UNIT 1: BASIC CONCEPTS AND LAWS OF THERMODYNAMICS


UNIT II: IC ENGINES AND GAS TURBINES

Air standard cycles: Otto, diesel and dual cycles and comparison of efficiency - Working Principle of four stroke and two stroke engines - Working principle of spark ignition and compression ignition engines - Applications of IC engines

UNIT III: STEAM BOILERS AND TURBINES

Formation of steam - Properties of steam – Use of steam tables and charts – Steam power cycle (Rankine) - Modern features of high-pressure boilers – Mountings and accessories – Testing of boilers.
Steam turbines: Impulse and reaction principle - Velocity diagrams - Compounding and governing methods of steam turbines (qualitative treatment only) - Layout diagram and working principle of a steam power plant.

UNIT IV: COMPRESSORS, REFRIGERATION AND AIR CONDITIONING

Unit of refrigeration - Basic functional difference between refrigeration and air conditioning – Various methods of producing refrigerating effects (RE) – Vapour compression cycle: P-H and T-S diagram - Saturation cycles - Effect of subcooling and super heating - (qualitative treatment only) - Airconditioning systems – Basic psychrometry - Simple psychrometric processes - Types of airconditioning systems -Selection criteria for a particular application (qualitative treatment only).

UNIT V : HEAT TRANSFER

Convection: Free convection and forced convection - Internal and external flow -Empirical relations - Determination of convection heat transfer co-efficient by using Dittus–Baetter equation.
Radiation: Black–Gray bodies - Radiation Shape Factor (RSF) - Cooling of electronic components: Thermoelectric cooling – Chip cooling.

TEXT BOOKS


REFERENCE BOOKS


UNIT I : BASIC CONCEPTS AND LAWS OF THERMODYNAMICS

PART A

1. What is meant by thermodynamic system? How do you classify it?
Ans: A system is defined as a definite space or area on which the study of energy transfer and energy conversions are made.
It may be classified as
(a) Closed system
(b) Open system
(c) Isolated system.

2. Define the terms: Thermodynamic property, process, and cycle.
Property: It is defined as any measurable or observable characteristics of the substance, when the system remains in equilibrium state.
Process: It is the change of state undergone by a system.
Cycle: If a thermodynamic system undergoes a series of processes and returns to its initial position, then the process is called a cycle.

3. What do you understand by Macroscopic and microscopic viewpoints?
In the macroscopic point of view, a certain quantity of matter is considered, without the events occurring at the molecular level being taken into account.
From the microscopic viewpoint, matter is composed of infinite molecules.

4. Distinguish between the open and closed system.
In a closed system, the working substance is recirculated again and again in the system.
In an open system, the working substance is exhausted to atmosphere after the process takes place.

5. Define isolated system.
If there is no flow of mass and energy to and from a system it is known as an isolated system.
6. What is thermal Equilibrium?
*Thermal Equilibrium:* A system is in Thermal Equilibrium if the temperature is the same throughout the entire system, i.e. the system involves no temperature differential, which is the driving force for heat flow.

- **Mechanical Equilibrium:** Mechanical equilibrium is related to pressure, and a system is said to be in mechanical equilibrium if there is no change in pressure at any point of the system with time.
- **Chemical Equilibrium:** A system is in chemical equilibrium if its chemical composition does not change with time or no chemical reaction occurs in that system.
- **Thermal Equilibrium:** A system is in Thermal Equilibrium if the temperature is the same throughout the entire system, i.e. the system involves no temperature differential, which is the driving force for heat flow.

8. What is meant by Quasi static process?
*Quasi static/Quasi Equilibrium process:* When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a quasi-static process.

9. Define intensive and extensive property?
- **Intensive Property:** An intensive property is one whose value does not depend on the mass of the system. Such properties include Temperature, pressure, density, and specific volume. Whatever may be the mass of the system, these are the same for the entire system.
- **Extensive property/Extrinsic Properties:** Those properties which depend on the size, extent, or the mass of the system are called the extensive properties. Eg.: mass m, volume v, total energy E.

10. What is the concept of continuum?
*Continuum:* In Classical Thermodynamics, the atomic structure of a substance is neglected and hence is considered to be a continuous, homogeneous matter with no macroscopic holes that is called a continuum. (or) A continuous, homogeneous matter with no microscopic holes is called continuum.

11. Define Zeroth law of thermodynamics.
*Zeroth Law of Thermodynamics:* If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. This law was first formulated and labeled by R.H. Fowler in 1931.
12. What is ideal gas?

*Ideal gases (perfect gas)*: An ideal gas strictly obeys all the gas laws under all condition of pressure and temperature. In this sense no gas, which exists in nature, is perfect. eg. air and nitrogen.

13. What is constant volume gas thermometer? Why is it preferred to a constant pressure gas thermometer?

In a constant volume gas thermometer, a small amount of gas is enclosed in the bulb, which is in communication via the capillary type with one limb of the mercury manometer. The other limb of the mercury manometer is open to the atmosphere and can be moved vertically to adjust the mercury levels so that the mercury just touches lip of the capillary.

The constant pressure gas thermometer is less preferred than the constant temperature one because,

In a constant pressure gas thermometer, the mercury levels have to be adjusted to keep the value of $Z$ constant and the volume of gas $V$, which would vary with the temperature of the system, becomes the thermodynamic property.

14. What is the advantage of thermocouple in temperature measurement?

The advantage of a thermocouple is that it comes to thermal equilibrium with the system, whose temperature is to be measured. Quite rapidly, its mass is small.

15. How does a resistance thermometer measure temperature?

Here, the change in resistance of a metal wire due to its change in temperature is the thermodynamic property.

16. Define heat and work.

Heat is defined as the energy transferred without transfer of mass, across the boundary of a system because of temperature difference between the system and surroundings.

Work is defined as the energy transferred across the boundary of a system because of intensive property difference other than temperature that exists between the system and surroundings.

17. When is work said to be done by a system?

When the value of the work is positive, then it is said to be done by a system.
18. Define displacement work.
The work done by a piston when it moves from one point to another, with the volume changing, is known as the displacement work.

19. What do you understand by path and point function?
The functions which depend on the path followed by the system are known as path functions.
The functions which have a definite value for each property are known as the point functions.

20. What are positive and negative interactions?
Positive work is the work done by the system, and negative work is the work done on the system.

21. A mass of 0.2 kg of air initially at temperature of 165°C, expands reversibly at a constant pressure of 7 bar until the volume is doubled. Find the work transfer.
\[ m = 0.2 \text{ kg}, \ T_1 = 165 + 273 = 438 \text{ K}, \ p_1 = 7 \text{ bar} = 7 \text{ N/m}^2. \]
For air, \( R = 287 \text{ J/kg K} \)
Work done \( = m \times R \times (T_2 - T_1) \)

For a constant pressure process,
\[ \frac{V_1}{V_2} = \frac{T_1}{T_2} \]
As, \( V_2 = 2V_1 \), \( V_2 /V_1 = 2 \)
\[ T_1/T_2 = 0.5 \]
\[ T_2 = 438 /0.5 = 876 \text{ K} \]
\[ W = 0.2 \times 287 \times (876 - 438) = 25.14 \text{ kJ} \]

22. Show that work and heat are path function, and not a property.
When the system changes from its initial state to final state the quantity of heat transfer and work transfer depend upon the intermediate stages through which the system passes, i.e. the path.

23. What is an indicator diagram?
*Indicator diagram*: The indicator diagram is simply a pictured record of the simultaneous variation of volume and pressure of the working substance in a cylinder as the piston reciprocates. The indicator card may be a closed pressure volume diagram.

24. What is reversibility?
**Reversible process**: A process is said to be reversible if means can be found to restore the system and all elements of its surroundings to their respective initial states. (or) A reversible process is one which is performed in such a way that at the end of the process, both the system and the surroundings may be restored to their initial states.

25. **Define free expansion.**

It is an irreversible process. If a fluid is allowed to expand suddenly into a vacuum chamber through an orifice of large dimension, it is known as free expansion process.

26. **Define specific heat and latent heat.**

*Specific Heat (C):* The heat required by a unit mass of a substance to raise temperature by one temperature by one degree is called the specific heat of the substance; it is called the heat capacity of the substance.

*Latent heat:* The amount of heat absorbed at its saturation temperature is known as latent heat. (or) The heat transferred resulting in a change of phase at constant temperature is called latent heat. Latent heat exchange processes correspond to those melting, evaporation and sublimation, and vice versa, viz. fusion, condensation and desublimation and the heat transferred is measured as $Q_L = m (\Delta h)$.

27. **What is mean effective pressure? How is it measured?**

*Mean Effective Pressure (MEP):* The pressure which, when acts on the piston, during the entire power stroke, would produce the same amount of net work as that produced during the actual cycle is known as Mean Effective Pressure. It is found out mathematically by dividing the work done per cycle to the stroke volume.

*It is measured using an Indicator diagram*

*Indicator diagram:* The indicator diagram is simply a pictured record of the simultaneous variation of volume and pressure of the working substance in a cylinder as the piston reciprocates. The indicator card may be a closed pressure volume diagram.

28. **Define first law of thermodynamics.**

*First Law of Thermodynamics:* Whenever a system undergoes a cyclic change, the algebraic sum of work transfer is proportional to the algebraic sum of heat transfers or work and heat are mutually convertible from one into the other. (or) In a cyclic process, the net heat added is equal to the work done (or), The heat lost by the system is equal to the heat gained by the surrounding. e.g. A coffee left in a cooler.
29. **What are the modes in which the energy is stored in a system?**

Energy is stored in macroscopic mode and microscopic mode. The macroscopic mode includes the macroscopic kinetic energy and potential energy of a system. The microscopic energy mode refers to the energy stored in the molecular and atomic structure of the system, which is called the molecular internal energy.

