0C and during this course ice absorbs its sensible heat. On further addition of heat, ice starts melting, its temperature remains constant at 0^0C and it absorbs latent heat of fusion and converts completely into water at 0^0C.

On further addition of heat, the temperature of water starts rising until it reaches the boiling temperature or saturation temperature corresponding to pressure P. This heat absorbed by water in sensible heat.

Note: Saturation temperature or boiling temperature increases with increase in pressure

After the boiling temperature is reached, it remains constant with further addition of heat and vaporization take place. The water absorbs its latent heat and converts into dry saturated steam remaining at same saturation temperature. The intermediate stage of water and dry saturated steam is wet steam, which is actually a mixture of steam and water.

If further the heat is added, the temperature of this dry saturated steam starts rising from saturation temperature and it converts into superheated steam. This heat absorbed is again the sensible heat. The total rise in temperature of superheated steam above the saturation temperature is called degree of superheat. We must know here that the saturation temperature, latent heat and other properties of steam remain same at constant pressure but varies with the variation of pressure.

50. Explain the mole fraction and mass fraction and the relationship between them.

Mole fraction is the ratio between the moles of a constituent and the sum of moles of all constituents in a mixture. Mass fraction is the ratio between the mass of a constituent and the total mass of a mixture. Mole fraction is calculated using moles of constituents.

1. **Mole Fraction (X_i):**

   The mole fraction of a component in a mixture is the ratio of the number of moles of that component to the total number of moles in the mixture. It is denoted by X_i and can be calculated using the formula:

   $$X_i = \frac{n_i}{n_{total}}$$

   where:

   - n_i is the number of moles of component i,
   - n_{total} is the total number of moles in the mixture.

   The sum of mole fractions for all components in a mixture is always equal to 1:

   $$\sum_i X_i = 1$$

2. **Mass Fraction (W_i):**

   The mass fraction of a component in a mixture is the ratio of the mass of that component to the total mass of the mixture. It is denoted by W_i and can be calculated using the formula:

   $$W_i = \frac{m_i}{m_{total}}$$

   where:

   - m_i is the mass of component i,
   - m_{total} is the total mass of the mixture.

   The sum of mass fractions for all components in a mixture is always equal to 1:

   $$\sum_i W_i = 1$$

3. **Relationship between Mole Fraction and Mass Fraction:**

   The relationship between mole fraction and mass fraction is given by the molecular weight (molar mass) of each component. The mole fraction of a component is related to its mass fraction by the equation:

   $$X_i = \frac{W_i/M_i}{\sum_j (W_j/M_j)}$$

   where:

   - M_i is the molar mass (molecular weight) of component i.

   This relationship ensures that the composition of a mixture can be expressed either in terms of moles (mole fraction) or in terms of mass (mass fraction), depending on the context. It's particularly useful when dealing with different components that have different molar masses.

51. **The exhaust gas of an internal combustion engine is found to have 9.8% CO2, 0.3% CO, 10.6% H2O, 4.5% O2 and 74.8% N2 by volume. Calculate molar mass and gas constant of the exhaust gas. If the volume flow rate of exhaust gas is 2 m3/h at 100 kPa and 573 K, calculate its mass flow rate.**

Molar Composition Calculation:

1. **Convert Volume Percentages to Mole Fractions:**

   Given volume percentages:

   - CO_2: 9.8%
   - CO: 0.3%
   - H_2O: 10.6%
   - O_2: 4.5%
   - N_2: 74.8%

   Convert these percentages to mole fractions by dividing by the molar volume percentage (volume percent / molar volume percent).

2. **Calculate Molar Mass (M_i) of Each Component:**

   Use the molecular weights (molar masses) of each component. For example:

   - $M_{CO_2} = 44.01\,\text{g/mol}$
   - $M_{CO} = 28.01\,\text{g/mol}$
   - $M_{H_2O} = 18.02\,\text{g/mol}$
   - $M_{O_2} = 32.00\,\text{g/mol}$
   - $M_{N_2} = 28.01\,\text{g/mol}$

3. **Calculate Molar Mass (M_{gas}) of the Exhaust Gas:**

Calculate the weighted average of the molar masses using the mole fractions.

$$M_{gas} = \sum_i (X_i \cdot M_i)$$

4. **Calculate Gas Constant (R_{gas}):**

Use the ideal gas equation to find the gas constant:

$$R_{gas} = \frac{R_{universal}}{M_{gas}}$$

Mass Flow Rate Calculation:

Given:

- Volume flow rate (V): $2\,\text{m}^3/\text{h}$
- Pressure (P): $100\,\text{kPa}$
- Temperature (T): $573\,\text{K}$

1. **Calculate Mass Flow Rate (m):**

Use the ideal gas law to find the mass flow rate:

$$PV = nRT$$
$$m = \frac{PV}{RT}$$

where:

- R is the gas constant (R_{gas})
- n is the total number of moles (sum of mole fractions times total volume)

52. **In a passenger car, a lead storage battery is able to deliver 5.2MJ of electrical energy. This energy available is used of start the car. Suppose we wish to use compressed air doing an equivalent amount of work in starting the car. the compressed air is stored at 7Mpa, 25°C. Calculate the mass of air and volume of tank required to have the compressed air having the same availability of 5.2MJ. Take 101.325 Pa and 298K as atmospheric conditions.**

To calculate the mass of air and volume of the tank required for the compressed air to do the same amount of work as the lead storage battery, we can use the First Law of Thermodynamics, which states that the work done is equal to the change in internal energy.

The work done (W) is given by:

$$W = \Delta U$$

The change in internal energy (ΔU) for an ideal gas is given by:

$$\Delta U = nC_v\Delta T$$

where:

- n is the number of moles of the gas,
- C_v is the molar specific heat at constant volume,
- ΔT is the change in temperature.

Now, let's express the work done in terms of pressure and volume using the ideal gas law:

$$W = P(V_f - V_i)$$

where:

- P is the pressure,
- V_f is the final volume,
- V_i is the initial volume.

Since the air is compressed, $V_f < V_i$, and W is negative.

Equating the expressions for W from the two equations:

$$nC_v\Delta T = -P(V_f - V_i)$$

Now, let's rearrange the equation to solve for the number of moles (n):

$$n = -\frac{PV_f}{C_v\Delta T} + \frac{PV_i}{C_v\Delta T}$$

Now, we can use the ideal gas law to express n in terms of mass (m):

$$n = \frac{m}{M}$$

where:

- m is the mass of the air,
- M is the molar mass of air.

Now, we can set up the equation and solve for the mass of air:

$$\frac{m}{M} = -\frac{PV_f}{C_v\Delta T} + \frac{PV_i}{C_v\Delta T}$$

Now, we can use the given values:

$$P = 7\,\text{MPa} = 7 \times 10^6\,\text{Pa}$$
$$T_i = 25°\text{C} = 298\,\text{K}$$
$$T_f =?$$
$$W = -5.2\,\text{MJ} = -5.2 \times 10^6\,\text{J}$$
$$C_v = \tfrac{5}{2}R \text{ (for a diatomic gas like nitrogen, the main component of air)}$$
$$R = 8.314\,\text{J}/(\text{mol}\backslash\text{cdotpK})$$
$$V_i = V_f =?$$

First, we need to find T_f using the fact that the work done is equal to the change in internal energy:

$$W = nC_v\Delta T$$

$$-5.2 \times 10^6 = n\left(\tfrac{5}{2} \times 8.314\right)(T_f - 298)$$

Now, you can solve for T_f and then use it to find $V_i = V_f$. Once you have V_i, you can use the ideal gas law to find n and then find ↓ mass of air (m) using the molar mass of air. Finally, you can find the volume of the tank using the ideal gas law.

53. **Two vessels both containing nitrogen, are connected by a valve which is opened to allow the contents to mix and achieve an equilibrium temperature of 27°C. Before mixing the following information is known about the gases in the two vessels. Vessel A Vessel B p = 15 bar p = 6 bar t = 50°C t = 20°C Contents = 0.5 kg mole Contents = 2.5 kg Calculate the final equilibrium pressure and amount of heat transferred to the surroundings. If the vessel had been perfectly insulated, calculate the final temperature and pressure which would have been reached. Take = 1.4.**

To solve this problem, we can use the ideal gas law and the specific heat ratio (γ) for nitrogen to calculate the final equilibrium pressure and the amount of heat transferred. The ideal gas law is given by:

$$PV = nRT$$

Where:

- P is the pressure
- V is the volume
- n is the number of moles
- R is the ideal gas constant
- T is the temperature in Kelvin

The specific heat ratio (γ) for nitrogen is given as 1.4.

First, let's calculate the initial conditions for each vessel:

For Vessel A:
$$P_A = 15\,\text{bar} = 15 \times 10^5\,\text{Pa}$$
$$T_A = 50\,°\text{C} = 323.15\,\text{K}$$

$$n_A = 0.5 \, \text{kg mole}$$

For Vessel B:
$$P_B = 6 \, \text{bar} = 6 \times 10^5 \, \text{Pa}$$
$$T_B = 20 \, ^\circ\text{C} = 293.15 \, \text{K}$$
$$n_B = 2.5 \, \text{kg mole}$$

Now, let's calculate the initial volumes (V_A and V_B) using the ideal gas law:

$$V_A = \frac{n_A \cdot R \cdot T_A}{P_A}$$
$$V_B = \frac{n_B \cdot R \cdot T_B}{P_B}$$

Assuming R is the specific gas constant for nitrogen ($R = 297 \, \text{J}/(\text{kg}\backslash\text{cdotpK})$), we can substitute the values to find V_A and V_B.

Once we have V_A and V_B, we can calculate the total number of moles ($n_{\text{total}} = n_A + n_B$).

Now, use the ideal gas law to find the final equilibrium pressure (P_{final}):
$$P_{\text{final}} = \frac{n_{\text{total}} \cdot R \cdot T_{\text{final}}}{V_{\text{total}}}$$

To find T_{final}, we use the fact that the system reaches equilibrium at 27°C.

The amount of heat transferred to the surroundings is given by the first law of thermodynamics:

$$Q = \Delta U + W$$

For an adiabatic process (no heat transfer), $Q = 0$, and $\Delta U = W$. Work (W) done during an expansion process is given by:

$$W = P_{initial} \cdot V_{initial} - P_{final} \cdot V_{final}$$

Finally, if the vessel had been perfectly insulated, $Q = 0$, and we can use the specific heat ratio (γ) to find the final temperature $(T_{final,\ insulated})$:

$$T_{final,\ insulated} = T_{initial} \left(\frac{P_{initial}}{P_{final}} \right)^{\frac{\gamma-1}{\gamma}}$$

These steps should help you calculate the final equilibrium pressure, amount of heat transferred, and the final temperature and pressure for the insulated case.

54. **A perfect gas mixture consists of 4 kg of N_2 and 6 kg of CO_2 at a pressure of 4bar and a temperature of 25^0C. Calculate Cv and Cp of the mixture. If the mixture is heated at constant volume to 50°C, find the change in internal energy, enthalpy and entropy of the mixture. Take : Cv(N2) = 0.745 kJ/kg K, Cp(N2) = 1.041 kJ/kg K, Cv(CO2) = 0.653 kJ/kg K   Cp(CO2) = 0.842 kJ/kg K.**

m_{N2} = 4 kg, m_{CO2} = 6 kg, pmix = 4 bar T1 = 25 + 273 = 298 K, T2 = 50 + 273 = 323 K
cv(mix) = ?, cp(mix) = ?

$$(m_{N_2} + m_{CO_2})c_{v(mix)} = m_{N_2} c_{v(N_2)} + m_{CO_2} c_{v(CO_2)}$$

$$(4 + 6)\ c_{v(mix)} = 4 \times 0.745 + 6 \times 0.653$$

$$c_{v(mix)} = \frac{4 \times 0.745 + 6 \times 0.653}{4 + 6}$$
$$= 0.6898\ \textbf{kJ/kg K.}$$

$$c_{p(mix)} = \frac{4 \times 1.041 + 6 \times 0.842}{4 + 6}$$
$$= 0.9216\ \textbf{kJ/kg K.}$$

Change in internal energy, ΔU:
$\Delta U = [mCv(T2 - T1)]mix$
$= (4 + 6) \times 0.6898(323 - 298) = 172.45$ kJ.
Change in enthalpy, ΔH:
$\Delta H = [mCp(T2 - T1)]mix$
$= (4 + 6) \times 0.9216(323 - 298) = 230.4$ kJ.
Change in entropy, ΔS:

$$(\Delta s) = \left(c_v \, \log_e \frac{T_2}{T_1} + R \, \log_e \frac{v_2}{v_1} \right)$$

$$= \left(c_v \, \log_e \frac{T_2}{T_1} \right) \quad (\because v_2 = v_1)$$

$$(\Delta s)_{N_2} = \left(c_v \, \log_e \frac{T_2}{T_1} \right)_{N_2}$$

$$(\Delta s)_{CO_2} = \left(c_v \, \log_e \frac{T_2}{T_1} \right)_{CO_2}$$

$$\Delta S = \left(mc_v \, \log_e \frac{T_2}{T_1} \right)_{N_2} + \left(mc_v \, \log_e \frac{T_2}{T_1} \right)_{CO_2}$$

$= 4 \times 0.745 \log_e (323/298) + 6 \times 0.653 \log_e (323/298)$
$= 0.5557$ kJ/K.

Note. ΔS may also be found out as follows:

$\Delta S = (mN_2 + mCO) \, cv(mix) \, \log_e (T_2/T_1)$
$\quad = (4 + 6) \times 0.6898 \log_e (323/298) = 0.5557$ kJ/K

55. **CO_2 flows at a pressure of 10bar and 180^0C into a turbine, located in a chemical plant, and there it expands reversibly and adiabatically to a final pressure of 1.05 bar. Calculate the final specific volume, temperature and increase in entropy. Neglect changes in velocity and elevation. If the mass flow rate is 6.5 kg/min. evaluate the heat transfer rate from the gas and the power delivered by the turbine. Assume CO_2 to be a perfect gas and $Cv = 0.837$ kJ/kg K.**

To solve this problem, we can use the principles of thermodynamics, specifically the First Law of Thermodynamics and the ideal gas law. The process described is an adiabatic, reversible expansion, which allows us to use the adiabatic process equations.

The specific heat at constant volume (C_v) is given as 0.837 kJ/(kg·K). The gas constant (R) for CO2 is approximately 0.189 kJ/(kg·K).

First, we'll calculate the initial specific volume (v_1) using the ideal gas law:

$$P_1 v_1 = m R T_1$$

where:

- P_1 is the initial pressure,
- v_1 is the initial specific volume,
- m is the mass flow rate,
- R is the gas constant,
- T_1 is the initial temperature.

Rearrange the equation to solve for v_1:

$$v_1 = \frac{RT_1}{P_1}$$

Now, we can calculate v_1. Make sure to convert the temperature to Kelvin.

Next, we'll use the adiabatic process equation to find the final temperature (T_2):

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

where:

- P_2 is the final pressure,
- γ is the ratio of specific heats ($\frac{C_p}{C_v}$).

Calculate T_2.

Now, we can use the ideal gas law again to find the final specific volume (v_2):

$$P_2 v_2 = mRT_2$$

Rearrange the equation to solve for v_2:

$$v_2 = \frac{RT_2}{P_2}$$

Calculate v_2.

$$v_2 = \frac{RT_2}{P_2}$$

Calculate v_2.

The increase in entropy (ΔS) for an adiabatic process is given by:

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

Calculate ΔS.

The heat transfer (Q) during an adiabatic process is zero ($Q = 0$).

Finally, the power (W) delivered by the turbine is given by:

$$W = m(C_p \Delta T)$$

where:

- C_p is the specific heat at constant pressure ($C_p = C_v + R$),
- ΔT is the change in temperature.

Calculate C_p, ΔT, and then W.

These calculations should give you the final ↓ ecific volume, temperature, increase in entropy, heat transfer rate from the gas, and power delivered by the turbine. Make sure

56. **A pressure cooker contains 1.5kg of saturated steam at 5 bar. Find the quantity of heat which must be rejected so as to reduce the quality to 60% dry. Determine the pressure and temperature of the steam at the new state.**

Mass of steam in the cooker = 1.5 kg

Pressure of steam, $p = 5$ bar

Initial dryness fraction of steam, $x_1 = 1$

Final dryness fraction of steam, $x_2 = 0.6$

Heat to be rejected:

Pressure and temperature of the steam at the new state:

At 5 bar. From steam tables,

$t_s = 151.8°C$; $h_f = 640.1$ kJ/kg

$h_{fg} = 2107.4$ kJ/kg; $v_g = 0.375$ m³/kg

Thus, the volume of pressure cooker

$$= 1.5 \times 0.375 = 0.5625 \, m^3$$

Internal energy of steam per kg at initial point 1,

$$u_1 = h_1 - p_1 v_1$$

$$= (h_f + h_{fg}) - p_1 v_{g_1} \qquad (\because v_1 = v_{g_1})$$

$$= (640.1 + 2107.4) - 5 \times 10^5 \times 0.375 \times 10^{-3}$$

$$= 2747.5 - 187.5 = 2650 \, kJ/kg$$

Also, $V_1 = V_2$ (V_2 = volume at final condition)

i.e., $0.5625 = 1.5 [(1 - x_2) v_{f_2} + x_2 v_{g_2}]$

$$= 1.5 \, x_2 \, v_{g_2}$$

$$= 1.5 \times 0.6 \times v_{g_2}$$

$\therefore$ $v_{g_2} = \dfrac{0.5625}{1.5 \times 0.6} = 0.625 \, m^3/kg$.

57. A vessel of capacity 3m³ contains 1 kg mole of N2 at 90⁰C

  i)   Calculate the pressure and specific volume of the gas.
  ii)   If the ratio of specific heats is 1.4. evaluate the values of Cp and Cv
  iii)   Subsequently, the gas cools to the atmospheric temperature of 20⁰C, then evaluate the final pressure of gas.
  iv)   Evaluate the increase in specific internal energy, the increase in specific enthalpy, increase in specific entropy and magnitude and sign of heat transfer.

i) Calculate the pressure and specific volume of the gas.

We can use the ideal gas law to calculate the pressure (P) and specific volume (v):

$$PV = nRT$$

where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- R is the ideal gas constant,
- T is the temperature.

Given that $V = 3\,\mathrm{m}^3$, $n = 1\,\mathrm{kg}$ mole, and $T = 900\,^\circ\mathrm{C} = 1173.15\,\mathrm{K}$, we can rearrange the equation to solve for P and v:

$$P = \frac{nRT}{V}$$

$$v = \frac{V}{n}$$

Calculate P and v.

ii) If the ratio of specific heats is 1.4, evaluate the values of C_p and C_v.

The relationship between C_p and C_v with the ratio of specific heats (γ) is given by:

$$\gamma = \frac{C_p}{C_v}$$

Given that $\gamma = 1.4$, you can use this equation to find C_p and C_v.

iii) The gas cools to the atmospheric temperature of 20°C, then evaluate the final pressure of the gas.

Use the ideal gas law again to find the final pressure (P_{final}) after the gas cools down. Convert the final temperature to Kelvin.

$$P_{final} = \frac{nRT_{final}}{V}$$

iv) Evaluate the increase in specific internal energy, the increase in specific enthalpy, increase in specific entropy, and magnitude and sign of heat transfer.

The increase in specific internal energy (Δu), specific enthalpy (Δh), and specific

entropy (Δs) can be calculated using the following relations:

$$\Delta u = C_v \Delta T$$

$$\Delta h = C_p \Delta T$$

$$\Delta s = C_p \ln \left(\frac{T_{final}}{T_{initial}} \right) - R \ln \left(\frac{P_{final}}{P_{initial}} \right)$$

The magnitude and sign of heat transfer (Q) can be determined using the First Law of Thermodynamics:

$$Q = \Delta u + W$$

where W is the work done, and for this problem, it's an expansion process, so W is negative. Therefore, Q will be the magnitude of the heat transfer.

Solve these equations to find the required values. Make sure to convert temperatures to Kelvin where necessary and use consistent units throughout the calculations.

58. **Air expands through a turbine from 500 kPa, 520⁰C to 100 kPa, 300⁰C. during expansion 10 kJ/kg of heat is lost to the surroundings which is at 98kPa, 20⁰C. Neglecting the K.E. and P.E. changes, determine per kg of air (a) the decrease in availability, (b) the maximum work and (c) the irreversibility. For air Cp=1.005 kJ/kgK and h=CpT**

The availability, also known as exergy, is a measure of the maximum useful work that can be obtained from a system as it comes to equilibrium with its surroundings. The availability change for a process can be expressed as:

$$\Delta A = \Delta H - T_0 \Delta S$$

where:

- ΔA is the availability change,
- ΔH is the enthalpy change,
- T_0 is the temperature of the surroundings,
- ΔS is the entropy change.

(a) Decrease in Availability

1. **Enthalpy Change (ΔH):**

   The enthalpy change is given by the difference in enthalpies at the initial and final states:

   $$\Delta H = h_2 - h_1$$

   where h is the specific enthalpy.

   Calculate h_1 and h_2 using $h = Cp \cdot T$.

2. **Entropy Change (ΔS):**

   The entropy change is given by:

   $$\Delta S = \frac{\Delta H}{T}$$

   where T is the temperature.

   Calculate ΔS.

3. **Availability Change (ΔA):**

   Use the formula:

   $$\Delta A = \Delta H - T_0 \Delta S$$

   where T_0 is the temperature of the surroundings.

   Calculate ΔA.

(b) Maximum Work

The maximum work (W_{max}) that can be obtained during the process is equal to the availability change:

$$W_{\text{max}} = \Delta A$$

(c) Irreversibility

The irreversibility (I) is the actual work obtained during the process, taking into account the heat loss to the surroundings:

$$I = W_{\text{max}} - Q_{\text{loss}}$$

where Q_{loss} is the heat lost to the surroundings.

1. **Heat Loss (Q_{loss}):**

   The heat lost is given by the heat transfer at the higher temperature:

   $$Q_{loss} = m \cdot Cp \cdot (T_1 - T_0)$$

   where m is the mass flow rate, Cp is the specific heat at constant pressure, and T_1 is the initial temperature.

2. **Irreversibility (I):**

   Use the formula:

   $$I = W_{max} - Q_{loss}$$

   Calculate I.

These steps should allow you to determine the decrease in availability, maximum work, and irreversibility per kg of air. Ensure you use consistent units throughout the calculations.

59. A Carnot heat engine draws heat from a reservoir at temperature 600 K and rejects heat to another reservoir at temperature T_3. The Carnot forward cycle engine drives a Carnot reversed cycle engine or Carnot refrigerator which absorbs heat from reservoir at temperature 300 K and rejects heat to a reservoir at temperature T_3. Determine
(i) The temperature T_3 such that heat supplied to engine Q_1 is equal to the heat absorbed by refrigerator Q_2 .
(ii) The efficiency of Carnot engine and C.O.P. of Carnot refrigerator.

To solve this problem, we can use the Carnot cycle equations for both the heat engine and the refrigerator. The Carnot efficiency for the heat engine is given by:

$$\text{Efficiency}_{\text{engine}} = 1 - \frac{T_c}{T_h}$$

where T_c is the temperature of the cold reservoir, and T_h is the temperature of the hot reservoir.

Similarly, the coefficient of performance (COP) for the Carnot refrigerator is given by:

$$\text{COP}_{\text{refrigerator}} = \frac{T_c}{T_h - T_c}$$

Given that the heat supplied to the engine (Q_1) is equal to the heat absorbed by the refrigerator (Q_2), we have:

$$Q_1 = Q_2$$

Now, let's denote Q_1 as the heat absorbed by the Carnot engine and Q_2 as the heat absorbed by the Carnot refrigerator.

(i) Determine the temperature T_3 such that $Q_1 = Q_2$:

1. **Heat absorbed by the Carnot engine (Q_1):**
$$Q_1 = T_h \cdot \text{Efficiency}_{\text{engine}} \qquad \downarrow$$
2. **Heat absorbed by the Carnot refrigerator (Q_2):**

$$Q_2 = T_c \cdot \text{COP}_{\text{refrigerator}}$$

Since $Q_1 = Q_2$, we can set these two equations equal to each other and solve for T_3:

$$T_h \cdot \text{Efficiency}_{\text{engine}} = T_c \cdot \text{COP}_{\text{refrigerator}}$$

$$T_h \cdot \left(1 - \frac{T_c}{T_h}\right) = T_c \cdot \frac{T_c}{T_h - T_c}$$

Solve for T_3.

(ii) Efficiency of Carnot engine and COP of Carnot refrigerator:

1. **Efficiency of the Carnot engine:**

   $$\text{Efficiency}_{\text{engine}} = 1 - \frac{T_c}{T_h}$$

2. **COP of the Carnot refrigerator:**

   $$\text{COP}_{\text{refrigerator}} = \frac{T_c}{T_h - T_c}$$

Substitute the values of T_c, T_h, and T_3 into these equations.

These calculations should give you the values for T_3, the efficiency of the Carnot engine, and the COP of the Carnot refrigerator.