30. **Define specific heat at constant volume and specific heat at constant pressure.**

*Specific heat at constant pressure* \( (c_p) \): The amount of heat required to raise the temperature of a unit mass of a gas by one degree at constant pressure is known as the specific heat at constant pressure. It is given by \( c_p = \frac{(dh/d\dot{t})_p} \).

*Specific Heat at constant volume* \( (c_v) \): The amount of heat required to raise the temperature of a unit mass of a gas by one degree at constant volume is known as the specific heat at constant volume and is given by \( (du/dT)_v \).

31. **What is the product of mass and specific heat?**

The product of mass and specific heat is called **heat**.

32. **Define enthalpy.**

*Enthalpy (h)*: Enthalpy is a calculated property of substance, which is sometimes defined as “total heat content”. It is given by \( h = u + pv \) (or) The total heat energy contained in one kg of gas, known as its enthalpy \( H \), is the sum of its internal energy \( U \) and the external energy \( pv \) due to its pressure and volume.

33. **What is PMM!? Why it impossible?**

*Perpetual Motion machine of the first kind*: A perpetual motion machine will give continuous work without receiving any energy from other system to surroundings. It will violate the First law of Thermodynamics.

It is impossible because a machine cannot work continuously without any heat input as it is against the first law of thermodynamics.

34. **Define control volume.**

*Control volume*: Control Volume is an imaginary envelope around the flow system to facilitate analysis.

35. **What is steady flow process?**

*Steady flow process*: A large number of engineering devices such as turbines,
compressors, operate for a long time under the same conditions of Temperature and pressure. This process is called the steady flow process.

36. State the Kelvin planck and the Clausius statement of the second law of thermodynamics.

*Kelvin Planck’s statement*: It is impossible to construct a heat engine which while operating in a cycle produces no effect except to do work and exchange heat with a single reservoir.

*Clausius Statement of second law of thermodynamics*: It is known that heat flows from a hot body to a cold body without any aid. It is impossible for heat to flow from a colder body (body at lower temperature) to a hot body (body at higher temperature) without the aid of external work.

37. Define heat engine, heat pump, and refrigerator.

*Heat engine*: A system which by operating in a cyclic manner produces net work from a supply of heat. (or) A heat engine is any continuously operating thermodynamic system across the boundaries of which flow only heat and work.

*Heat Pump*: A device that transfers heat from a low temperature medium to a high temperature one is called a heat pump.

*Refrigerators*: A device that transfers heat from low temperatures to high temperature region is known as refrigerator.

38. Show that the COP of a heat pump is greater than the COP of a refrigerator by unity.

The COP of a refrigerator is \( \frac{T_1}{T_2-T_1} \)

Now if,

\[
\text{COP}_{\text{Ref}} + 1 = \frac{T_1}{T_2-T_1} + 1 = \frac{T_2}{T_2-T_1}
\]

39. Define PMM2. Why is it impossible?

Perpetual motion machine of the second kind is a machine which receives heat energy from hot reservoir and converts it into equivalent amount of work. PMM2 gives 100% efficiency. Therefore it is impossible to construct and it violates the second law of thermodynamics.

40. State Carnot’s theorem.
No heat engine operating in a cyclic process between two fixed temperature, can be more efficicnet than a reversible engine operating between the same temperature limits.

41. A closed system receives the heat input of 450kJ and increases the internal energy of the system by 325kJ. Determine the work done by the system.
We know that,
\[ \Delta Q = \Delta W + \Delta U \]
Here, \( \Delta Q = 450kJ, \Delta U = 325kJ \).
\[ \Delta W = \Delta Q - \Delta U \]
\[ = 125kJ \].

UNIT – II

PART A
1. Draw the carnot cycle on PV and Ts diagram and also comment on its efficiency.
Ans: Refer Unit I Part A Qns.

2. Discuss the difficulties experienced in the practical use of carnot cycle in any engine.
Ans:
(i) The friction between the piston and the cylinder has been neglected, although in actual practice it is impossible to have such an arrangement.
(ii) It has been suggested that heat is added during isothermal expansion at constant temperature. For any heat transfer from hot reservoir to the working substance finite temperature difference is essential.
(ii) Heat flows very slowly for a small temperature difference, and therefore the movement of the piston and the rate of doing work would be less.

3. What is meant by air standard efficiency of the cycle?
Ans:
The ratio of work done to the heat supplied is known as air standard efficiency of the cycle.

4. Write down the expression for efficiency of the otto cycle?
\[ \eta = 1 - \left\{ 1 / (r^{\gamma - 1}) \right\} \]
where, \( \gamma \) is the ratio of specific heat
and \( r \) is the compression ratio.

5. What is the other name given to Otto cycle?
   Constant volume cycle.

6. Draw the pv and Ts diagram for Otto cycle.

7. Draw the pv – and Ts diagram of a diesel engine.

8. In petrol engine, charge is ignited with the help of Spark plug.
9. **What is fuel injector?**
   A device for injecting fuel in a diesel engine.

10. **For the same compression ratio, and heat rejection, which cycle is most efficient: Otto, Diesel, and Dual?**
   \[ \eta_{\text{Otto}} > \eta_{\text{Dual}} > \eta_{\text{Diesel}} \]

11. **Prove with Ts diagram that Otto cycle, is more efficient than Diesel cycle for the same compression ratio and same heat input.**

   ![Ts Diagram]

   In the Ts diagram the area under 2-3 represents Q1 for the Otto cycle, and the area under 2-7 represents Q1 for the diesel cycle and the area under 2-5-6 represents Q1 for the Dual cycle.

12. **Write down the expression for Air standard efficiency of Diesel cycle.**
   **Ans:**
   \[ \eta = 1 = \left[ \frac{r^{\frac{1}{\gamma} \left( \rho - 1 \right)}}{(\rho - 1)} \right] \]

13. **Determine the air standard efficiency of a diesel cycle using compression ratio of 16 and if the cut off takes place at 8% of the stroke.**
   **Ans:**
   \[ \eta = 1 = \left[ \frac{r^{\frac{1}{\gamma} \left( \rho - 1 \right)}}{(\rho - 1)} \right] \]
\[ r = 16, \]
\[ \rho - 1/(r - 1) = 8/100 = k \]
\[ \rho = 1 + k (r - 1) = 2.2 \]
\[ \eta = 1 - (0.235 \times 1.679) = 1 - 0.394 = 0.60525 \]
\[ \eta = 60.5\% \]

14. Sketch the limited pressure cycle on Pv and Ts diagram and name various process.

14. The compression ratio of diesel cycle lies in the range of 14 – 22.

15. Compression ratio of spark ignition engines are 5 to 10.

16. Define compression ratio, expansion ratio and cut off ratio

17. Define mean effective pressure of an IC engine.
   The mean effective pressure of an IC engine is the average pressure on the piston during the working stroke and is given by the mean height of the p-V diagram in N/m².

18. Write the expression for the MEP of an Otto cycle?
ME P = p1 Rc [ (α-1) / (γ -1 ) ] [ {Rc (γ-1) / ( Rc -1) }]

19. What are the assumptions made for the air standard cycles?
The assumptions for the cycles are
- The gas in the engine cylinder is a perfect gas.
- The physical constants of the gas in the cylinder are the same as those of air at moderate temperatures.
- The compression and expansion processes are adiabatic.
- No chemical reaction takes place in the cylinder.
- The cycle is considered closed.

20. What is the difference between Otto and diesel cycle.

<table>
<thead>
<tr>
<th></th>
<th>OTTO CYCLE</th>
<th>DIESEL CYCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Used in Petrol engines</td>
<td>Used in Diesel engines</td>
</tr>
<tr>
<td>2</td>
<td>Heat addition and heat rejection is done at constant volume.</td>
<td>Heat addition and heat rejection is done by constant pressure processes.</td>
</tr>
</tbody>
</table>

21. Define IC engine and the various types of it.
An IC engine is one in which the combustion takes place inside a confined cylinder.
The types of IC engines.
(i) Type of ignition used
Spark ignition engine and Compression ignition engine.
(ii) Type of fuel used
Petrol and Diesel engine
(iii) Number of strokes used
Four and two stroke engine
(iv) Type of cooling system
Air cooled engine
Water cooled engine

22. Give an example of External Combustion engine.
Steam engine
23. Compare 2 stroke and 4 stroke engines with respect to power output and thermal efficiency.

<table>
<thead>
<tr>
<th></th>
<th>Power output</th>
<th>Thermal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 stroke engine</td>
<td>more</td>
<td>More</td>
</tr>
<tr>
<td>2 Stroke engine</td>
<td>Less</td>
<td>Less</td>
</tr>
</tbody>
</table>

24. Define brake thermal efficiency.
The ratio of brake or shaft work obtained to the energy supplied by fuel.

25. Define the Volumetric efficiency of an IC engine.
Ans: The volumetric efficiency of an IC engine may be defined as the ratio of the actual reduced to NTP of the charge admitted during the suction stroke to the swept volume of piston.

26. What is meant by SI engine and CI engine?
SI engine: Spark Ignition Engine
CI engine: Compression Ignition engine.

27. Define the term compression ratio.

28. What is meant by 2 stroke and 4 stroke engines?
Ans: 2 stroke engines are engines which produce the power in 2 strokes and 4 stroke engines are those which produces the power in 4 strokes.

29. Which device is used to control the air fuel ratio in the petrol engine?
Throttling device
UNIT III
STEAM BOILERS AND TURBINES

PART A

1. Define Quality of steam.
   The Quality of steam is the ratio of mass of dry steam actually present to the mass of wet steam which contains it.

2. Draw the layout of thermal power plant.

   ![Diagram of thermal power plant]

3. Define superheated steam
   When saturated steam is heated above 250 deg C d, it is known as superheated steam.

4. Draw the Ts diagram for regenerative cycle.
5. **Define Saturation temperature.**
   It is defined as the temperature at the saturation curve.

6. **Write a note on steam table/**
   It is a table having the properties of steam at various pressures and temperatures and different conditions like saturated and superheated steam.