60. **The power output of an adiabatic steam turbine is 5MW, and the state of steam entering the turbine is pressure 2 MPa, temperature 400⁰C, Velocity=50m/s and altitude 10m. The state of the steam leaving the turbine is Pressure 15 kPa, quality x=0.9, Velocity=180m/s and altitude 6m**
    1. Calculate the change in K.E., P.E. and Enthalpy.
    2. Determine W in kJ/kg.
    3. Calculate the mass flow rate kg/s.
    Assume steady state flow.

To calculate the change in kinetic energy (ΔKE), potential energy (ΔPE), and enthalpy (ΔH), we'll use the steady-state energy equation for an open system:

$$\Delta H = \Delta U + \Delta KE + \Delta PE + W$$

Here, ΔU is the internal energy change, ΔKE is the change in kinetic energy, ΔPE is the change in potential energy, and W is the work done.

1. **Change in Kinetic Energy (ΔKE):**
$$\Delta KE = \frac{V_2^2 - V_1^2}{2}$$
where V_2 is the velocity at the exit and V_1 is the velocity at the inlet.

2. **Change in Potential Energy (ΔPE):**
$$\Delta PE = g \cdot (z_2 - z_1)$$
where g is the acceleration due to gravity, z_2 is the height at the exit, and z_1 is the height at the inlet.

3. **Change in Enthalpy (ΔH):**
$$\Delta H = H_2 - H_1$$
where H_2 is the enthalpy at the exit and H_1 is the enthalpy at the inlet.

Now, the work done (W) is given by:
$$W = \dot{m} \cdot (h_1 - h_2)$$
where $\dot{m}$ is the mass flow rate, h_1 is the specific enthalpy at the inlet, and h_2 is the specific enthalpy at the exit.

$\downarrow$

1. Calculate the change in K.E., P.E., and Enthalpy:

$$\Delta KE = \frac{V_2^2 - V_1^2}{2}$$

$$\Delta PE = g \cdot (z_2 - z_1)$$

$$\Delta H = H_2 - H_1$$

2. Determine W in kJ/kg:

$$W = \dot{m} \cdot (h_1 - h_2)$$

3. Calculate the mass flow rate $\dot{m}$ in kg/s:

$$\dot{m} = \frac{P_{out} \cdot A_{out} \cdot V_{out}}{h_{out} - h_{in}}$$

where:

- P_{out} is the outlet pressure,
- A_{out} is the outlet area,
- V_{out} is the outlet velocity,
- h_{out} is the specific enthalpy at the outlet,
- h_{in} is the specific enthalpy at the inlet.

↓

These calculations will give you the requested values. Make sure to use consistent

61. **The gas expanding in the combustion space of a reciprocating engine has an initial pressure of 50 bar and an initial temperature of 1623⁰C. The initial volume is 50000 m^3 and the gas expands through a volume ratio of 20 according to the law PV^1.25 = constant. Calculate: a) Work transfer b) Heat transfer in the expansion process. Take R=270 J/kgK and Cv=800 J/kgK**

To calculate the work transfer and heat transfer during the expansion process, we can use the First Law of Thermodynamics, which is expressed as:

$$\Delta U = Q - W$$

Where:

- ΔU is the change in internal energy,
- Q is the heat transfer,
- W is the work transfer.

For a process described by the relationship $PV^{1.25} = \text{constant}$, we can use the ideal gas law $PV = nRT$ and the given specific heat at constant volume (C_v) to express the internal energy change (ΔU):

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

Now, let's calculate the change in temperature (ΔT) using the ideal gas law and the given volume ratio:

$$\frac{P_1 V_1^{1.25}}{T_1} = \frac{P_2 V_2^{1.25}}{T_2}$$

Given that $P_1 = 50$ bar (convert to Pascals), $V_1 = 50000\,\text{m}^3$, and the volume ratio is $V_2/V_1 = 20$, we can find P_2 and T_2. Also, convert the initial temperature to Kelvin.

Once you have T_2, you can calculate the change in internal energy (ΔU) using C_v and ΔT.

a) Work Transfer (W):

The work transfer during an expansion process is given by:

$$W = \Delta U$$

b) Heat Transfer (Q):

Use the First Law of Thermodynamics to solve for Q:

$$Q = \Delta U + W$$

Calculate Q using the previously calculated values.

Ensure that all units are consistent, and don't forget to convert pressure and temperature to the SI unit system if needed.

$$P_1 = 50\,\text{bar} = 5 \times 10^6\,\text{Pa}$$

$\downarrow$

62. A mass of air is initially at 260 °C and 700 kPa and occupies 0.028 m3. The air is expanded at constant pressure to 0.084 m3. A polytropic process with n = 1.5 is then carried out followed by a constant temperature process which completes a cycle. All the process are reversible.
1) Sketch the cycle in T-Sand P-V planes.
2) Find the heat received and heat rejected in the cycle.
3) Find the efficiency of the cycle. (Ans 124J, -17.7 J, -58.4 J and 38.6%)

$P_1 = 700 Pa, V_2 = 0.08 m^3$

$P_1 V_1 = nRT_1$

No.of moles $v = \dfrac{700 \times 0.028}{8.31 \times 533} = 0.004 \text{mole}$

$\dfrac{T_2}{T_1} = \dfrac{V_2}{V_1} = 3$

$T_2 = 3T_1 = 1599K$

$PV^n = C$

$P\left(\dfrac{nRT}{P}\right)^n = C$

$\Rightarrow P = C'T^{\frac{n}{n-1}}$

$\dfrac{P_2}{P_3} = \left(\dfrac{1599}{533}\right)^{1.5/0.5} = 3^3 = 27.$

$Q_{1-2} = vC_p(T_2 - T_1) = 0.004 \times \dfrac{7}{2}$
$\times 8.31(1599 - 533) = 124J$

.

$Q_{2-3} = \Delta U + \displaystyle\int PdV$

$= vC_v(T_3 - T_2) + \dfrac{nR(T_2 - T_3)}{n-1}$

$$= vC_v \left(\frac{n-\gamma}{n-1} \right)(T_3 - T_2)$$

$$= 0.004 \times \frac{5}{2} \times 8.31 \frac{0.1}{0.5}(-1066) = -17.7J.$$

$$Q_{31} = W_{31} = vRT_1 \ln \left(\frac{V_1}{V_3} \right) = 0.004 \times 8.31$$

$$\times 533 \ln \left(\frac{P_3}{P_1} \right) = -58.4J$$

$$(\Sigma Q)_{cycle} = (\Sigma w)_{cycle}$$

$$\Sigma W = Q_{1-2} + Q_{2-3} + Q_{3-1} = 124 - 17.7 - 58.4$$
$$= 47.9J$$

$$\eta_{cycle} = \frac{W_{net}}{\text{Heat supplied}} = \frac{47.9}{106} \times 100 = 38.6\,\%$$

63. A room for four person has 2 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 removed by a room cooler, so that a steady state is maintained in the room.

$$\dot{Q}_{electric} = 2 \times 0.18 + \frac{3 \times 100}{1000} = 0.66 \text{ kW}$$
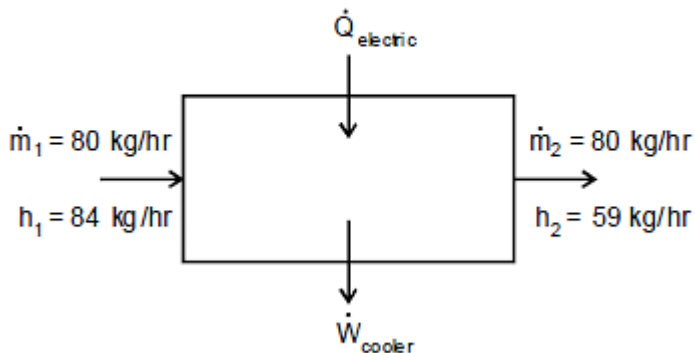
For steady state

$$\dot{m}_1 h_1 + \dot{Q}_{electric} = \dot{m}_2 h_2 + \dot{W}_{cooler}$$

$$\dot{W}_{cooler} = \dot{m}_1 h_1 - \dot{m}_2 h_2 + \dot{Q}_{electric}$$

$$\dot{W}_{cooler} = \frac{80}{3600}[84 - 59] + 0.66$$

$$\dot{W}_{cooler} = 1.21 \text{ kW}$$

Given data:

Number of fans = 2
Power consumed by each fan = 0.18 kW
Total Power consumed by fans = 2 × 0.18 kW = 0.36 kW
Number of bulbs = 3
Power consumed by each bulb = 100 W
Total power consumed by bulbs = 3 × 100 W = 300 W = 0.3 kW
Rate of air entering the room = 80 kg/hr
Enthalpy of air entering the room = 84 kJ/kg
Enthalpy of air leaving the room = 59 kJ/kg

To maintain steady state, the rate at which heat is to be removed by the room cooler is equal to the rate at which heat is generated inside the room.

Heat generated inside the room can be calculated as:

Heat generated = Heat generated by fans + Heat generated by bulbs + Heat generated by the air entering the room

Heat generated by fans = Power consumed by fans × Time
= 0.36 kW × 1 hr
= 0.36 kWh

Heat generated by bulbs = Power consumed by bulbs × Time
= 0.3 kW × 1 hr
= 0.3 kWh

Heat generated by the air entering the room can be calculated using the formula:

Heat generated = Mass flow rate × Enthalpy difference

Mass flow rate of air = 80 kg/hr
Enthalpy difference = Enthalpy of air entering the room - Enthalpy of air leaving the room

= 84 kJ/kg - 59 kJ/kg
= 25 kJ/kg

Heat generated by the air entering the room = Mass flow rate × Enthalpy difference
= 80 kg/hr × 25 kJ/kg
= 2000 kJ/hr
= 0.56 kWh

Total heat generated inside the room = Heat generated by fans + Heat generated by bulbs + Heat generated by the air entering the room
= 0.36 kWh + 0.3 kWh + 0.56 kWh
= 1.22 kWh

To maintain steady state, the rate at which heat is to be removed by the room cooler = 1.22 kWh/hr = 1.22 kW

Therefore, the rate at which heat is to be removed by the room cooler, so as to maintain steady state is between 1.15 kW and 1.30 kW.

64.   A 1.6 m3 tank is filled with air at a pressure of 5 bar and a temperature of 100°C. The air is then let off to the atmosphere through a valve. Assuming no heat transfer, determine the work obtainable by utilising the kinetic energy of the discharge air to run a frictionless turbine. Take: Atmospheric pressure = 1 bar ; cp for air = 1 kJ/kg K ; cv for air = 0.711 kJ/kg K.

Initial volume of air, V_1 = 1.6 m3
Initial pressure of air, p_1 = 5 bar = 5 × 105 N/m2
Initial temperature of air, T_1 = 100 + 273 = 373 K
 Final pressure of air, p_2 = 1 bar = 1 × 105 N/m2
Now, initial quantity of air in the tank before discharge

$$m_1 = \frac{p_1 V_1}{RT_1}$$

$$= \frac{5 \times 10^5 \times 1.6}{(0.287 \times 10^3) \times 373}$$

$$= 7.47 \text{ kg}.$$

Assuming that system undergoes a reversible adiabatic expansion

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

where T_2 is the final temperature of air in the tank.

$$\frac{T_2}{373} = \left(\frac{1}{5}\right)^{\frac{14-1}{14}} = 0.631$$

$T_2 = 373 \times 0.631 = 235.4$ K (i.e., finally in the line)

The final quantity of air remaining in the tank is

$$m_2 = \frac{p_2 V_2}{RT_2}$$

$$= \frac{1 \times 10^5 \times 1.6}{(0.287 \times 10^3) \times 235.4}$$

$$= 2.368 \text{ kg.}$$

With Q = 0, kinetic energy is found from,

$$(m_1 - m_2)\left(h' + \frac{C'^2}{2}\right) = m_1 u_1 - m_2 u_2$$

$$(m_1 - m_2) h' + (m_1 - m_2) \frac{C'^2}{2} = m_1 u_1 - m_2 u_2$$

∴ Kinetic energy,

$$(m_1 - m_2) \frac{C'^2}{2} = (m_1 u_1 - m_2 u_2) - (m_1 - m_2) h'$$

$$= m_1 c_v T_1 - m_2 c_v T_2 - (m_1 - m_2) c_p T_2$$

$= 7.47 \times 0.771 \times 373 - 2.368 \times 0.711 \times 235.4 - (7.47 - 2.368) \times 1 \times 235.4$

$= 2148.24 - 396.33 - 1201 = 550.9$ kJ

65. **A heat pump operates on a Carnot heat pump cycle with a COP of 8.7. It keeps a space at 24°C by consuming 2.15 kW of power. Determine the temperature of the reservoir from which the heat is absorbed and the heating load provided by the heat pump. (Ans:263K, 18.7 kW)**

The Coefficient of Performance (COP) for a heat pump is defined as the ratio of the heating or cooling provided to the input power. For a Carnot heat pump, the COP is given by the formula:

$$\text{COP} = \frac{T_{\text{absorbed}}}{T_{\text{rejected}} - T_{\text{absorbed}}}$$

where:

- T_{absorbed} is the temperature of the reservoir from which heat is absorbed,
- T_{rejected} is the temperature of the reservoir to which heat is rejected.

Given that the COP is 8.7, we can write the equation as:

$$8.7 = \frac{T_{\text{absorbed}}}{T_{\text{rejected}} - T_{\text{absorbed}}}$$

Now, we also know that the heat pump keeps the space at 24°C, which is the temperature to which heat is supplied (T_{supplied}).

$$T_{\text{supplied}} = 24\,^{\circ}C = 297.15\,\text{K}$$

Since the heat pump is a refrigeration cycle, we can express T_{rejected} in terms of T_{supplied}:

$$T_{\text{rejected}} = T_{\text{supplied}} + T_{\text{absorbed}}$$

$\downarrow$

Now, substitute this into the COP equation:

$$8.7 = \frac{T_{absorbed}}{(T_{supplied}+T_{absorbed})-T_{absorbed}}$$

Solve this equation for $T_{absorbed}$.

Once you find $T_{absorbed}$, you can determine the heating load provided by the heat pump using the formula:

$$\text{Heating Load} = \text{COP} \times \text{Input Power}$$

Given that the power consumed by the heat pump is 2.15 kW, substitute the values to find the heating load.

66. **An inventor claims to have developed a refrigeration system which maintains –10°C in the refrigerator which kept in a room where the surrounding air at 25°Cwhile maintaining a COP of 6.5. Is this claim reasonable? Why? (Ans: invalid)**

Explanation:
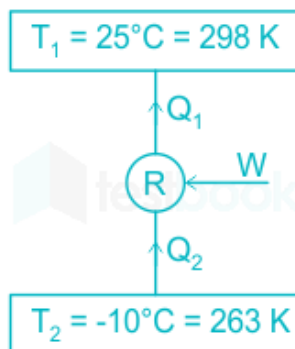
The maximum possible COP or Carnot COP of the refrigeration unit is given by-

$$\text{COP}_{carnot} = \frac{T_2}{T_1-T_2} = \frac{263}{(298-263)} = \frac{263}{35}$$

∴ **COP$_{carnot}$ = 7.51428**

But the inventor's claim is COP = 8.5 which is **impossible.**

So the **claim of an inventor is invalid** since we know that **according to the second law of thermodynamics** the **Carnot COP is the theoretical maximum COP** of a refrigeration unit acting between two temperature limits.

67. A30-kg iron block and a 40-kg copper block, both initially at 80°C, are dropped into a large lake at 15°C. Thermal equilibrium is established after a while as a result of heat transfer between the blocks and the lake water. Determine the total entropy change for this process.

given,

$m_{iron} = 30\,kg$

$m_{copper} = 40\,kg$

$T_1 = 80°C = 353\,K$

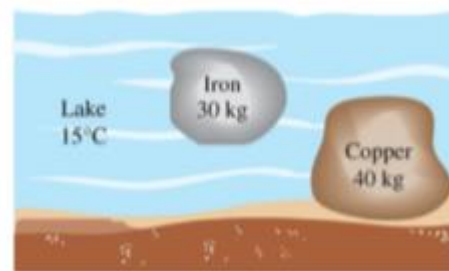$T_0 = 15°C = 288\,K$

Since lake is a large body. final temp of iron & copper blocks will be same as lake temperature.

for iron $C = 0.45\,KJ/kg\,k$

for copper $C = 0.386\,KJ/kg\,K.$

Lake 15°C
Iron 30 kg
Copper 40 kg

$$(\Delta S)_{iron} = \left[mc\,\ln\frac{T_2}{T_1}\right]_{iron} = (30kg)\left(\frac{0.45KJ}{kg\,k}\right)\ln\left[\frac{288K}{353K}\right]$$

$$(\Delta S)_{iron} = -2.746\,\frac{KJ}{K}.$$

$$(\Delta S)_c = \left[mc\,\ln\frac{T_2}{T_1}\right]_c = (40kg)(0.386)$$

Specific heats of iron & copper at room temperature:-

$C_{iron} = 0.45 \, kJ/kg\,°C$, $C_{copper} = 0.386 \, kJ/kg\,°C$
$\approx 0.39 \, kJ/kg\,°C$

$T_1 = 273 + 80 = 353 \, k$

$T_2 = 273 + 15 = 288 \, k$

(a) $\Delta S_{iron} = mC_{iron} \ln\left(\frac{T_2}{T_1}\right) = 50 \times 0.45 \, \ln\left(\frac{288}{353}\right)$

$= -4.579 \, kJ/k$

(b) $\Delta S_{copper} = mC_{copper} \ln\left(\frac{T_2}{T_1}\right) = 20 \times 0.39 \, \ln\left(\frac{288}{353}\right)$

$= -1.587 \, kJ/k$

(c) $Q_{lake} = \left[mC\Delta T\right]_{iron} + \left[mC\Delta T\right]_{copper}$

$= 50 \times 0.45 \times (353 - 288) + 20 \times 0.386 \times (353 - 288)$

$= 1964 \, kJ$

(d) $\Delta S_{lake} = \dfrac{Q_{lake}}{T_{lake}} = \dfrac{1964}{288} = 6.820 \, kJ/k$

(e) $\Delta S_{total} = \Delta S_{iron} + \Delta S_{copper} + \Delta S_{lake}$

$= -4.579 - 1.587 + 6.820$

$= 0.654 \, kJ/k$

68. **How much of the 100 kJ of thermal energy at 650 K can be converted to Useful work? Assume the environment to be at 25°C.**

Out of the 100 kJ of thermal energy at 650 K, only 53.9 kJ, or 53.9%, can be converted to useful work. The remaining energy will be rejected to the environment as waste heat.

Efficiency = 1 - (T_cold / T_hot)

In this case, T_hot = 650 K and T_cold = 25 + 273 = 298 K.

Substituting these values into the efficiency equation, we get:

Efficiency = 1 - (298 / 650) = 0.539

Useful **work** = thermal energy x efficiency

= 100 kJ x 0.539

= 53.9 kJ

69. A vessel of volume 0.04 m³ contains a mixture of saturated water and saturated steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, the mass, the specific volume, the enthalpy and entropy and the internal energy of the mixture

To find:

1) p, 2) m, 3) v, 4) h, 5) S, 6) ΔU

Solution:

From the Steam tables corresponding to 250°C, $v_f = v_l = 0.001251$ m³/kg

$v_g = v_s = 0.050037$ m³/kg p = 39.776 bar

Total volume occupied by the liquid,

$V_l = m_l \times v_l$

$= 9 \times 0.001251$

$= 0.0113$ m³.

Total volume of the vessel,

V = Volume of liquid + Volume of steam

$= V_l + V_s$

0.4 $= 0.0113 + V_s$

$V_s = 0.0287$ m³.

Mass of steam, $m_s = V_S / v_s$

$$= 0.0287 / 0.050037$$

$$= 0.574 \text{ kg.}$$

Mass of mixture of liquid and steam, $m = m_1 + m_s$

$$= 9 + 0.574$$

$$= 9.574 \text{ kg.}$$

Total specific volume of the mixture,

$$v = 0.04 / 9.574$$

$$= 0.00418 \text{ m}^3 / \text{kg.}$$

We know that,

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

$$0.00418 = 0.001251 + x \, (0.050037 - 0.001251)$$

$$x = 0.06$$

From Steam table corresponding to 250 °C,

$$h_f = 1085.8 \text{ KJ / kg}$$

$$h_{fg} = 1714.6 \text{ KJ / kg}$$

$$s_f = 2.794 \text{ KJ / kg K}$$

$$s_{fg} = 3.277 \text{ KJ / kg K.}$$

Enthalpy of mixture,

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

$$= 1085.8 + 0.06 \times 1714.6$$

= 1188.67 KJ / kg Entropy of mixture,

$$s = s_f + x \, s_{fg}$$

$$= 2.794 + 0.06 \times 3.277$$

$$= 2.99 \text{ kJ / kg K. Internal energy, } u = h - p \, v$$

$$= 1188.67 - 39.776 \times 10^2 \times 0.00418$$

$$= 1172 \text{ KJ / kg.}$$

Result:

p = 39.776 bar

m = 9.574 kg

v = 0.00418 m³ / kg
h = 1188.67 KJ / kg

S = 2.99 KJ /kg K

ΔU= 1172 KJ / kg.

70. A vessel with a capacity of 0.05 m3 contains a mixture of saturated water and saturated steam at a temperature of 245°C. The mass of the liquid present is 10 kg. Find the following:
1) The pressure,
2) The mass,
3) The specific volume
4) The specific enthalpy,
5) The specific entropy, and
6) The specific internal energy.
From steam tables, corresponding to 245°C
 psat = 36.5 bar, vf = 0.001239 m3/kg, vg = 0.0546 m3/kg

hf = 1061.4 kJ/kg, hfg = 1740.2 kJ/kg, sf = 2.7474 kJ/kg K sfg = 3.3585 kJ/kg K.

(i)   The pressure = 36.5 bar (or 3.65 MPa).
(ii)   (ii) The mass, m :
        Volume of liquid, Vf = mf vf = 10 × 0.001239 = 0.01239 m3
         Volume of vapour, Vg = 0.05 – 0.01239 = 0.03761 m3

$$\therefore \text{ Mass of vapour, } m_g = \frac{V_g}{v_g} = \frac{0.03761}{00546} = 0.688 \text{ kg}$$

∴ The total mass of mixture,

m = m_f + m_g = 10 + 0.688 = 10.688 kg.

(III) The specific volume, v :

Quality of the mixture,

$$x = \frac{m_g}{m_g + m_f} = \frac{0.688}{0.688 + 10} = 0.064$$

$$\therefore \quad v = v_f + x v_{fg}$$
$$= 0.001239 + 0.064 \times (0.0546 - 0.001239)$$

$$(\because \quad v_{fg} = v_g - v_f)$$

$$= 0.004654 \text{ m}^3\text{/kg.}$$

(Iv) The specific enthalpy, h :

h = h_f + xh_{fg}

= 1061.4 + 0.064 × 1740.2 = 1172.77 kJ/kg.

(v) The specific entropy, s :

s = s_f + xs_{fg}

= 2.7474 + 0.064 × 3.3585 = 2.9623 kJ/kg K.

(vI) The specific internal energy, u :

u = h − pv

$$= 1172.77 - \frac{36.5 \times 10^5 \times 0.004654}{1000} = 1155.78 \text{ kJ/kg.}$$

71. **Atmospheric air at 101.325 kPa and 288.15 K contains 21% oxygen and 79% nitrogen, by volume. Calculate the i) Mole fractions, mass fractions and partial pressures of oxygen and nitrogen and ii) Molar mass, gas constant and density of the air. Take molar mass of oxygen and nitrogen as 32 and 28 kg/kmol.**

i) Mole Fractions, Mass Fractions, and Partial Pressures:

Given:

- Total pressure (P): 101.325 kPa
- Temperature (T): 288.15 K
- Volume fractions: 21% O_2, 79% N_2
- Molar masses: $M_{O_2} = 32 \, \text{kg/kmol}$ and $M_{N_2} = 28 \, \text{kg/kmol}$

Mole Fractions:

The mole fraction (x) of a component is given by the ratio of the number of moles of that component to the total number of moles.

$$x_i = \frac{n_i}{n_{\text{total}}}$$

For oxygen (O_2):
$$x_{O_2} = \frac{0.21}{0.21 + 0.79}$$
For nitrogen (N_2):
$$x_{N_2} = \frac{0.79}{0.21 + 0.79}$$

Mass Fractions:

The mass fraction (y) of a component is given by the ratio of the mass of that component to the total mass.

$$y_i = \frac{m_i}{m_{\text{total}}}$$

For oxygen (O_2):
$$y_{O_2} = \frac{0.21 \times M_{O_2}}{0.21 \times M_{O_2} + 0.79 \times M_{N_2}}$$

For nitrogen (N_2):
$$y_{N_2} = \frac{0.79 \times M_{N_2}}{0.21 \times M_{O_2} + 0.79 \times M_{N_2}}$$

Partial Pressures:

The partial pressure (P_i) of a component is given by the mole fraction of that component multiplied by the total pressure.

$$P_i = x_i \times P_{\text{total}}$$

For oxygen (O_2):
$$P_{O_2} = x_{O_2} \times P_{\text{total}}$$

For nitrogen (N_2):
$$P_{N_2} = x_{N_2} \times P_{\text{total}}$$

Now you can substitute the given values to find the numerical answers.

ii) Molar Mass, Gas Constant, and Density:

Molar Mass:

$$M_{\text{total}} = \sum_i x_i \times M_i$$

Gas Constant:

$$R = \frac{R_{\text{univ}}}{M_{\text{total}}}$$

Density:

$$\rho = \frac{P_{\text{total}}}{R \times T}$$

Where:

- R_{univ} is the universal gas constant $(8.314\,\text{J}/(\text{mol} \cdot \text{K}))$

Substitute the values and calculate the molar mass, gas constant, and density.