7. **Determine the state of steam for the following conditions .**
   (a) Steam has a pressure of 15 bar and specific volume of 0.12 m$^3$/kg.
   (b) Steam has a pressure of 10 bar and Temperature of 250°C

   Ans: (1) Saturated
   (2) Super heated

8. **Draw the practical Ts diagram of the steam power plant .**
9. Give the example of water tube boiler.
Babcock and Wilcox boiler.

10. An example of fire tube boiler.
Benson boiler

11. Write the difference between water tube and fire tube boiler.

<table>
<thead>
<tr>
<th></th>
<th>Fire tube boiler</th>
<th>Water tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot Gases flows through the tubes.</td>
<td>Water flows through the tube.</td>
</tr>
<tr>
<td>2</td>
<td>Compact and easy design</td>
<td>Complicated design</td>
</tr>
</tbody>
</table>

12. Lancashire boiler is a Fire tube boiler.

13. The position of fire tubes in Cochran boiler are Horizontal.

14. What is the use of superheater in a boiler?
Superheater is used to superheat the dry saturated steam hence increasing the efficiency of the thermal power plant.
15. What do you understand by forced circulation boiler?
In Forced circulation boilers, external devices like feed pump are used to circulate the feed water.

16. Name the few boiler mountings.
Manhole, safety valves, blow off cock, pressure gauge.

17. What is the function of economizer in a boiler?
An economizer is used to reheat the feed water using the flue gases.

18. List the difference between impulse and reaction turbine.

<table>
<thead>
<tr>
<th></th>
<th>Impulse turbine</th>
<th>Reaction turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steam completely expands in the nozzle.</td>
<td>Steam partially expands in the nozzle and remaining expansion takes place when it moves over the rotor blades.</td>
</tr>
<tr>
<td>2</td>
<td>Steam strikes the blade with kinetic energy.</td>
<td>Steam strikes the blade with kinetic energy And pressure energy.</td>
</tr>
<tr>
<td>3</td>
<td>The blades are symmetrical.</td>
<td>The blades are not symmetrical.</td>
</tr>
</tbody>
</table>

19. Why compounding is necessary in steam turbines?
If the entire pressure drop from boiler pressure to condenser pressure is carried out in its single stage nozzle, then the velocity of the steam entering the turbine blades will be very high. It will make the turbine rotor to run at a very high speed. Such high speed of the turbine rotors is not useful for practical purposes.
UNIT – IV
AIR COMPRESSORS, REFRIGERATION AND AIR CONDITIONING

PART A

1. How air compressors are classified?
Air compressors be classified as follows:
(i) According to design and principle of operation.
(a) Reciprocating compressor
(b) Rotary compressor
(ii) According to the action
(a) Single acting
(b) Double acting
(iii) According to the number of stages
(a) Single stage
(b) Double stage
(iv) According to pressure limit
(a) Low pressure
(b) Medium pressure
(c) High pressure

2. Explain the working of a single acting reciprocating air compressor?
In this compressor, the compression of air from the initial pressure to final pressure is carried out in one cylinder only.

3. What is meant by single acting compressor?
In these compressors, suction, compression and delivery of air takes place on one side of the piston.

4. What is meant by double acting compressor?
Here, the suction, delivery and compression takes place in both sides of the piston.

5. What is meant by multistage compression?
Here, the compression of the air from the initial to the final pressure is carried out in more than in one cylinder only.

6. Define clearance ratio.
Clearance ratio is defined as the ratio of clearance volume to swept volume or stroke volume.

\[ C = \frac{V_c}{V_s} \]

Where,
Vc is the clearance volume
And Vs = Stroke volume

**7. What is compression ratio?**
Compression ratio is defined as the ratio between the total volume and clearance volume.
Compression ratio = Total volume / Clearance volume

**8. Give two merits of multistage compressors.**
Ans:
* Improves the volumetric efficiency for the given pressure ratio.
* Work done per kg of air is reduced in multistage compression with intercooler as compared to single stage compression for the same delivery pressure.

**9. Define the volumetric efficiency of a reciprocating compressor.**
Ans:
The volumetric efficiency is the ratio of volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder.

\[ \eta_{vol} = 1 - \left( \frac{V_c}{V_s} \right) \left( \frac{V_4}{V_c} - 1 \right) \]

**10. Explain the effect of intercooler in a reciprocating compressor.**
The intercooler is a heat exchanger in which heat of compression generated in the first stage cylinder is removed from the air before it passes to the second stage cylinder.
It increases the efficiency of the compressor.

**11. Why do we go for multi stage compression?**
Multistage compression is preferred because of the following factors.
* Improves the volumetric efficiency for the given pressure ratio.
* Work done per kg of air is reduced in multistage compression with intercooler as compared to single stage compression for the same delivery pressure.
12. **Mention two uses of reciprocating compressor.**
Reciprocating compressors are used in pneumatic brakes, drills, jacks, lifts, etc.

13. **Give two merits of rotary over reciprocating compressors.**
* Rotary compressor gives uniform delivery of air compared to the reciprocating compressors.
* Rotary compressors are small in size, for the same discharge compared with the other one.
* Lubricating system is more complicated in reciprocating compared to the rotary compressor.

14. **Mention any four applications of compressed air.**
Spray painting, shop cleaning, injecting fuel in diesel engines, supercharging internal combustion engines, refrigeration, air conditioning. Reciprocating compressors are used in pneumatic brakes, drills, jacks, lifts, etc.

15. **Name the compression process in which the work done is minimum in reciprocating air compressor.**
Work done is minimum in an isothermal compression process.

16. **Compressor capacity is referred in m³/min.**

17. **In compressor, the cylinder clearance should be minimum.**

18. **What is refrigeration?**
The process of providing and maintaining the temperature below that of the atmospheric temperature.

19. **Define COP of a refrigerator.**
The COP of a refrigeration system is defined as the ratio of heat absorbed by the refrigerant while passing through the evaporator to the work supplied.

20. **Define; Ton of Refrigeration.**
A tonne of refrigeration is defined as the quantity of heat required to be removed from one tonne of water (1000 kg) at 0°C to convert that into ice at 0°C in 24 hrs.
21. **Explain the principle of vapour absorbtion system of refrigeration.**

The working of an absorprion system depends upon the use of two substances which have great affinity for each other and which can be easily separated by the application of heat. The principal combinations are sulphuric acid and water or ammonia and water.

22. **Name the components of a vapour compression system with their use.**

The components are:

* Compressor
  
  The main function of compressor is to increase the pressure and temperature of the vapour refrigeration above atmospheric.

* Condenser
  
  The function is to cool the vaporu and the vapour will be converted into liquid.

* The receiver is a storage tank, which stores the liquid.

23. **A refrigerant should have low boiling point and high freezing point.**

24. **What are the applications of a refrigeration system?**

25. **What are the desirable properties of a refrigerant?**

* Thermodynamic properties
  
  Condensing pressures and boiling pressures, freezing point, Latent heat, and volume flow per ton.

26. **What are the main components of an air conditioning plant?**

Fan, damper, cooling coil, filter, heating coil, etc.

27. **Define dew point temperature.**

The temperature at which the water vapour in air starts to condense is the dew point temperature.

28. **Define wet bulb temperature.**

The temperature measured when the bulb of the thermometer is covered by a cold wick is known as wet bulb temperature.

29. **Define relative humidity and degree of saturation.**
Relative humidity is the ratio of actual partial pressure of water vapour in a given volume of moist air to the saturation pressure of the vapour at the same dry bulb temperature.

Degree of saturation: The ratio of prevailing humidity ratio of moist air to the humidity ratio of saturated air at the same temperature and pressure.

30. Name any four commonly used refrigerants?
Refrigerant 11, Refriegrenat – 12, 22, 113, Freon. Etc

UNIT V

HEAT TRANSFER

PART A

1. Define Heat transfer
   It is defined as the transmission of energy from one region to another due to temperature difference.

2. Explain briefly the principle of conduction heat transfer.
   In conduction, heat flows from a region of high temperature to a region of low temperature within a medium or between different medium in direct physical contact.
   Here, energy exchange takes place by the kinematic motion or direct impact of molecules.

3. Fourier’s law is based on the assumption that Heat transfer is steady state.

4. Define black body.
A black body is one which absorbs heat radiation of all wave length falling on it.

5. Define grey body.
If a body absorbs definite percentage of incident radiations irrespective of their wavelength, the body is known as grey body.

They are
Conduction
Convection
Radiation

7. Define thermal conductivity of a material.
It is the ability of a substance to conduct heat.

8. The unit of Thermal conductivity is W/mK

9. What are the uses of fins?
Fins increase the heat transfer area, and hence the heat transfer rate is increased.

10. What is the difference between forced and free convection?
If the fluid motion is produced due to change in density resulting from temperature gradients, the mode of heat transfer is said to be free or natural convection.

If the fluid is artificially created by means of an external force like a blower or fan, that type of heat transfer is known as forced convection.

11. Write down the Stefan Boltzman law with its unit.
The total energy emitted by a black body at a particular temperature is given by
\[ E_b = \sigma T^4. \]
Where, \( \sigma = \) Stefan Boltzmann constant

Emissivity is defined as the ratio between energy radiated by the surfaces at temperature and the energy radiated by black surface at same temperature.
13. Define Emissive power.
Emissive power of a black surface is defined as the energy emitted by the surface per unit time per unit area and is dependent upon a number of parameters among which are the surface material and roughness.

This law states that the ratio of total emissive power to the absorptivity is constant for all the surfaces which are in thermal equilibrium with the surroundings.

15. What is meant by radiation shape factor?
The shape factor is defined as the fraction of the radiative energy that is diffused from one surface element and strikes the other surface directly with no intervening reflections.

The relation between the monochromatic emissive power of a black body and wavelength of a radiation at a particular temperature.

PART B QUESTIONS OF UNITS I TO V
UNIT I

1.0.2 Kg of air at 1.5 bar and 27°C is compressed to a pressure of 15 bar according to the law pv 1.25 = C, Determine the work done on by air, heat flow to or from the air, and increase or decrease of entropy.

Solution:
Given data:
Mass of air, m = 0.2 kg
P1 = 1.5 bar = 1.5 x 105N/m2
T1 = 27+273 = 300 K
n = 1.25
Polytropic process.
To find:
(i) Work done:
\[ W = \frac{mR(T_1-T_2)}{n-1} \]
\[
\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \\
T_2 = 300(15/1.5)^{\frac{1.25 - 1}{1.25}} = 475.46K \\
W = \frac{0.2 \times 0.287 \times (300 - 475.46)}{1.25 - 1} = -40.285kJ \\
W = -40.285kJ \\
(ii)\text{Heat Transfer, } Q \\
Q = \frac{\gamma - n}{\gamma - 1} W = \frac{1.4 - 1.25}{1.4 - 1} (-40.285) = -15.10kJ \\
Q = -15.1 kJ \\
(iii)\text{change in entropy} \\
\Delta s = m \left[ R \ln \frac{V_2}{V_1} + C_v \ln \frac{T_2}{T_1} \right] \\
V_2/V_1 = \left(\frac{p_2}{p_1}\right)^{1/n} \\
\Delta s = 0.2 \left[ 0.287 \ln 0.1584 + 0.718 \ln \frac{475}{300} \right] = -0.0396kJ/K \\

2. One kg of air occupies 0.084m³ at 12.5 bar and 537°C. It is expanded at a constant temperature to a final volume of 0.336m³. Calculate the pressure at the end of expansion, work done, heat absorbed and change in entropy.

Solution:
Given data:

\(m = 1\)kg \\
\(v_1 = 0.084\)m³ \\
\(p_1 = 12.5\) bar \\
\(T_1 = 537°C + 273 = 810\) K \\
Constant temperature process. \\
\(V_2 = 0.336\)m³ \\
To find \\
P2, W, Q, \Delta s.
So1n:
P1/p2 = v2/v1
12.5 /p2 = 0.336 /0.084
p2 = 3.125 bar

W = p1v1 ln ( V2/V1 ) = 12.5 x 10^5 x 0.084 ln (0.336 / 0.084)
= 1455kJ

\[ \Delta Q = \Delta W = 145kJ \]

\[ \Delta s = mR ( \frac{V2}{V1} ) = 0.45 x 0.287 ln ( \frac{0.336}{0.084} ) \]

as
p1V1 = mRT1
m = 0.4516kg

\[ \Delta s = 0.1797 \text{ kJ/K} \]

3. A mass of 1.5 kg of air is compressed in a quasi static process from 0.1 Mpa to 0.7 Mpa for which \( P_v = C \). the initial density of air is 1.16 kg /m^3. Find the work done by the piston to compress the air.

Solution.
Given data:
.m= 1.5kg
p1 = 0.1 MN/m^2
p2 = 0.7 MN/m^2.

PV = C
\( \rho_1 = 1.16 \), \( V_1 = \frac{1}{\rho_1} = 0.862 \text{ m}^3. \)

\[ W = p1V1 \ln ( \frac{p1}{p2} ) \]

As \( V2 /V1 = P1/P2 \)

\[ W = -167.73 \text{ kJ}. \]

4.2 kg of air at 32°C is expanded in a closed system process following \( P^1.25 = C \) until the pressure is halved. Compute (a) Change in internal energy
(b) Change in entropy
(c) Work done.

Solution:
Given data:
\(m = 2 \text{ kg}\)
\(T_1 = 32 + 273 = 305 \text{ K}\)
\(Pv^{1.25} = C\)
\(n = 1.25\)
\(P_2 = P_1 / 2\)

\(C_v\) for air is 0.718 kJ/kg K

To find:
\(\Delta U, \Delta S, \text{ and } W\)

Soln

For polytropic process

\[
\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}.
\]

\(T_2 = 265.5 \text{ K}\)

Change in internal energy

\[
\Delta U = mC_v (T_2 - T_1)
= -56.72 \text{ kJ}
\]

Change in entropy

\[
\Delta s = \int \left[ R \frac{p_1}{p_2} + C_p \frac{T_2}{T_1} \right] \, \text{d}V
\]

\[
= \Delta s = \left[ 0.287 \ln\left(\frac{p_1}{p_1/2}\right) + 1.005 \ln\left(\frac{265.5}{305}\right) \right] = 0.119 \text{ kJ}
\]

Work done,

\[
W = \frac{mR(T_1 - T_2)}{n-1} = 90.69 \text{ kJ}.
\]

5. Gas at 5 bar abs, and 20°C in a closed vessel is compressed to 10 bar abs. Its temperature then becomes 180°C. If the compression follows the law \(pV^n = C\), find the value of \(n\).
Solution:

Given data:

\[ \begin{align*} 
P1 &= 1.5 \text{ bar} \\
T1 &= 20+273 = 293 \text{ K} \\
P2 &= 10 \text{ bar} \\
T2 &= 180+ 273 = 453 \text{ K} \\
\text{Law} &: \ pV^n = C 
\end{align*} \]

To find: \( n \)

From the polytropic relation ,

\[ \frac{T2}{T1} = \left( \frac{p2}{p1} \right)^{\frac{n-1}{n}}. \]

Taking log on both sides,

\[ \log \left( \frac{T2}{T1} \right) = \frac{n-1}{n} \log \left( \frac{p2}{p1} \right) \]

Solving ,

\[ n = 1.298 \]

6. The efficiency of a carnot cycle rejecting heat to a pond at 28°C is 30%. If pond receives 1050kJ/min, what is the power developed by the cycle and temperature of the source?

Solution:

Given data:

\[ \begin{align*} 
T2 &= 28+273 = 301 \text{ K} \\
\eta &= 0.3 \\
Qs &= 1050\text{kJ/min} \\
W &= ? \\
T1 &= ? 
\end{align*} \]

Soln

\[ \eta = \frac{W}{Qs} = \frac{(T1 - T2)}{T1} = 0.3 \]
\( \frac{T_1 - 301}{T_1} = 0.3 \)

\( T_1 = 430 \text{ K} \)

\( \frac{(1050 - Q_r)}{1050} = 0.3 \)

if \( Q_r \) is the heat rejected to the sink

\( Q_r = 1050 - 315 = 735 \text{ kJ/min} \)

\( W = Q_s - Q_r = 1050 - 735 = 315 \text{ kJ/min} = \frac{315}{60} = 5.25 \text{ kW} \)

**7.** Sketch the Carnot cycle on PV and Ts Coordinates and name the various processes.

**Ans:**

![Carnot cycle diagram](image)

the various processes are

1-2 : Isothermal Expansion
2-3 : Isentropic Expansion
3-4 : Isothermal compression
4-1: Isentropic Compression
8. A Carnot heat engine cycle works at maximum and minimum temperature of 1000°C and 40°C respectively. Calculate the thermal efficiency and work done if \( Q_s = 1010 \text{kJ} \).

Solution:
Given data:
\[ T_1 = 1000 + 273 = 1273 \text{ K} \]
\[ T_2 = 40 + 273 = 313 \text{ K} \]

To find:
\( \eta \), and Work done

Soln:
\[ \eta = \frac{(T_1 - T_2)}{T_1} = 0.7541 \]
\[ \eta = 75\% \]
also \[ \eta = \frac{W}{Q_s} = 0.7541 \]

\[ W = 0.7541 \times 1010 = 761.641 \text{ kJ} \]

9. A reversible heat engine operating between reservoirs at 900K and 300K drives a reversible refrigerator operating between reservoirs at 300K and 250K. The engine receives heat at 1800kJ. The net output from the combined engine refrigerator is 360kJ. Find the heat transferred to the refrigerator and the net heat rejected to the reservoir at 300K.

To find:
\( Q_3 = ? \)
\( Q_1 + Q_4 = ? \)
Solution:
Maximum efficiency of heat engine

$$\eta_{max} = \frac{(T_3 - T_2)}{T_3} = 0.66$$

$$\eta_{max} = \frac{W_1}{Q_2} =$$

$$W_1 = Q_2 \times \eta_{max} = 1800 \times 0.66 = 1200 \text{kJ}$$

$$W_1 = Q_2 - Q_1$$

$$Q_1 = Q_2 - W_1 = 1800 - 1200 = 600 \text{kJ}$$

$$\eta_{ref} = \frac{(T_1 - T_3)}{T_3} = 0.2 = 20\%$$

$$\eta_{ref} = \frac{W_2}{Q_3}$$

$$Q_3 = \frac{W_2}{\eta_{ref}} = \frac{840}{0.2} = 4200 \text{kJ}$$

$$W_2 = Q_3 - Q_4$$

$$Q_4 = Q_3 - W_2 = 4200 - 840 = 3360 \text{kJ}$$

Net heat transfer to 300K = $$Q_1 + Q_4 = 600 + 3360 = 3960 \text{kJ}$$

10. Two Carnot engines A and B are operated in series. The first one A receives heat from a reservoir at 870K and rejects heat to a reservoir at temperature T. The second engine B receives heat rejected by the first engine and in turn rejects to a heat reservoir at 300K. Calculate the temperature T in °C for the following cases
(i) the work output of the two engines are equal and
(ii) the efficiencies of the two engines are equal
Given data
\[ T_1 = 300K \]
\[ T_2 = 870K \]
(i) Case \( WA = WB \)
(ii) Case \( \eta_A = \eta_B \)

To find
\[ T \text{ in } ^\circ C \text{ (i) & (ii) case} \]

Solution
\[ WA = WB \]
\[ WA = Q_2 - Q \]
\[ WB = Q - Q_1 \]
\[ Q_2 - Q = Q - Q_1 \]
\[ 2Q = Q_2 + Q_1 \]
\[ 2T = T_2 + T_1 = 870 + 300 = 1170K \]

\[ T = 1170/2 = 585K = 312^\circ C \]

Case (ii)
\[ \eta_A = \eta_B \]
\[ \eta_A = \frac{WA}{Q_2} = \frac{(870-T)}{870} \]
\[ \eta_B = \frac{WB}{Q} = \frac{(T-T_1)}{T} = \frac{(T-300)}{T} \]
\[ \frac{(870-T)}{870} = \frac{(T-300)}{T} \]

\[ T = 510.88 K = 237.88^\circ C \]

11. The temperature in a domestic refrigerator is to be maintained at \(-10^\circ C\). The ambient air temperature is \(30^\circ C\). If the heat leaving through the refrigerator is 3kW. Determine the lease power necessary to pump out this heat continuously.
Solution:

Given data:

- $T_1 = -10°C = 263 K$
- $T_2 = 30°C = 303 K$
- $Q_1 = 3 kW$

To find: Power ($P$)

For reversible engine condition of minimum power requirement:

\[
\frac{Q_2}{T_2} = \frac{Q_1}{T_1}
\]

\[
Q_2 = \left(\frac{T_2}{T_1}\right) \times Q_1 = 3.456 kW
\]

\[
\eta = \frac{T_2 - T_1}{T_2} = 0.746 = 74.6%
\]

12. An inventor claims to have developed an efficient hot engine which would have a heat source at $1000°C$ and rejects heat to a sink at $50°C$ and gives an efficiency of $90%$. Justify whether his claim is possible.