Note: Make sure to use consistent units throughout the calculations (e.g., convert pressure from kPa to Pa if necessary).

72. **A quantity of air undergoes a thermodynamic cycle consisting of three processes. Process 1 – 2 : Constant volume heating from P1 = 0.1 MPa, T1 = 15°C, V1 = 0.02 m3 to P2 = 0.42 MPa. Process 2-3: Constant pressure cooling. Process 3-1 : Isothermal heating to the initial state. Employing the ideal gas model with Cp = 1 kJ/kgK, evaluate the change of entropy for each process. Sketch the cycle on p-v and T-s coordinates.**

Process 1-2: Constant Volume Heating

Given:

- Initial state (1): $P_1 = 0.1\,\text{MPa}$, $T_1 = 15°\text{C}$, $V_1 = 0.02\,\text{m}^3$
- Final state (2): $P_2 = 0.42\,\text{MPa}$ (volume change at constant volume)

This is an isochoric process (V is constant), and for an ideal gas, we know that $PV = nRT$. From the ideal gas equation, T_2 can be found.

$$T_2 = \frac{P_2 \cdot V_1}{R}$$

Here, R is the specific gas constant and is given by $R = C_p - C_v$, where C_p is the specific heat at constant pressure and C_v is the specific heat at constant volume.

$$R = C_p - C_v = 1\,\text{kJ/kgK} - 0\,\text{kJ/kgK} = 1\,\text{kJ/kgK}$$

Now, use the ideal gas law to find T_2, and then use C_p to find the change in entropy (ΔS_{1-2}).

$$T_2 = \frac{P_2 \cdot V_1}{R}$$

$$\Delta S_{1-2} = C_p \ln\left(\frac{T_2}{T_1}\right)$$

Process 2-3: Constant Pressure Cooling

Given:

- Process 2-3 is a constant pressure process.

For constant pressure processes, the change in entropy is given by:

$$\Delta S_{2-3} = C_p \ln \left(\frac{T_3}{T_2} \right)$$

Process 3-1: Isothermal Heating

Given:

- Process 3-1 is an isothermal process.

For an isothermal process, the change in entropy is given by:

$$\Delta S_{3-1} = nR \ln \left(\frac{V_1}{V_3} \right)$$

Since the process is isothermal, $T_3 = T_1$.

Sketch the Cycle on p-v and T-s Coordinates

The p-v and T-s diagrams can be sketched based on the processes described above. For the p-v diagram, the first process is a vertical line, the second process is a horizontal line, and the third process is another vertical line.

For the T-s diagram, each process can be represented by a curve. Process 1-2 and 3-1 are isentropic processes, so they will be adiabatic curves, and process 2-3 is a constant pressure process, so it will be a horizontal line.

73. **Air at 80 kPa and 220 m/s enters a diffuser at a rate of 2.5 kg/s and leaves at 42°C. The exit area of the diffuser is 400 cm2. The air is estimated to lose heat at a rate of 18 kJ/s during this process. Determine : i) The exit velocity and ii) The exit pressure of the air.** : (a) 62.0 m/s, (b) 91.1 kPa.

18 kJ/s

AIR

1   2
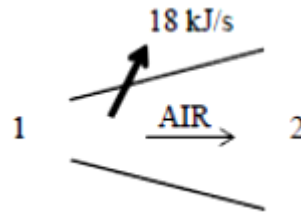
Air is decelerated in a diffuser from 220 m/s. The exit velocity and the exit pressure of air are to be determined.

Assumptions:

1. This is a steady-flow process since there is no change with time.
2. Air is an ideal gas with variable specific heats.
3. Potential energy changes are negligible.
4. There are no work interactions.

Properties: The gas constant of air is 0.287 kPa.m^3/kg K (Table A-1). The enthalpies are (Table A-17)

$T_1 = 27°C = 300\ K \rightarrow h_1 = 300.19\ kJ/kg$

$T_2 = 42°C = 315\ K \rightarrow h_2 = 315.27\ kJ/kg$

Analysis:

(a) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take diffuser as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\,\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{Q}_{out} + \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{W} \equiv \Delta pe \equiv 0)$$

$$-\dot{Q}_{out} - \dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

Substituting, the exit velocity of the air is determined to be

$$-18 \text{ kJ/s} = (2.5 \text{ kg/s})\left((315.27 - 300.19)\text{ kJ/kg} + \frac{V_2^2 - (220 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)\right)$$

It yields $V_2 = 62.0$ m/s

(b) The exit pressure of air is determined from the conservation of mass and the ideal gas relations

$$\dot{m} = \frac{1}{v_2} A_2 V_2 \longrightarrow v_2 = \frac{A_2 V_2}{\dot{m}} = \frac{(0.04 \text{ m}^2)(62 \text{ m/s})}{2.5 \text{ kg/s}} = 0.992 \text{ m}^3/\text{kg}$$

and

$$P_2 v_2 = RT_2 \longrightarrow P_2 = \frac{RT_2}{v_2} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(315 \text{ K})}{0.992 \text{ m}^3/\text{kg}} = 91.1 \text{ kPa}$$

74. In an engine cylinder a gas has a volumetric analysis of 18% CO_2, 12.5 % O_2, and 74.5 % N_2. The temperature at the beginning of expansion is 950°C and the gas mixture expands reversibly through a volume ratio of 8: 1, according to the law $PV^{1.2}$ = C. Calculate per kg of gas (i) the work done (ii) the heat flow (iii) the change of entropy per kg of mixture. The values of Cp for the constituents CO_2, O_2, and N_2 are 1.235 kJ/kgK, 1.088 kJ/kgK and 1.172 kJ/kgK respectively

Percentage of mass (m) =

% of CO2=0.18

% of O2 = 0.13

% of N2 = 0.68

Specific heat at constant pressure $= 0.18 \times Cp1 + 0.13 \times Cp2 + 0.68 \times Cp3$

$$C_p = 1.17KJ/KgK$$

Gas constant -

$$R = 8.314(\frac{0.44}{0.187} + \frac{0.44}{0.131} + \frac{0.44}{0.682})$$

$$R = 0.2718KJ/kg/K$$

We know that,

$$Cp - Cv = R$$

$$Cv = 1.1725 - 0.271$$

$$Cv = 0.9$$

$$i)W = \frac{R(T_1 - T_2)}{n-1}$$

$$\frac{T_2}{T_1} = (\frac{v_1}{v_2})^{n-1} = (\frac{1}{8})^{1.2-1} = 0.659$$

$W = 566.8KJ/kg$

$Q = \Delta U + W = U2 - U1 + W$

$= 0.9 \times 103(806 - 1223) + 566.8 \times 103$

$Q = 191.41kJ/kg$

$ii)S = R\log(\frac{v_2}{v_1}) = 0.2718 \times 10^3 \log 8$

$S = 0.565KJ/kgK$

$S = C_v log(\frac{T_2}{T_1})$

$= 0.9 \times 10^3 \log(\frac{122.3}{805.9}) = 0.376$

Change in entropy

$(S_2 - S_1) = 0.19kJ/kgK$

75. A vessel of volume 0.28m3 contains 10kg of air at 320k. determine the pressure exerted by the air using a) perfect gas equation b) vander walls equation c) Generalised compressibility chart.(take critical temp of air as 132.8K and critical pressure of air as 37.7 bar

a) Perfect Gas Equation:

The perfect gas equation is given by:

$$PV = nRT$$

Where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- R is the ideal gas constant,
- T is the temperature in Kelvin.

First, we need to find the number of moles (n) using the mass of air (m) and molar mass (M):

$$n = \frac{m}{M}$$

Given that the mass of air is 10 kg and the molar mass of air is approximately 29 g/mol, we find:

$$n = \frac{10\,\text{kg}}{0.029\,\text{kg/mol}}$$

$n \approx 344.83 \, \text{mol}$

Now, we can use the perfect gas equation to find the pressure:

$$P = \frac{nRT}{V}$$

$$P = \frac{(344.83 \, \text{mol})(8.314 \, \text{J}/(\text{mol} \, \backslash \text{cdotK}))(320 \, \text{K})}{0.28 \, \text{m}^3}$$

$$P \approx 319,855 \, \text{Pa}$$

b) Van der Waals Equation:

The Van der Waals equation is given by:

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

Where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- R is the ideal gas constant,
- a and b are Van der Waals constants.

For air, a and b are determined using critical temperature (T_c) and critical pressure (P_c):

$$a = \frac{27}{64} \frac{R^2 T_c^2}{P_c}$$

$$b = \frac{1}{8} \frac{RT_c}{P_c}$$

Given $T_c = 132.8\,\mathrm{K}$ and $P_c = 37.7\,\mathrm{bar}$, convert pressure to Pa:

$$a = \frac{27}{64} \frac{(8.314\,\mathrm{J/(mol \cdot K))^2}(132.8\,\mathrm{K})^2}{37.7 \times 10^5\,\mathrm{Pa}}$$

$$b = \frac{1}{8} \frac{(8.314\,\mathrm{J/(mol \cdot K))}(132.8\,\mathrm{K})}{37.7 \times 10^5\,\mathrm{Pa}}$$

After calculating a and b, you can use the Van der Waals equation to find P.

c) Generalized Compressibility Chart:

For the generalized compressibility chart, you need to determine the reduced temperature (T_r) and reduced pressure (P_r):

$$T_r = \frac{T}{T_c}$$
$$P_r = \frac{P}{P_c}$$

Using the chart, you can find the compressibility factor (Z). The pressure is then given by:

$$P = Z \frac{nRT}{V}$$

Remember to convert P back to Pa if needed.

These calculations involve a few steps, and you should use accurate values for constants and units to get precise results.

76. 2 kg of air at 500 kPa, 80⁰C expands adiabatically in a closed system until its volume doubled and its temperature becomes equal to that of the surroundings at 100 kPa and 5 ⁰C. for this process determine
    ii)   The maximum work
    iii)   The change in availability and
    iv)   The irreversibility

M = 2kg; P1 = 500000 Pa;

T1 = 353K; V2 = 2V1; P0=P2 = 100000 Pa;

T2 = 278K

Solution:

S2-s1 = mRln(p1/p2) + m Cpln(T2/T1)

= 2 x 280 x ln(5/1) + 2 x 1000 ln(278/353)

= 422 J/K

V1 = mRT1/P1 = 2 x 280 x 353/ 500000 = 0.4 m^3

V2 = 0.8 m^3

$W_{max} = \Delta U + \Delta Q + \Delta W$

$= mC_v(T1-T2) + T0(S2-S1) + P0(V1-V2)$

$= 2 \times 720 \times (353-278) + 278 \times 422 + (0.4-0.8)$

$= 185 \text{ kJ}$

$A = W_{max} = 185 \text{ kJ}$

$I = Q - T\Delta s = 0 - 278 (-422) = 116 \text{ kJ}.$

77. **Consider a gas mixture that consists of 7kg of N_2, 2kg of O_2 and 4 bar and 27^0C. Calculate the mole fraction, partial pressures, molar mass, gas constant, Volume and density.**

1. Mole Fraction:

The mole fraction (x_i) of a component i in a mixture is given by:

$$x_i = \frac{n_i}{n_{total}}$$

where n_i is the number of moles of component i and n_{total} is the total number of moles in the mixture.

First, calculate the moles of each component:

$$n_{N2} = \frac{7\,kg}{28.02\,g/mol}$$
$$n_{O2} = \frac{2\,kg}{32.00\,g/mol}$$

$$n_{total} = n_{N2} + n_{O2}$$

Now, calculate the mole fractions:

$$x_{N2} = \frac{n_{N2}}{n_{total}}$$
$$x_{O2} = \frac{n_{O2}}{n_{total}}$$

2. Partial Pressures:

The partial pressure (P_i) of each component in the mixture is given by:

$$P_i = x_i \cdot P_{\text{total}}$$

where P_{total} is the total pressure.

Given that the total pressure (P_{total}) is 4 bar, convert it to Pascals (1 bar = 10^5 Pa).