Given data:

- $T_2 = 1000 + 273 = 1273 K$
- $T_1 = 50 + 273 = 323 K$
- $\eta = 0.9$

\[
\eta = \frac{T_2 - T_1}{T_2} = 0.746 = 74.6%
\]

The maximum efficiency (74.6%) is less than proposed engine efficiency which is 90%.
Therefore,
- His claim is impossible.

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

Solution:

- $\eta = 59%$
- $T_2 = 600°C + 273 = 873 K$

\[
W = 1 kW
\]

\[
\eta = \frac{W}{Q_s}
\]
Qs = W/\eta = 1/0.59 = 1.695 kW

W = Qs - Qr
Qr = Qs - W = 1.695 - 1 = 0.695 kW

14. Water flows through a turbine in which friction causes the water temperature to rise from 35°C to 37°C. If there is no heat transfer, how much does the entropy of the water change in passing through the turbine? (Water is incompressible and the process can be taken as constant volume)

Given data:

T1 = 35°C
T2 = 37°C
Take m = 1 kg
Cv = Cp = C = 4.18 kJ/kgK (as water is incompressible)
\(\Delta s = mC\ln\left(\frac{T_2}{T_1}\right) = 0.2322 \text{ kJ/K}\)

15. In a vessel 10 kg of Oxygen is heated in a reversible non-flow constant volume process, so that the pressure of Oxygen is increased two times that of initial value. The initial temperature is 20°C. Calculate the final temperature, change in internal energy, the change in enthalpy and heat transfer. Take R = 257 J/kg K, and Cv = 0.652 kJ/kg K for Oxygen.

Solution

Given data:

m = 10 kg
T1 = 20°C
T2 = ?
P2 = 2P1
\(\Delta U = ?\)
\(\Delta H = ?\)
Q = ?
R = 257 J/kg K
Cv = 0.652 kJ/kg K

\[
P_1 /P_2 = T_1 /T_2
\]
\[
0.5 = \frac{(20 +273 )}{T_2}
\]
T2 = 586 K
\[ \Delta U = mC_v (T_2 - T_1) \]
\[ = 1910.36 \text{ kJ} \]

\[ \Delta H = mC_p(T_2 - T_1) = 2663.37 \text{ kJ} \]

\[ C_p - C_v = R \]
\[ C_p = R + C_v = 0.909 \text{ kJ/kg K} \]

\[ Q = \Delta U = 1910 \text{ kJ} \]

**UNIT 2**

1. Air enters into Otto cycle at 27°C and 1 bar the compression ratio is 7.5. The maximum temperature of cycle is 1000K. Find the efficiency and mean effective pressure.

**Ans:**

Given data:
- \( P_1 = 1 \) bar
- \( T_1 = 300 \) K
- \( T_3 = 1000 \) K
- \( \gamma = 7.5 \)

To find:
- \( \eta \) and MEP.

**Efficiency**, \( \eta = 1 - \{ 1 / (\gamma - 1) \} \)

\[ = 55.33\% \]

\[ V_1 = (RT_1 / p_1) = 0.86 \text{ m}^3/\text{kg} \]

\[ V_1 / V_2 = 7.5 \]
Mean Effective pressure:

\[ w / ( V1 - V2 ) \]

\[ = 1.748 \text{ bar} \]

2. Air enters an air standard Otto cycle at 1 bar and 290ºK. The ratio of heat rejection and heat supply is 0.4. The maximum temperature of the cycle is 1500K. Find efficiency, compression ratio, network and mean effective pressure.

Solution:

Given data:

\( P1 = 1 \text{ bar} \)

\( T1 = 290 \text{ K} \)

\( Qr/Qs = 0.4 \)

\( T3 = 1500 \text{ K} \)

To find:

\( \eta, r, W, p4 \)

Soln:

\[ \eta = 1 - \left\{ 1 / (r^{\gamma-1}) \right\} \]

\[ \eta = 1 - (Qr/Qs) = 1 - 0.4 = 0.6 \]

\[ \eta = 60\% \]

using the eqn, 1

Compression ratio:

\[ r = 9.88 \]

\[ V1 = (R \ T1)/p1 \]
\[ V_1 / V_2 = 9.88 \]
\[ V_2 = 0.0842 \text{ m}^3/\text{kg} \]
\[ T_2 = T_1 \times \left( \frac{V_1}{V_2} \right)^{\gamma - 1}. \]
\[ T_2 = 725 \text{ K} \]

Heat supply; \( Q_s = C_v \left( T_3 - T_2 \right) \)
\[ = 556.45 \text{ kJ/kg} \]

Work done = \( \eta \times Q_s \)
\[ = 33.87 \text{ kJ/kg} \]
\[ T_4 = T_3 \left( \frac{V_3}{V_4} \right)^{\gamma - 1}. \]
\[ = 600 \text{ K} \]
\[ p_4 = \frac{RT_4}{V_4} = 2.06 \text{ bar}. \]

3. An Otto cycle has an air standard efficiency of 56% what will be the compression ratio?
Given data:
\[ \eta = 1 - \left\{ \frac{1}{(r^{\gamma - 1})} \right\} \quad \text{---------1} \]

\[ \frac{0.56 = 1 - \left\{ \frac{1}{(r^{\gamma - 1})} \right\}}{\gamma} = 1.4 \]
Hence, \( r = 7.79 \)

4. An engine 20cm bore and 30cm stroke works on Otto cycle. The clearance volume is 1600cc. The initial pressure and temperature are 1bar and 60°C. If the maximum pressure limited to 24bar, find the following

a. The air standard efficiency of the cycle

b. The mean effective pressure of the cycle.

Solution:

\[ v_s = \left( \frac{\pi}{4} \right) \left( \frac{d^2}{L} \right) \]

\[ = 9425 \text{ cc} \]

\[ Rc = \frac{(v_s + v_c)}{v_c} = 6.89 \]
\[ \eta = 1 - \{ 1 / (r^{\gamma - 1}) \} \]
\[ \eta = 53.79\% \]

For the isentropic process 1 to 2;
\[ p_2 = p_1 \left( \frac{v_1}{v_2} \right)^\gamma \]
\[ = 14.91 \text{ bar} \]
\[ \alpha = p_3 / p_2 = 1.61 \]

Mean effective pressure,
\[ p_m = p_1 R_c \left[ (\alpha - 1) / (\gamma - 1) \right] \left[ \{ R_c \left( r^{-1} \right) - 1 \} / \{ R_c - 1 \} \right] \]
\[ p_m = 2.077 \text{ bar} \]

5. A diesel engine operating on an standard diesel cycle has 20 cm bore and 30 cm stroke. The clearance volume is 420 cm\(^3\). The fuel is injected at 5% of the stroke. Find the air standard efficiency?

Given data:
\[ .d = 20 \text{ mm} \]
\[ .l = 30 \text{ mm} \]
\[ Vc = 420 \text{ cm}^2 \]

5%

To calculate:
Air standard efficiency (\( \eta \))
\[ Vs = \left( \frac{\pi}{4} \right) \left( \frac{d^2}{L} \right) \]
\[ = 9.434 \times 10^{-3} \text{ m}^3. \]

Compression ratio: (\( r \))
\[ r = (vs + vc) / vc = V1 / V2 \]
\[ = 23.44 \]
Cut off ratio: \( \rho = \frac{(V_c + 0.05 \ V_s)}{V_c} = \frac{[V_2 + (V_3 - V_2)]}{V_2} = 2.12 \)

Air standard efficiency:
\[ \eta = 1 = \left[ \frac{\gamma - 1}{\gamma} \right] \frac{\rho^{\gamma-1}}{\gamma \left( \rho - 1 \right)} \]
\[ \eta = 66.35 \% \]

6. The maximum pressure and temperature in a Carnot cycle is limited to 20 bar and 400ºC. The volume ratio of isentropic compression is 6 and that of isothermal expansion is 1.5. Assuming the volume of air at the beginning of isothermal expansion is 0.2 m³. Find the following:

- c. The maximum temperature in the cycle.
- d. Change in entropy during isothermal expansion and compression.
- e. Thermal efficiency of the cycle.
- f. Mean effective pressure of the cycle.
- g. The theoretical power if there are 200 working cycles per minute.

Given data:
\( T_1 = T_2 \) and \( T_3 = T_4 = 400 + 273 \ K = 673 \ K, \)
\( v_3 = 0.2 \ m^3. \)
\( p_3 = 20 \ bar \)
\( v_2 / v_3 = 6 \)
\( v_4 / v_3 = 1.5 \)

with respect to the pv and TS diagram of a Carnot cycle,
\[ T_3 / T_2 = (v_2 / v_3)^{\gamma-1} = 2.05 \]
\[ T_2 = T_3 / 2.05 = 328.29 = T_1 \]
\[ P_3 / p_2 = 12.29 \]
P2 = 1.627 bar
For the isothermal process 3-4.
.p3 v3 = p4v4
.p4 = 13.3 bar
For the isentropic process 4-1.
.p1 = p4 ( v4 /v3 ) ^{r-1} .= 1.08 bar
(ii) Change in entropy during isothermal expansion
(s4-s3 ) = [ (p3v3 ) /T3 ]log ( v4 /v3 ) = 0.24 kJ/K
(iii) Qs = T3 ( s4 - s3 ) = 162 kJ
Qr = T2 ( s4 - s3 ) = 78.72 kJ
\( \eta = 1 - \frac{Qr}{Qs} = 51.4\% \)
(iv) Mean effective pressure
pm = Work done per cycle /Stroke volume
pm = 0.52 bar
(v) Power of the engine = 277.6kW

Refer: Thermodynamics and Thermal Engg by C P Kothandaraman, Page # 15.17; Qn No # 15.1

7. A Carnot cycle works between the temperature limits of 900K and 300K and the pressure limit of 60bar and 1bar. Find the following

h. Pressure and temperature at all salient points
i. Work done per kg of air.
j. Heat supplied and rejected
k. Thermal efficiency of the cycle.
l. Mean effective pressure of the cycle.

Refer: Thermodynamics and Thermal Engg by C P Kothandaraman, Page # 15.20 Qn No # 15.3
8.1 kg of air is taken through a Diesel cycle. Initially at 1 atm and 15°C. The compression ratio is 15 and heat added is 1850 KJ. Find the idle cycle efficiency?

Refer Thermodynamics for EEE, By Vijayaraghavan and Senthil kumar; Lakshmi publications; Page # 2.61; Qn 3.

9. A Diesel engine working on an air standard cycle taken in air at 1 bar and 25°C. The specific volume of air at inlet is 0.8 m³/kg. The compression ratio is 14 and heat is added at constant pressure is 840 KJ/kg. Find cut-off ratio and air standard efficiency?

Refer Thermodynamics for EEE, By Vijayaraghavan and Senthil kumar; Lakshmi publications; Page # 2.66; Qn 5.

10. In an engine working on diesel cycle inlet pressure and temperature are 1 bar and 17°C respectively. Pressure at the end of adiabatic compression is 35 bar. The ratio of expansion i.e after constant pressure heat addition is 5, calculate the heat addition, heat rejection and the efficiency of the cycle.

Assume γ = 1.4, \( C_p = 1.004 \text{ KJ/kgK} \) and \( C_v = 0.717 \text{ KJ/kgK} \).

Refer Thermodynamics for EEE, By Vijayaraghavan and Senthil kumar; Lakshmi publications; Page # 2.69; Qn 7.

11. Obtain an expression for the efficiency of a dual cycle in terms of compression ratio \( (r_k) \), constant volume pressure ratio \( (r_p) \) and cut-off ratio \( (r_c) \).

Refer : Thermodynamics and Thermal Engg by C P Kothandaraman, ‘Page # 15.10

12. In an engine working on dual combustion cycle, the temperature and pressure at beginning of compression are
100°C and 1bar. The compression ratio is 10. If the maximum pressure is limited to 70bar and 1700kJ of heat is added per kg of air. Determine the temperature at salient points of the cycle and air standard efficiency.

Refer : Thermodynamics and Thermal Engg by C P Kothandaraman, Page # 15

13. Air enters a Brayton cycle at 100Kpa, 300K. The compression ratio is 8:1. The maximum temperature in the cycle is 1300k. Find
a. Air standard efficiency
b. Compressor and Turbine work
c. Work ratio.

Given data:
P1 = 100kPa
T1 = 300 K
γ = 8
T3 = 1300 K

To find:
Air standard efficiency
Compressor and turbine work
Work ratio

Solution:
WT = C p(T3 - T4)
= 391.145 kJ/kg

η = η = 1 - { 1 /(r γ-1) }
η = 56.47%

Work ratio = [Turbine work – Compressor work] / Turbine work
= 0.471
14. In a gas turbine power plant working on Brayton cycle, the inlet air temperature is 30°C and pressure is 1 bar, the pressure ratio is 6.25 and the maximum temperature is 827°C. Find
m. The compression work
n. The Turbine work
o. The cycle efficiency
p. The work ratio.

Compare the efficiency with that of Carnot cycle operating between the same temperature limits.

Solution:
Given data:
T1 = 30°C
P1 = 1 bar
Pressure ratio , = 6.25
T3 = 1100 K

Soln:
Wc = Cp (T2 – T1 )
= 209.62 kJ/kg
Wt = Cp (T3 – T4 )
= 450 kJ/kg
η = 1 – { 1/(rγ-1) }
= 40.76%

Work ratio = Network / Gross ratio
= 0.535
ηcarnot = 1- [T1/T2]
= 72.45%

15. A gas turbine works on Brayton cycle, gas is supplied to the turbine at a pressure of 600 kN/m² and a temperature of
1200K. The gas expands in the turbine isentropically (γ = 1.4) to the atmospheric pressure 100kN/m². Calculate
a) Air standard efficiency of the cycle.
b) The temperature of the exhaust gas, if the atmospheric temperature is 300K
c) Temperature of air at the exit end of compressor. Assume that the compression process isentropic.

Solution:
Given data:
P₁ = 100kN/m².
T₁ = 300 K
P₃ = 600 kN/m².
T₃ = 1200 K

To find:
η, T₄, T₂

Solution:
(i) Efficiency,
$$\eta = 1 - \frac{1}{\left(\frac{P_3}{P_1}\right)^{\frac{\gamma-1}{\gamma}}} = 0.40 = 40\%$$

(ii) Consider process, 3-4
$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \quad T_4 = 719.2 \text{ K}$$

(iii) Consider process, 1-2
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} $$
$$T_2 = 500.5 \text{ K}$$
UNIT – III

1. Find the enthalpy and internal energy of unit mass of steam at temperature of 200°C when (a) Dry saturated (b) Steam delivered at 0.7MPa and (c) quality is 0.85
Refer: Thermodynamics for EEE; By Vijayaraghavan; Page # 3.43

2. Calculate the state of the steam using steam tables.
   a. Steam has pressure of 15bar and specific volume of 0.12m³/kg.
   b. Steam has a pressure of 10bar and temperature of 200°C
   c. Steam has a pressure of 30bar and enthalpy 2700kJ/kg.
Refer: Thermodynamics for EEE; By Vijayaraghavan; Page # 3.47

3. Find the change in internal energy when one kg of steam expands from 10bar and 300°C to 0.5 bar and 0.9 dryness.
   Take Cp= 2.1kJ/kgK
Refer: Thermodynamics and Thermal Engineering by C P Kothandaraman; Page # 10.21; Qn # 10.3

4. Determine the quality of steam in the following cases:
   (a) The absolute pressure of the steam is 5 bar and specific volume is 0.32 m³/kg.
   (b) The absolute pressure of the steam is 8 bar and temperature is 200°C
   (c) The absolute pressure of the steam is 10 bar and enthalpy is 2605 kJ/kg
(d) The absolute pressure of steam is 10 bar and enthalpy is 2960 kJ/kg. Assume \( C_p = 2.1 \text{ kJ/kg K} \)

Refer: Thermodynamics and Thermal Engineering by C P Kothandaraman; Page # 10.20; Qn # 10.2

5. Steam at 10 bar and 0.95 dryness fraction is available. Find the final dryness fraction of steam in each of the following operations:
(a) 160 kJ of heat is removed per kg of steam at constant pressure.
(b) It is cooled at constant volume till its temperature falls at 140°C
(c) Steam expands adiabatically in the steam turbine developing 200 kJ per work per kg of steam flow and pressure becomes 0.5 abr.

Refer: Thermodynamics and Thermal Engineering by C P Kothandaraman; Page # 10.30; Qn # 10.18

6. Steam at 15 bar and 300°C is throttled till its pressure becomes 10 bar and then expanded isentropically passing through a turbine until pressure falls to 1 bar. The exhaust steam from the turbine is used for process work.
(a) Find the condition of the steam leaving the turbine and work done per kg of steam passing through the turbine.
(b) If the steam is directly passed through the turbine.
(c) What is the work done per kg of steam? Use chart for solution.
7. **Steam enters a steam turbine at a pressure of 10 bar and 300°C with a velocity of 50m/s.** The steam leaves the turbine at 1.5 bar and with a velocity of 200m/s. Determine the work done per kg of steam flow through the turbine. Assume that the process to be reversible and neglect the change in potential energy.

Refer: Thermodynamics and Thermal Engineering by C P Kothandaraman; Page  # 10.40; Qn # 10.35

8. A cylinder fitted with a piston contains 0.5 kg of steam at 4 bar. The initial volume of the steam is 0.1 m³. Heat is transferred to the steam at constant pressure until the temperature becomes 300°C. Determine the heat transfer and work done during the process.

Refer: Thermodynamics and Thermal Engineering by C P Kothandaraman; Page  # 10.31; Qn # 10.21

9. **Steam turbine receives steam at a pressure of 20 bar superheated at 300°C.** The exhaust pressure is 0.07 bar and expansion takes place isentropically. Using table calculate the following:
   (a) Heat supplied assuming that the feed pump supplies water to the boiler at 20 bar.
   (b) Heat rejected
   (c) Work done
   (d) Thermal efficiency
   (e) Theoretical steam consumption

Refer: Thermodynamics for EEE; By Vijayaraghavan; Page # 3.47
10. A rigid vessel of 1 m³ capacity contains a mixture of saturated water and saturated steam at 200°C. When this steam is heated, it passes through critical point. Find out:
(i) Mass of water and mass of steam initially present in the vessel.
(ii) The quality of steam when the system is heated to 100 bar pressure.
(iii) Amount of heat required for heating mentioned in (ii)

Refer: Thermodynamics and Thermal Engineering by C.P. Kothandaraman; Page # 10.26; Qn # 10.27

UNIT – IV

1. A single cylinder, single acting air compressor has cylinder diameter 160 mm and stroke length 300 mm. It draws air into its cylinder at a pressure of 100 kPa at 27°C. The air is then compressed to a pressure of 650 kPa. If the compressor runs at a speed of 2 rev/s, determine
   a. Mass of air compressed per cycle.
   b. Work required per cycle.
   c. Power in kW required to drive the compressor.