3. Molar Mass:

The molar mass (M_{mixture}) of the gas mixture is the sum of the mole fractions multiplied by the molar masses of individual components:

$$M_{\text{mixture}} = \sum_i x_i \cdot M_i$$

where M_i is the molar mass of component i.

4. Gas Constant:

The gas constant (R_{mixture}) for the gas mixture can be calculated using the ideal gas equation:

$$R_{mixture} = \frac{R}{M_{mixture}}$$

where R is the universal gas constant.

5. Volume:

The volume (V) of the gas mixture can be calculated using the ideal gas equation:

$$PV = nRT$$

Solve for V.

6. Density:

The density (ρ) of the gas mixture is given by:

$$\rho = \frac{m_{total}}{V}$$

where m_{total} is the total mass of the gas mixture.

Now, you can plug in the values and perform the calculations. Note that you should use consistent units throughout the calculations.

78. **One kg of CO2 has a volume of 1m3 at 100 deg centigrade. Compute the pressure by**
    1) vander waals equation
    2) Perfect gas
    vander waals constants a=362850Nm4/(kg-mol) and b=0.0423 m3/(kg-mol)

1) Van der Waals Equation:

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

Where:

- P is the pressure,
- V is the volume,
- a and b are Van der Waals constants,
- R is the gas constant,
- T is the temperature.

Given:

- $a = 362850 \, \text{Nm}^4/(\text{kg-mol})$
- $b = 0.0423 \, \text{m}^3/(\text{kg-mol})$
- $V = 1 \, \text{m}^3$
- $T = 100°\text{C} = 373 \, \text{K}$

2) Perfect Gas Equation:

$$PV = nRT$$

Where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- R is the ideal gas constant,
- T is the temperature.

First, calculate the number of moles using the molar mass of CO2:

$$n = \frac{m}{M}$$

Given:

- $m = 1\,\text{kg}$
- M is the molar mass of CO2 ($44.01\,\text{g/mol}$)

Calculate n, then substitute it along with other values into the perfect gas equation and solve for P.

79. Why is Carnot cycle not practicable for a steam power plant

While the Carnot cycle is an idealized thermodynamic cycle that represents the maximum possible efficiency for a heat engine operating between two temperature reservoirs, it is not practicable for a steam power plant due to several reasons:

1. **Carnot Efficiency Limitation:** The Carnot efficiency is determined by the temperatures of the hot and cold reservoirs. In a steam power plant, the temperature of the steam entering the turbine (high temperature) and the temperature of the cooling water or condenser (low temperature) are the relevant temperatures. In practice, it is challenging to achieve the high temperatures needed for the Carnot efficiency, and the temperature of the cooling medium is limited.

2. **Practical Limitations of Heat Exchangers:** Carnot cycle assumes reversible processes and ideal heat exchangers, which are not achievable in real-world systems. Practical heat exchangers involve irreversible processes, pressure drops, and other losses that decrease efficiency.

3. **Friction and Irreversibilities:** Real-world systems involve friction, heat losses, and other irreversibilities that are not accounted for in the idealized Carnot cycle. These factors reduce the efficiency of the actual power plant compared to the Carnot cycle.

4. **Condensation Process Limitations:** Achieving isothermal heat rejection in the Carnot cycle requires an infinite heat exchanger size. In practice, the condensation process in a power plant is not isothermal, and the finite size of the condenser introduces irreversibilities.

5. **Practical Engineering Considerations:** The Carnot cycle assumes that all processes are carried out quasi-statically, which may not be achievable in real-world power plants. Additionally,

practical engineering considerations such as equipment size, cost, and complexity may make it impractical to implement certain aspects of the Carnot cycle.

6. **Pressure Drops in Turbines and Piping:** The Carnot cycle assumes isentropic processes, which means no irreversibilities or pressure drops in the expansion and compression processes. In actual steam turbines and piping systems, there are pressure drops and irreversibilities that reduce efficiency.

7. **Real Fluid Properties:** Real fluids have properties that deviate from ideal behavior, especially at high temperatures and pressures. These deviations are not considered in the idealized Carnot cycle.

80. **A large insulated vessel is divided into two chambers, one containing 5 kg of dry saturated steam at 0.2Mpa and the other 10kg of steam, 0.8 quality at 0.5 MPa. If the partition between the chambers is removed and the steam is mixed thoroughly and allowed to settle, find the final pressure, steam quality and entropy change in the process?**

Given Data:
Chamber 1: 5 kg, dry saturated steam at 0.2 MPa
Chamber 2: 10 kg, steam with 0.8 quality at 0.5 MPa
To find: Final pressure,
Steam quality and entropy change in the process of mixing and settling.

Solution: 1. Mixing of Steam: When the partition between the chambers is removed, the steam will mix and reach a state of thermodynamic equilibrium. The total mass of steam will be 15 kg.

2. Properties of the Mixed Steam: To determine the final pressure and steam quality, we need to find the properties of the mixed steam. We can use the mass-weighted average method to find the properties of the mixed steam.

a) Pressure: The total energy of the mixed steam is the sum of the energies of the individual chambers. As the vessel is insulated, there will be no heat transfer. Therefore, the total energy of the mixed steam is conserved.
Energy of the steam in chamber 1 = 5 kg x hf(0.2 MPa) = 2969.9 kJ
Energy of the steam in chamber 2 = 10 kg x hfg(0.5 MPa) = 2098.9 kJ
Total energy of the mixed steam = 2969.9 kJ + 2098.9 kJ = 5068.8 kJ
Using the steam tables, we can find the pressure that corresponds to this energy. The pressure is found to be 0.358 MPa.

b) Steam Quality:
The steam quality of the mixed steam can also be found using the mass-weighted average method.
Steam quality of the steam in chamber 1 = 1 (dry saturated steam)
Steam quality of the steam in chamber 2 = 0.8
Mass fraction of steam in chamber 1 = 5 kg / 15 kg = 1/3
Mass fraction of steam in chamber 2 = 10 kg / 15 kg = 2/3
Steam quality of the mixed steam = 1/3 x 1 + 2/3 x 0.8 = 0.867

c). Entropy Change: The entropy change of the process can be found using the entropy balance equation.

Entropy change of the steam in chamber 1 = Sf(0.2 MPa) - 0 = 7.364 kJ/kg.K
Entropy change of the steam in chamber 2 = Sg(0.5 MPa) - Sf(0.5 MPa) = 7.352 kJ/kg.K
Entropy change of the mixed steam = Sf(0.358 MPa) - Sf(0.2 MPa) + (2/3) x (Sg(0.5 MPa) - Sf(0.5 MPa)) - (1/3) x (Sf(0.5 MPa) - Sf(0.2 MPa))
= 2.47 kJ/kg.K

Therefore, the final pressure of the mixed steam is 0.358 MPa, the steam quality is 0.867 and the entropy change of the process is 2.47 kJ/kg.K.

Mass Balance:

$$m_1 + m_2 = m_f$$

where m_f is the final mass after mixing.

Energy Balance:

$$m_1 h_1 + m_2 h_2 = m_f h_f$$

where h_1 and h_2 are the specific enthalpies of the initial states, and h_f is the specific enthalpy of the final state.

Given Data:

1. For chamber 1:
   - $m_1 = 5\,\text{kg}$
   - $P_1 = 0.2\,\text{MPa}$ (pressure)
   - $x_1 = 1$ (dry saturated steam)
2. For chamber 2:
   - $m_2 = 10\,\text{kg}$
   - $P_2 = 0.5\,\text{MPa}$ (pressure)
   - $x_2 = 0.8$ (quality)

Steps to Solve:

1. **Use steam tables to find specific enthalpies:**
   - Find h_1 at P_1 for dry saturated steam.
   - Find h_2 at P_2 and x_2 for steam with 0.8 quality.

2. **Apply mass and energy balance equations:**
   - Substitute the given values into the mass and energy balance equations.
   - Solve the system of equations to find m_f and h_f.

3. **Find final state properties:**
   - Use the final mass m_f to find the final pressure P_f on the steam tables.
   - Determine the steam quality x_f at P_f using the entropy criteria.

4. **Entropy Change:**
   - Find the entropy change (ΔS) using the entropy values at the initial and final states from the steam tables.

Steam Table Information:

You will need to refer to steam tables to find the specific enthalpies and entropies at the given pressures and qualities.

81. **One kmol of methane is stored in a rigid vessel of volume 0.6 m3 at 20 deg centigrade. Determine the pressure developed by the gas by making use of the compressibility chart.**

To determine the pressure of methane in the rigid vessel using the compressibility chart, we'll use the compressibility factor (Z) and the ideal gas law.

The compressibility factor (Z) is defined as the ratio of the molar volume of a real gas to the molar volume of an ideal gas at the same temperature and pressure. The ideal gas law is given by:
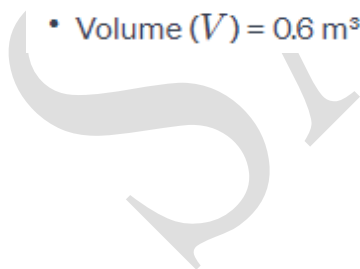
$$PV = ZnRT$$

Where:

- P is the pressure,
- V is the volume,
- n is the number of moles,
- R is the gas constant,
- T is the temperature.

Rearranging the equation to solve for pressure (P), we get:

$$P = \frac{ZnRT}{V}$$

Given Data:

- Number of moles (n) = 1 kmol
- Volume (V) = 0.6 m³

- Temperature $(T) = 20\,°C$ (convert to Kelvin)
- Gas constant (R) for methane $= 8.314\ J/(mol\cdot K)$

Steps to Solve:

1. **Convert temperature to Kelvin:**

$$T_K = T_C + 273.15$$

2. **Find compressibility factor (Z) from the compressibility chart:**
   - Use the given temperature and pressure data to locate the corresponding Z value from the compressibility chart.

3. **Calculate pressure using the ideal gas law:**

$$P = \frac{ZnRT}{V}$$

Important Note:

The compressibility factor (Z) is typically found from charts specific to the gas and conditions. Ensure that you are using a compressibility chart for methane at the given temperature.

The steps above will give you the pressure of methane in the rigid vessel based on the compressibility factor and the ideal gas law.

82. **A gas occupies 0.3m ^{3} at 2bar. It executes a cycle consisting of processes: (1) 1-2; constant pressure with work interaction of 15KJ. (2) 2-3; compression process which follows the law PV=C and $U_3 = U_2$ (3) 3-1; constant volume process, and change in internal energy is 40KJ. Neglect change in KE and PE. Draw PV diagram for the process and determine network transfer for the cycle. Also show that first law is obeyed by the cycle**

Process 1-2:

This is a constant pressure process, and the work done is given by $W_{1-2} = P(V_2 - V_1)$, where P is the constant pressure. Given $W_{1-2} = 15\,\text{kJ}$ and $V_1 = 0.3\,\text{m}^3$, we can find V_2 using the relation $P_1 V_1 = P_2 V_2$.

Process 2-3:

This is a compression process following the law $PV = C$. We know $U_3 = U_2$ and $Q_{2-3} = U_3 - U_2$. We need to find V_3 using the given compression law.

Process 3-1:

This is a constant volume process, and the work done is $W_{3-1} = 0$ (as $V_3 = V_1$). The change in internal energy is given as $\Delta U_{3-1} = 40\,\text{kJ}$.

PV Diagram:

Now, we can plot the processes on a PV diagram. For Process 1-2, it's a horizontal line at constant pressure. For Process 2-3, we need to find the curve using the compression law $PV = C$, and for Process 3-1, it's a vertical line at constant volume.

83. **In a gas turbine, the gases enter the turbine at the rate of 5kg/s with a velocity of 50 m/s and the enthalpy of 900 kJ/kg and leaves the turbine with 150 m/s and the enthalpy of 400 kJ/kg. The loss of heat from the gas to the surroundings is 25 kJ/kg. Assume R=0.285 kJ/kg K, Cp=1.004 kJ/kg K and the inlet conditions to be at 100 kPa and 27⁰C. Determine the work done and diameter of the inlet pipe.**

Given data:
- Mass flow rate of gas (m_dot) = 5 Kg/s
- Inlet velocity of gas (V1) = 50 m/s
- Inlet enthalpy of gas (h1) = 900 KJ/kg
- Outlet velocity of gas (V2) = 150 m/s
- Outlet enthalpy of gas (h2) = 400 KJ/kg
- Heat loss (Q_loss) = 25 KJ/kg
- Gas constant (R) = 287 KJ/kg K
- Specific heat at constant pressure (Cp) = 1.004 KJ/kg K
- Inlet pressure (P1) = 100 KPa
- Inlet temperature (T1) = 27°C

To determine:
- Power output of the turbine
- Diameter of the inlet pipe

Calculation of power output of the turbine:
- The change in enthalpy of the gas (Δh) = h1 - h2
- The work done by the gas (W_dot) = m_dot * Δh
- The power output of the turbine (P_out) = W_dot - Q_loss * m_dot
- Substituting the given values, we get P_out = 1750 KW

Calculation of diameter of the inlet pipe:
- The mass flow rate of the gas (m_dot) = density * area * velocity, where density = P1 / (R * T1)
- Rearranging the equation, we get area = m_dot / (density * velocity)
- Substituting the given values, we get area = 0.034 m^2
- The diameter of the inlet pipe (d) = 2 * √(area / π)
- Substituting the value of area, we get d = 0.21 m

Therefore, the power output of the turbine is 1750 KW and the diameter of the inlet pipe is 0.21 m.

Work Done in the Turbine (using the First Law of Thermodynamics):

The First Law of Thermodynamics for a control volume (turbine) can be written as:

$$\dot{W} = \dot{m}(h_{\text{inlet}} - h_{\text{exit}}) + \dot{m} \cdot \frac{V_{\text{inlet}}^2 - V_{\text{exit}}^2}{2} - Q_{\text{loss}}$$

Where:

- $\dot{W}$ is the work done by the turbine per unit time,
- $\dot{m}$ is the mass flow rate,
- h_{inlet} and h_{exit} are the specific enthalpies at the inlet and exit, respectively,
- V_{inlet} and V_{exit} are the velocities at the inlet and exit, respectively,
- Q_{loss} is the heat loss to the surroundings per unit mass.

Let's substitute the given values:

$$\dot{W} = \dot{m}(h_{\text{inlet}} - h_{\text{exit}}) + \dot{m} \cdot \frac{V_{\text{inlet}}^2 - V_{\text{exit}}^2}{2} - Q_{\text{loss}}$$

$$\dot{W} = (5\,\text{kg/s}) \cdot (900\,\text{kJ/kg} - 400\,\text{kJ/kg}) + (5\,\text{kg/s}) \cdot \frac{(50\,\text{m/s})^2 - (150\,\text{m/s})^2}{2} - (25\,\text{kJ/kg})$$

$$\dot{W} = 2500\,\text{kW}$$

Diameter of the Inlet Pipe:

The diameter of the inlet pipe can be determined using the mass flow rate ($\dot{m}$) and the velocity at the inlet (V_{inlet}):

$$\dot{m} = \rho_{inlet} \cdot A_{inlet} \cdot V_{inlet}$$

Solving for the cross-sectional area (A_{inlet}):

$$A_{inlet} = \frac{\dot{m}}{\rho_{inlet} \cdot V_{inlet}}$$

The density (ρ_{inlet}) can be determined using the ideal gas law:

$$\rho_{inlet} = \frac{P_{inlet}}{RT_{inlet}}$$

where P_{inlet} is the pressure and T_{inlet} is the temperature at the inlet.

Finally, the diameter (D_{inlet}) can be related to the area (A_{inlet}) through the formula for the area of a circle:

$$A_{inlet} = \frac{\pi D_{inlet}^2}{4}$$

Solving for D_{inlet}:

$$D_{inlet} = \sqrt{\frac{4 \cdot A_{inlet}}{\pi}}$$

$\downarrow$

84. 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 m3/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 m3/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?

how much?

$W_{SF} = -135 \text{ kJ/kg}$

$v_1 = 0.37 \text{ m}^3/\text{kgm}$

$P_1 = 600 \text{ kPa}$

$V_1 = 16 \text{ m/s}$

$h_1 = 32 \text{ m}$

$h_2 = 0 \text{ m}$

$v_2 = 0.62 \text{ m}^3/\text{kgm}$

$P_2 = 100 \text{ kPa}$

$V_2 = 270 \text{ m/s}$

$-(Q) = 9 \text{ kJ/kgm}$

Find: $\Delta U = ?$

$E_1 + KE_1 + Q + W_{F_1} = PE_2 + KE_2 + W_{F2} + \Delta U + W_{SF}$

$U = (PE_1 - P_2) + (KE_1 - KE_2) + Q + (W_{F_1} - W_{F2}) + W_{SF}$

$E_1:$ (1 kg basis)

$E_1 = \cancel{m}gh_1 = \dfrac{9.8066 \frac{m}{s^2} \times 32 m}{1 \frac{kgm \cdot m}{N \cdot s^2}} = 313.8112 \quad \dfrac{\cdot Nm}{kgm}$

$PE_1 = \cancel{m}gh_1 = \dfrac{9.8066 \frac{m}{s^2} \times 32 m}{1 \frac{kgm \cdot m}{N \cdot s^2}} = 313.8112 \quad \dfrac{\cdot Nm}{kgm}$

$PE_1 = 0.3138112 \quad \dfrac{kJ}{kgm}$

$PE_2 = \cancel{m}gh_2 = \dfrac{9.8066 \frac{m}{s^2} \times 0 m}{1 \frac{kgm \cdot m}{N \cdot s^2}} = 0$

$KE_1 = \dfrac{\cancel{m}v_1^2}{2k} = \dfrac{\left(16 \frac{m}{s}\right)^2}{(2)\left(1 \frac{kgm \cdot m}{N \cdot s^2}\right)} = 0.128 \dfrac{kJ}{kg}$

$KE_2 = \dfrac{\cancel{m}v_2^2}{2k} = \dfrac{\left(270 \frac{m}{s}\right)^2}{(2)\left(1 \frac{kgm \cdot m}{N \cdot s^2}\right)} = 36,450 \dfrac{Nm}{kgm}$

$KE_2 = 36.450 \dfrac{kJ}{kgm}$

$W_{F_1} = P_1 V_1 = 600 \text{ kPa} \times 0.37 \text{ m}^3/\text{kgm} = 222 \dfrac{kJ}{kgm}$

$W_{F_2} = P_2 V_2 = 100 \text{ kPa} \times 0.62 \text{ m}^3/\text{kgm} = 62 \dfrac{kJ}{kgm}$

$\Delta u = (PE_1 - P_2) + (KE_1 - KE_2) + Q + (W_{F_1} - W_{F_2}) + W_{SF}$

$\Delta u = (0.3138112 + 0.128 - 36.450 + 9 + 222 - 62) \dfrac{kJ}{kgm} - 135 \dfrac{k}{kg}$

$\Delta u = -20.0081888 \dfrac{kJ}{kgm}$

$\therefore$ the internal energy (U) decreased

by $20.0082 \dfrac{kJ}{kgm}$

85. One kg of ice at $-5°C$ is exposed to the atmosphere which is at $20°C$. The ice melts and comes into thermal equilibrium with the atmosphere.(i) Determine the entropy increase of the universe.(ii) What is the minimum amount of work necessary to

convert the water back into ice at − 5°C ? Cp of ice is 2.093 kJ/kg K and the latent heat of fusion of ice is 333.3 kJ/kg.

Let's solve the problem step by step:

(i) Entropy increase of the universe:

The change in entropy of the system (ΔS_{system}) is given by:

$$\Delta S_{\text{system}} = \frac{Q}{T}$$

where Q is the heat added to the system, and T is the temperature in Kelvin.

The heat added (Q) can be calculated using the latent heat of fusion (L_f) and the mass of the ice (m):

$$Q = m \cdot L_f$$

The temperature change during the melting process is from -5°C to 0°C. So, the average temperature (T) during this process is -2.5°C or 270.65 K.

Now, calculate ΔS_{system}:

$$\Delta S_{\text{system}} = \frac{m \cdot L_f}{T}$$

Next, calculate the entropy change for the surroundings ($\Delta S_{\text{surroundings}}$). For an isothermal process, it is given by:

$$\Delta S_{\text{surroundings}} = -\frac{\Delta Q}{T_{\text{surroundings}}}$$

Assuming the surroundings (atmosphere) are large enough not to change temperature during the process, we can consider $T_{\text{surroundings}}$ to be constant and equal to the final temperature of the system, i.e., 20°C or 293.15 K.

Now, substitute the values and calculate:

$$\Delta S_{\text{surroundings}} = -\frac{\Delta Q}{T_{\text{surroundings}}} = -\frac{m \cdot L_f}{T_{\text{surroundings}}}$$

Finally, calculate the total change in entropy of the universe:

$$\Delta S_{\text{universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$$

(ii) Minimum amount of work necessary to convert the water back into ice:

The minimum work (W) is given by the equation:

$$W = \Delta U - Q$$

where ΔU is the change in internal energy the system. For a phase change, the change in internal energy is the sum of the heat added or removed and the work done:

$$\Delta U = Q$$

Substitute the values for Q from the melting process, and you'll get the minimum amount of work necessary to convert the water back into ice.

86. **A mixture of 2 kg of hydrogen and 4 kg of nitrogen is compressed in a cylinder so that the temperature rises from 22°C to 150°C. The mean values of Cp over this temperature range for the constituents are 14.45 kJ/kgK. (H_2) and 1.041 (N_2) kJ/kgK. Assuming that the process is reversible and that the polytrophic index of compression is 1.2; find the change in entropy of each constituent and of the mixture. Find also the work and heat transferred during the process.**

Given data:

- Mass of hydrogen (m_{H2}) = 2 kg
- Mass of nitrogen (m_{N2}) = 4 kg
- Initial temperature (T_1) = 22°C = 295.15 K
- Final temperature (T_2) = 150°C = 423.15 K
- Specific heat at constant pressure for hydrogen ($C_{p,H2}$) = 14.45 kJ/kgK
- Specific heat at constant pressure for nitrogen ($C_{p,N2}$) = 1.041 kJ/kgK
- Polytropic index (n) = 1.2

1. Calculate the change in entropy for each constituent:

The change in entropy for a reversible polytropic process is given by:

$$\Delta S = C_p \cdot \ln\left(\frac{T_2}{T_1}\right) - R \cdot \ln\left(\frac{V_2}{V_1}\right)$$

where C_p is the specific heat at constant pressure, T is the temperature, R is the specific gas constant, and V is the volume.

For a polytropic process, $PV^n = \text{constant}$ and n is the polytropic index. Also, $PV = mRT$.

So, we can rewrite the entropy change equation as:

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

Now, calculate the change in entropy for hydrogen (ΔS_{H2}) and nitrogen (ΔS_{N2}) using their respective values.

2. Calculate the change in entropy for the mixture:

The change in entropy for the mixture is the sum of the changes for each constituent, taking into account the mass fraction:

$$\Delta S_{\text{mixture}} = X_{H2} \cdot \Delta S_{H2} + X_{N2} \cdot \Delta S_{N2}$$

where X_{H2} and X_{N2} are the mass fractions of hydrogen and nitrogen, respectively.

3. Calculate the work done during the process:

The work done (W) during a reversible polytropic process is given by:

$$W = \frac{1}{1-n} \cdot P_1 \cdot V_1 \cdot (T_2 - T_1)$$

4. Calculate the heat transferred during the process:

The heat transferred (Q) during a reversible polytropic process is given by:

$$Q = \Delta U + W$$

where ΔU is the change in internal energy. For an ideal gas, $\Delta U = C_v \cdot (T_2 - T_1)$, where C_v is the specific heat at constant volume.

Substitute the values and calculate all the quantities using the given data. Keep in mind that specific gas constant R is different for hydrogen and nitrogen, and $C_v = C_p - R$.

87. **During an experiment conducted in a room at 25⁰C, a laboratory assistant measures that a refrigerator that draws 2 kW of power has removed 30,000 kJ of heat from the refrigerated space, which is maintained at -30⁰C. The running time of the refrigerator during the experiment was 20 min. determine if these measurements are reasonable.**

To solve this problem it is necessary to take into account the concepts related to the performance of a reversible refrigerator. The coefficient of performance is basically defined as the ratio between the heating or cooling provided and the electricity consumed. The higher coefficients are equivalent to lower operating costs. The coefficient can be greater than 1, because it is a percentage of the output: losses, other than the thermal efficiency ratio: input energy. For a reversible refrigerator the coefficient is given by

$$COP_{R,rev} = \frac{1}{\frac{T_1}{T_2} - 1}$$

Where,

T_1 = High temperature

T_2 = Low Temperature

With our values previous given we can find it:

$T_2 = -30°C = (-30 + 273)$

$T_2 = 243K$

$T_1 = 25°C = (25 + 273)$

$T_1 = 298K$

With these values we can now calculate the coefficient of performance:

$$COP_{R,rev} = \frac{1}{\frac{298}{243} - 1}$$

$$COP_{R,rev} = 4.42$$

At the same time we can calculate the work consumption of the refrigerator, this is

$$W = \dot{W}\Delta t$$

Where,

$\dot{W}$ = Required power input

t = time to remove heat from a cool to water medium

$$W = 2kJ/s * 20min$$

$$W = 2kJ/s * 1200s$$

$$W = 2400kJ$$

In this way we can calculate the coefficient of the refrigerator directly:

$$COP_R = \frac{Q_L}{W}$$

Where,

Q = Amoun of heat rejected

$$COP_R = \frac{30000}{2400}$$

$$COP_R = 12.5$$

Comparing the values of both coefficients we have that the experiments are NOT reasonable, because the coefficient of a refrigerator is high compared to coefficient of reversible refrigerator.