Assume the compression process follows PV = constant.

\[ \text{Ans: } d = 160 \text{ mm}, \ L = 300 \text{ mm}, \ P_1 = 100 \text{ kPa}, \ T_1 = 27{\degree}C + 273 = 300 \text{ K}, \ P_2 = 650 \text{ kPa}, \ N = 2 \text{ rev/s} = 120 \text{ rpm}, \ PV^\gamma = C, \ \gamma = 1.4 \]

To find: mass of air compressed, work required per cycle, power

Solution:

Work done during Isothermal compression: \( (PV = C) \)

\[ W = mRT_1 \ln \left( \frac{P_2}{P_1} \right) \]

\[ V_s = \left( \frac{\pi}{4} \right) D^2 L \]

\[ V_s = 6.03 \times 10^{-3} \text{ m}^3. = V_1 \]

Sub V1 in work done equation,
\[ W = 1.12 \text{ kJ} \]

\[ \text{Power} = \frac{(W \times N)}{60} = 2.24 \text{ kW} \]

It's known that,

\[ P_1V_1 = mRT_1 \]

\[ M_1 = 0.007 \text{ kg} \]

Result:

Mass = 0.007 kg

\[ W = 112 \text{ kJ} \]

\[ P = 2.24 \text{ kW} \]

2. Air is to be compressed in a single stage reciprocating compressor from 1.013 bar and 15\(^\circ\)C to 7bar. Calculate the indicated power required for a free air delivery of 0.3m\(^3\)/min. When the compression process is

a. Isentropic

b. Polytropic with n = 1.12

Given data:

To = 298 K

Po = 101.3 kPa

P1 = 1.013 bar

T1 = 15\(^\circ\) + 273 = 288 K

P2 = 7 bar = 700kPa

Vo = 0.3 m\(^3\)/min

N = 1.25

To find:

Power required for

(a) Isentropic

(b) Polytropic

Solution:

We know that

\[ \frac{(P_0V_0)}{To} = \frac{(P_1V_1)}{T_1} \]

\[ V_1 = 0.289 \text{ m}^3/\text{min} \]
Work done during isentropic compression \((PV' = C)\)

\[
W = \frac{\gamma}{\gamma - 1} \times PV_i \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]
\]

\(W_{isen} = 75.53\ \text{kJ/min} = 1.25\ \text{kJ/s}\)

\(P_{isen} = 1.25\ \text{kW}\)

Work done during polytropic compression.

\[
W = \frac{n}{n - 1} \times PV_i \left[ \left( \frac{P_2}{P_1} \right)^{\frac{n - 1}{n}} - 1 \right]
\]

\(W = 69.08\ \text{kJ/min}\)

\(= 1.15\ \text{kW}\)

\(P_{poly} = 1.15\ \text{kW}\)

Result: \(P_{isen} = 1.25\ \text{kW}\)

\(P_{poly} = 1.15\ \text{kW}\)

3. A single cylinder, single acting reciprocating air compressor with a bore of 12cm and stroke of 16cm runs at 410r.p.m. At the beginning of compression, the pressure and temperature in the cylinder is 0.98bar and 40°C. The delivery pressure is 6bar. The index of compression is 1.32. The clearance is 6% of stroke volume. Determine the volume of air delivered referred to 1bar and 20°C. What is the compressor power required?

**Given data:**

\(D = 12\ \text{cm}\)

\(L = 16\ \text{cm}\)

\(N = 410\ \text{rpm}\)

\(P_1 = 0.98\ \text{bar}\)

\(T_1 = 40\ ^\circ\text{C}\)

\(P_2 = 6\ \text{bar}\)

\(n = 1.32\)

\(V_c = 6\%\) \(Vs = 0.06\ \text{Vs}\)

\(P_0 = 1\ \text{bar}\)

\(T_0 = 20\ ^\circ\text{C}\)
To find:
1) Volume of air delivered \( V_o \)
2) Power required, \( P \)

Solution:

\[ V_s = \frac{\pi}{4} D^2 L \]
\[ V_s = 0.0018 \text{ m}^3. \]

From PV diagram,

\[ V_1 = V_c + V_s \]
\[ = 1.06 V_s \]
\[ = 1.908 \times 10^{-3} \text{ m}^3. \]

Work done by the single stage compressor with clearance volume

\[ W = \frac{n}{n-1} \times PV_a \left[ \left( \frac{P_4}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] \]

We know that,

\[ P_3 V_3^n = P_4 V_4^n \]
\[ V_4 = 4.26 \times 10^{-4} \text{ m}^3. \]

We know that

\[ V_a = V_1 - V_4 \]
\[ = 0.00148 \text{ m}^3. \]

Sun \( V_a \) value in work done equation,

\[ W = 0.0329 \text{ kJ} \]

Power = \((W \times N) / 60\)
\[ = 2.25 \text{ kW} \]

We know that

\[ \frac{P_3 V_3}{T_o} = \frac{P_2 V_d}{T_2} \]
\[
V_o = \frac{T_o}{P_o} \times \frac{P_2 V_d}{T_2}
\]

\( P_1 V_a = m R T_1 \)

\( V_a = 13.34 \text{ m}^3/\text{min} \)

Substituting the value of \( V_a \) in work done,

\( W = 51.1 \text{ kW} \)

Power = 51.1 kW

4. A single cylinder single acting compressor delivers 15m³ of free air per minutes from 1bar to 8bar. The speed of compressor is 300rpm. Assuming that compression and expansion follows the law \( PV^{1.3} = C \) and clearance is \( 1/16 \)th of swept volume. Find the diameter and stroke of the compressor, take \( L/D=1.5 \). The temperature and pressure of air at the suction are same as atmospheric air.

Given data: Refer: Thermodynamics and Thermal Engineering , CP Kothandaraman , Page # 18.23 .

5. Air enters a single stage double acting air compressor at 100kPa and 29°C. The compression ratio is 6:1. The index of compression and expansion is 1.3. The speed of compression is 550 rpm. The volume rate measured at suction condition is 5m³/min. Find the motor power required if the mechanical efficiency is 90%. If the volumetric efficiency is 80%. Find swept volume of cylinder.

Given data:
\( P_1 = 100 \text{ kPa} \)
\( T_1 = 29^\circ + 273 = 302 \text{ K} \)
Compression ratio = 6 :1
\( \eta_{\text{max}} = 0.9 \)
\( \eta_{\text{vol}} = 0.8 \)
To find:
Motor power required $P$
Swept volume $V_s$

Compression ratio $= \frac{\text{total clearance volume}}{\text{clearance volume}} = \frac{V_1}{V_c}$

$V_1/V_c = 6$
$V_c = 0.833 \text{ m}^3/\text{min}$

From p-v diagram,
We know that
$V_1 = V_c + C_s$
$V_s = 4.167 \text{ m}^3/\text{kg}$

Work done by the single compressor with clearance volume

$$W = \frac{n}{n-1} \times P_1 V_a \left[ \left( \frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

Volumetric efficiency

$$\eta_v = 1 + C - C \left[ \left( \frac{P_2}{P_1} \right)^{\frac{1}{n}} \right]$$

In the above equation substitute,

$C = \frac{V_c}{V_s}$

$P_2 = -247.03 \text{ kPa}$

We know that,

$$\eta_v = \frac{V_a}{V_s}$$

$V_a = 3.33 \text{ m}^3/\text{min}$.

Apply the Values of $V_a$ and $P^2$ in the work done equation,

$$W = 5.58 \text{ kJ/s}$$
$P = 5.58 \text{ kW}$
Mechanical Efficiency  = (power output of compressor )/(Power supplied to compressor )

Power supplied to compressor = 6.2 kW

Result :
Swept volume , Vs = 4.167 m$^3$/min
Motor power required , P = 6.2 kW

6. Estimate the work required by a two stage reciprocating single acting air compressor to compress 2.8 m$^3$ of air per minute at 1.05 bar and 10ºC to a final pressure of 35 bar. The inter cooler cools the air to 30ºC and 5.6 bar pressure. For air taken $n = 1.4$

Given data:
V1 = 2.8 m$^3$/min
P1 = 1.05 bar
T1 = 10 ºC + 273 K
P3 = 35 bar
T3 = 30 + 273 = 303 K
P2 = 5.6 bar

To find :
Work done

Solution :
Since T3 is not equal to T1 therefore it is incomplete inter cooling.
Work done by a two stage compressor when the cooling is incomplete.

\[
W = \frac{n}{n-1} PV_1 \left( \frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + \frac{n}{n-1} PV_2 \left( \frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]
\]

We know that ,

\[
\frac{PV_1}{T_1} = \frac{PV_2}{T_3}
\]

V2 = 0.562 m$^3$/min.
W = 1388.9 kJ/min

7. Determine the size of the cylinder of a double acting air compressor of 32kw I.P in which air is drawn in at 1bar and compressed to 16bar according to the law \( PV^{1.25} = C \), rpm=300, piston speed=180m/min, volumetric efficiency=0.8

Given data: Refer: Thermodynamics and Thermal Engineering, CP Kothandaraman, Page # 18.22

8. 3 kg/s of air enters the LP cylinder of 2stage compressor. The overall pressure ratio is 8.5 :1. The air at inlet to the compressor is at 100kPa and 30°C. The index of compression in each cylinder is 1.3. Find the intercooler pressure for perfect inter cooling. Also find the minimum power required for compression and percentage saved over single stage compression.