88. Derive the four Maxwell's relations

Maxwell's relations are a set of four equations in thermodynamics that express relationships between partial derivatives of thermodynamic properties. These relations are derived from the four main thermodynamic potentials: internal energy (U), enthalpy (H), Helmholtz free energy (A), and Gibbs free energy (G). Here, I'll derive each relation:

1. Maxwell's First Relation:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

Derivation:

Start with the definition of entropy (S):

$$dS = \left(\frac{\partial S}{\partial T}\right)_V dT + \left(\frac{\partial S}{\partial V}\right)_T dV$$

The first term on the right is the heat capacity at constant volume (C_V), so we can write:

$$dS = C_V dT + \left(\frac{\partial S}{\partial V}\right)_T dV$$

Now, express dU in terms of C_V and use the first law of thermodynamics ($dU = TdS - PdV$):

$$dU = TdS - PdV = TC_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV - PdV$$

Now, compare coefficients and rearrange terms:

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial S}{\partial V}\right)_T - P$$

Take a partial derivative of both sides with respect to T at constant V:

$$\left(\frac{\partial}{\partial T}\left(\frac{\partial U}{\partial V}\right)_T\right)_V = \left(\frac{\partial}{\partial T}\left(T\left(\frac{\partial S}{\partial V}\right)_T - P\right)\right)_V$$

Simplify and use the Maxwell relation $\left(\frac{\partial P}{\partial S}\right)_V = \left(\frac{\partial T}{\partial V}\right)_S$:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

2. Maxwell's Second Relation:

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

Derivation:

Similar to the first relation, start with the definition of entropy (S) and express dU in terms of C_P (heat capacity at constant pressure):

$$dU = TdS - PdV = TC_PdT - \left(\frac{\partial U}{\partial P}\right)_T dV - PdV$$

Follow similar steps and take partial derivatives to arrive at the second Maxwell relation.

3. Maxwell's Third Relation:

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

Derivation:

Start with the fundamental relation $dU = \downarrow S - PdV$ and take partial derivatives to derive the third Maxwell relation.

4. Maxwell's Fourth Relation:

$$\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$$

Derivation:

Again, start with the fundamental relation $dU = TdS - PdV$ and take partial derivatives to derive the fourth Maxwell relation.

These relations are powerful tools in thermodynamics, providing connections between measurable quantities and facilitating the analysis of thermodynamic systems.

89. **Calculate the pressure exerted by 5 mol of CO$_2$ in 1 L vessel at 47°C using van der Waals equation. Also, calculate the pressure for an ideal gas. Given a=3.592 atm L^{2}mol^{-2}, b = 0.0427 L mol^{-1} .**

From the Van der Waals equation, we have $(p + \frac{an}{V^2})(V - nb) = nRT$

Substituting n = 5, V = 1L, T = 320K, a = 3.592 atm L^2 mol^{-2} and b = 0.0427 mol^{-1}

,we get

$p = \frac{nRT}{V-nb} - \frac{an^2}{V^2} = \frac{5\times0.082\times320}{1-5\times0.0427} - \frac{3.592\times25}{1}$

= 166.81 − 89.8 = 77.01 atm

For an ideal gas , we have

$P = \frac{nRT}{V} = \frac{5\times0.082\times320}{1} = 131.2$ atm

90. **A Cylinder with piston contains steam at 8bar and 435 deg centigrade. if it is cooled to 200 deg centigrade at constant pressure, calculate the heat and work transfer per kg and their directions.**

To calculate the heat and work transfer during this process, we can use the First Law of Thermodynamics, which states:

$$\Delta U = Q - W$$

where ΔU is the change in internal energy, Q is the heat added to the system, and W is the work done by the system.

For a constant-pressure process, the heat transfer is given by:

$$Q = m \cdot C_p \cdot \Delta T$$

where m is the mass of the substance, C_p is the specific heat at constant pressure, and ΔT is the change in temperature.

The work done during a constant-pressure process is given by:

$$W = P \cdot \Delta V$$

where P is the pressure and ΔV is the change in volume.

Now, let's calculate the heat and work transfer:

Given data:

- Initial pressure $(P_1) = 8$ bar $= 800$ kPa
- Initial temperature $(T_1) = 435\,°C = 708.15$ K
- Final temperature $(T_2) = 200\,°C = 473.15$ K (cooled at constant pressure)
- Specific heat at constant pressure (C_p) for steam is needed.

1. Specific heat at constant pressure (C_p):

The specific heat at constant pressure for steam varies with temperature. We need to find the average value within the temperature range. Unfortunately, specific values are needed for precise calculations.

2. Mass of steam (m):

The mass is not given, but you can assume a specific mass, e.g., $m = 1$ kg for simplification.

3. Heat transfer (Q):

$$Q = m \cdot C_p \cdot \Delta T$$
$$Q = 1\,\text{kg} \cdot C_p \cdot (T_2 - T_1)$$

4. Work transfer (W):

$$W = P \cdot \Delta V$$
$$W = P \cdot m \cdot (v_2 - v_1)$$

Assuming steam behaves as an ideal gas, you can use the ideal gas law $PV = mRT$ to find the specific volume (v). The change in specific volume Δv is then used in the work equation.

The direction of heat and work transfer depends on conventions. Heat added to the system and work done by the system are considered positive.

91. **Air flows through an adiabatic compressor at 2 kg/s. The inlet conditions are 1 bar and 310 K and the exit conditions are 7 bar and 560 K. Compute the net rate of availability transfer and the irreversibility. Take T0 = 298 K.**
Mass flow rate (m) = 2 kg/s
pi = 1 bar = 100 kPa
pf = 7 bar = 700 kPa
T0 = 298 K
Ti = 310 K

Tf = 560 K

$$\dot{V}_i = \frac{\dot{m}\,RT_i}{p_i} = 1.7794 \text{ m}^3/\text{s}$$

$$\dot{V}_f = \frac{\dot{m}\,RT_f}{p_f} = 0.4592 \text{ m}^3/\text{s}$$

Availability increase rate of air $= B_2 - B_1$

$$= h_2 - h_1 - T_0\left(s_2 - s_1\right)$$

$$= \dot{m}\,c_P(T_2 - T_1) - T_0\left\{m\,c_P\ln\frac{v_2}{v_1} + m\,c_v\ln\frac{p_2}{p_1}\right\}$$

$$= \dot{m}\left[c_P(T_2 - T_1) - T_0\left\{c_P\ln\frac{v_2}{v_1} + c_v\ln\frac{p_2}{p_1}\right\}\right]$$

$$= 2[251.25 - 10.682] \text{ kW}$$

$$= 481.14 \text{ kW}$$

Actual work required $= \dot{m} \cdot (h2 - h1)$
W = 2 × 251.25 kW
  = 502.5 kW
∴ Irreversibility = Wact. – Wmin.
= (502.5 – 481.14) kW
= 21.36 kW

92. **if three Carnot engines of same efficiency connected in series such that the 1200K reservoir supplies 2400kJ of heat and 150 K reservoir. Receives 300kJ of heat, find out the intermediate temperature, the efficiency and the work output of all the engines.**

In a Carnot engine, the efficiency (η) is given by the formula:

$$\eta = 1 - \frac{T_C}{T_H}$$

where T_C is the absolute temperature of the cold reservoir and T_H is the absolute temperature of the hot reservoir.

For a series of Carnot engines, the intermediate temperature ($T_{\text{intermediate}}$) can be found using the efficiency of each engine. The efficiency of each engine is related to the temperatures of the hot and cold reservoirs:

$$\eta = 1 - \frac{T_C}{T_H}$$

Now, let's denote the temperatures of the hot reservoir for the first, second, and third engines as T_{H1}, T_{H2}, and T_{H3}, respectively. The temperatures of the cold reservoirs for the first, second, and third engines are T_{C1}, T_{C2}, and T_{C3}.

Given:

- $T_{H1} = 1200\,\text{K}$
- $Q_{in1} = 2400\,\text{kJ}$
- $T_{C2} = T_{H2}$ (because they are connected in series)
- $Q_{in2} = 300\,\text{kJ}$
- $T_{C3} = 150\,\text{K}$

Step 1: Find T_{C1} using the efficiency of the first engine.

$$\eta_1 = 1 - \frac{T_{C1}}{T_{H1}}$$

Solve for T_{C1}.

Step 2: Find T_{H2} using the efficiency of the second engine.

$$\eta_2 = 1 - \frac{T_{C2}}{T_{H2}}$$

Since $T_{C2} = T_{H2}$, you can solve for T_{H2} using the given efficiency.

Step 3: Find T_{C2} using the efficiency of the second engine.

$$\eta_2 = 1 - \frac{T_{C2}}{T_{H2}}$$

Solve for T_{C2}.

Step 4: Find T_{H3} using the efficiency of the third engine.

$$\eta_3 = 1 - \frac{T_{C3}}{T_{H3}}$$

Solve for T_{H3}.

Now, you have $T_{C1}, T_{C2}, T_{H2}, T_{C3}$, and T_{H3}.

Step 5: Find $T_{\text{intermediate}}$.

The intermediate temperature is the average of T_{H2} and T_{C2}:

$$T_{\text{intermediate}} = \frac{T_{H2}+T_{C2}}{2}$$

Step 6: Find the efficiency of the series connection.

$$\eta_{\text{series}} = 1 - \frac{T_{C1}}{T_{H1}} \times \frac{T_{C2}}{T_{H2}} \times \frac{T_{C3}}{T_{H3}}$$

Step 7: Find the total work output.

The total work output is the sum of the work outputs of each engine:

$$W_{\text{total}} = Q_{\text{in1}} \times \eta_1 + Q_{\text{in2}} \times \eta_2$$

Now, you have the intermediate temperature, the efficiency of the series connection, and the total work output. Perform the calculations with the given values.

93. 5 kg of air at 100 kPa pressure and 333K temperature is compressed polytropically to pressure 750 kPa as per the law Pv1.3. it is then cooled at constant temperature to its original condition. Plot the cycle on p-v diagram, calculate the work in each process and network and heat transfer.

To analyze the polytropic compression and subsequent constant-temperature cooling process of the air, we can use the ideal gas law and the polytropic process equation:

1. **Polytropic Compression (Process 1-2):**

$$P_1 V_1^n = P_2 V_2^n$$

Given:

- $P_1 = 100$ kPa
- V_1 is calculated using the ideal gas law: $V_1 = \frac{mRT_1}{P_1}$
- $n = 1.3$
- $P_2 = 750$ kPa
- Solve for V_2 using the polytropic process equation.

Work Done in Process 1-2:

$$W_{1-2} = \frac{P_1 V_1 - P_2 V_2}{1-n}$$

2. **Constant-Temperature Cooling (Process 2-3):**

This process is isothermal, so $PV = \text{constant}$.

Given:

- $T_3 = T_1$
- $P_3 = P_1$
- Use the ideal gas law to find V_3: $V_3 = \frac{mRT_3}{P_3}$

Work Done in Process 2-3:

$$W_{2-3} = P_3 V_3 \ln \left(\frac{V_2}{V_3} \right)$$

3. **Constant-Volume Heating (Process 3-4):**

    In this process, the volume is constant, so $V_3 = V_4$.

    Work Done in Process 3-4:

    $$W_{3-4} = 0$$

4. **Constant-Temperature Expansion (Process 4-1):**

    Again, this process is isothermal.

    Work Done in Process 4-1:

    $$W_{4-1} = P_1 V_1 \ln\left(\frac{V_4}{V_1}\right)$$

Net Work Output:

$$\text{Net Work Output} = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

Heat Transfer in each process:

$$Q_{1-2} = W_{1-2}$$
$$Q_{2-3} = W_{2-3}$$
$$Q_{3-4} = W_{3-4}$$
$$Q_{4-1} = W_{4-1}$$

Total Heat Transfer:

$$\text{Total Heat Transfer} = Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1}$$

Now, use the given data to calculate the values for V_1, V_2, V_3, and V_4 and then use the above equations to find the work done in each process, the net work output, and the heat transfer in each process. You can plot the cycle on a p-v diagram using these calculated values.