Given data:
\( \dot{m} = 3 \text{ kg/s} \)

\( \frac{P_3}{P_1} = 8.5 \)

\( P_1 = 100\text{kPa} \)
\( P_3 = 850 \text{kPa} \)
\( T_1 = 30 + 273 = 303 \text{ K} \)
\( n = 1.3 \)

To find:
Inter cooler pressure \( P_2 \)
Power \( P \)
Saving in power over single stage compression

Solution:

\[ P_2 = \sqrt{P_1 P_3} \]

= 291.5 kPa

Work done for \( x \) number of stages
\[ W = \frac{xn}{n-1} \times P_1 V_1 \left[ \left(\frac{P_{n+1}}{P_1}\right)^{\frac{n-1}{n}} - 1 \right] \]

\( x = 2. \)

\( W = 633.28 \text{ kJ/s} \)

**Power, \( P = 633.28 \text{ kW} \)**

**Work done for single stage**

\[ W = \frac{n}{n-1} \times P_1 V_1 \left[ \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right] \]

\( W = 721.96 \text{ kJ} \)

In single stage (\( p_3 = p_2 \) )

**Power, \( P = 721.96 \text{ kW} \)**

**Saving of power, 721.96 - 633.28 = 88.68 kW**

\( \% \text{ saving in power} = \frac{P_2 - P_1}{P_2} \)

\( = 0.122 = 12.2\% \)

9. **Find the work necessary to compress one kg of air in two stage from 15\(^\circ\)C and 1bar to 16bar if the law of compression is \( PV^{1.25} = C \) and inter cooling is perfect.**

Given data:

- \( m = 1 \text{ kg} \)
- \( \text{stages} = 2, \ x = 2 \)
- \( T_1 = 15 \degree C + 173 = 288 \text{ K} \)
- \( P_1 = 1 \text{ bar} \)
- \( P_3 = 16 \text{ bar} \)
- \( n = 1.25 \)

To find:

**Work done**
Solution:

Work done for x number of stages:

\[ W = \frac{x^n}{n-1} \times P_{V_1} \left[ \left( \frac{P_2}{P_1} \right)^n - 1 \right] \]

Here, \( n = 2 \)

\[ W = 264.09 \text{ kJ} \]

10. Derive the optimum intermediate pressure in a two stage reciprocating compressor for a minimum work, stating the assumption made.

The work done by a 2 stage reciprocating compressor with inter cooler is given by,

\[ W = \frac{n}{n-1} \times P_{V_1} \left[ \left( \frac{P_2}{P_1} \right)^{n-1} - 1 \right] + \frac{n}{n-1} P_{V_2} \left[ \left( \frac{P_3}{P_2} \right)^{n-1} - 1 \right] \]

Work input will be minimum if

\[ P_2 = \sqrt{P_1 P_3} \]

\[ P_2^2 = P_1 \times P_3. \]

Dividing both sides by \( P_1^2 \).

\[ \frac{P_2}{P_1} = \frac{P_3}{P_2} = \left[ \frac{P_3}{P_1} \right]^{\frac{1}{2}} \]

Substituting equations 2 in 1

\[ W = \frac{n}{n-1} \times P_{V_1} \left[ \left( \frac{P_3}{P_1} \right)^{\frac{n-1}{2n}} + \left( \frac{P_3}{P_1} \right)^{\frac{n-1}{2n}} - 2 \right] \]

\[ W_{\text{min}} = \frac{n}{n-1} \times P_{V_1} \left[ 2 \left( \frac{P_3}{P_1} \right)^{\frac{n-1}{2n}} - 2 \right] \]
11. Derive an expression for COP of Bell-Coleman cycle for refrigeration

Refer:
Net work done, 
\[ W = Q_r = Q_a \]

\[ = C_P \left( T_4 - T_1 \right) - C_P \left( T_3 - T_2 \right) \]

COP = Heat absorbed / Work done

\[ = \frac{Q_a}{W} \]

\[ COP = \frac{T_1 - T_2}{(T_4 - T_1) - (T_3 - T_2)} \]

By mathematical manipulations,

\[ COP = \frac{T_2}{(T_1 - T_2)} \]

12. With a neat flow diagram, explain the working of a vapour compression refrigeration system.

During suction, the flow pressure and temperature vapour refrigerant from evaporator is sucked into the compressor through the inlet valve. When it is compressed to a high pressure and temperature. At the end of the compression stroke delivery valve opens and the compressed vapour is allowed to flow through the condenser. The condenser consists of coils of tube in which the high pressure and temperature vapour refrigerant is cooled and condensed. The condensed liquid is stored in the receiver.

The condensed liquid refrigerant from the receiver is supplied to the evaporator through the expansion valve. The function of the expansion valve is to allow the liquid refrigerant under the high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature.
The liquid vapour refrigerant from the expansion valve is allowed to pass through the evaporator. The evaporator consists of coils of tube. In evaporator, the liquid vapour refrigerant absorbs the heat from the refrigerant is evaporated and changed into vapour refrigerant at low pressure and temperature. This low pressure and temperature vapour refrigerant from evaporator is again sucked into the compressor and the process is repeated.

Also refer: Refrigeration and Air conditioning by R S Khurmi; S Chand and Co.

13. In an open type of refrigeration installation 800kg of atmospheric air are circulated per hour. The air is drawn from the cold chamber at a temperature of 7°C and 1bar and then compressed to 5bar isentropically and then cooled at this pressure to 27°C before it is led to expansion where it expands isentropically to 1bar. Find out
a. Heat extracted from the cold chamber per hour
b. Heat rejected to the cooling water per hour.
c. C.O.P of the system.
Take $\gamma=1.4$ and $C_p = 1.005\text{kJ/kg}$

Given data:
\[ m = 800 \text{ kg} \]
\[ T_3 = 7 + 273 = 280 \text{ K} \]
\[ P_3 = 1 \text{ bar} \]
\[ P_4 = 5 \text{ bar} \]
\[ T_1 = 27 + 273 \]
\[ = 300 \text{ K} \]
\[ P_2 = 1 \text{ bar} \]

To find:
Heat Extracted from the cold chamber / hour
Heat rejected to the cooling water / hour
COP of the system

Solution:
(a) Heat extracted from the cold chamber
\[ Q = m \, Cp \, (T_3 - T_2) \]

Refer:
\[ \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \]
\[ T_2 = 189.6 \text{ K} \]

Apply \( m \), \( T_2 \), \( T_3 \), and \( Cp \) value in the \( Q \) equation;
\[ Q = 72681.6 \text{ kJ/hr} \]

(b) Heat rejected to cooling water

Heat rejected to cooling water
\[ \frac{T_4}{T_3} = \left( \frac{P_4}{P_3} \right)^{\frac{\gamma-1}{\gamma}} \]
\[ T_4 = 442.9 \text{ K} \]

Then, \( Q = 114891.6 \text{kJ/hr} \)

(C) COP of the system
\[ COP = \frac{T_2}{(T_1 - T_2)} \]
\[ = 1.71 \]
14. Explain the advantages of vapour absorption refrigeration system over vapour compression system. Refer: Refrigeration and Air conditioning; R S Khurmi;

15. An air refrigerator working on Bell-Coleman cycle takes air into the compressor at 1 bar and -17°C, where it is compressed isentropically to a pressure of 6 bar. Air enters the expander at 15°C. Compute
   a. Coefficient of performance of the cycle
   b. The mass rate flow of air into the compressor per minute for 1 tonne of refrigeration.

Given data:
P₃ = 1 bar
T₃ = -17°C + 273 = 256 K
P₄ = 6 bar
T₁ = 15 + 273 = 288 K

Refrigeration effect = 1 tonne = 3.5 kW

To find:
COP
Mass flow rate per minute

Solution:

Form PV diagram
P₃ = P₂ = 100 kPa
P₄ = P₁ = 600 kPa
\[ \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{r-1}{r}} \]

\( T_2 = 172.6 \text{ K} \)

\[ \text{COP} = \frac{T_2}{(T_1 - T_2)} \]

\( \text{COP} = 1.49 \)

Refrigeration effect = \( Q_a = \frac{\text{Cp}}{T} ( T_3 - T_2 ) \)

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**UNIT – V**

1. A mild steel tank of wall thickness 10mm contains water at 90°C. Calculate the rate of heat loss per m² if tank surface area when the atmospheric temperature is 15°C. The thermal conductivity of mild steel is 50w/mK and the heat transfer coefficient for inside and outside the tank are 2800 and 11w/m²K respectively. Calculate also the temperature of the outside surface the tank.

Solution : \( T_a = 90 + 273 = 363 \text{ K} \)

\( T_b = 15 + 273 = 288 \text{ K} \)

\( h_a = 2800 \text{ W/m}^2 \text{ K.} \)

\( h_b = 11 \text{ W/m}^2 \text{ K} \)

\( k = 50 \text{ W/m K} \)

\( L = 10 \text{ mm} = 0.01 \text{ m} \)

To find :
The rate of heat loss per m² of tank surface area
Tank outside surface temperature

Solution :
$Q = \frac{\Delta T_{\text{overall}}}{R}$

$\Delta T = T_a - T_b$

$R = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_b A}$

$T_1 = 362.7 \text{ K}$

$T_2 = 362.5 \text{ K}$

$Q/A = 819.9 \text{ W/m}^2$

2. The wall of a cold room is composed of three layers. The outer layer is brick 20cm thick, the middle layer is cork 10cm thick, the inside layer is cement 5cm thick. The temperature of the outside air is $25^\circ\text{C}$ and that on the inside air is $-20^\circ\text{C}$. The film coefficient for outside air and brick is $45.4\text{ W/m}^2\text{K}$. The film coefficient for inside air and cement is $17\text{ W/m}^2\text{K}$. Find

i. Thermal resistance.

ii. The heat flow rate.

Take $K$ for brick $= 3.45 \text{ W/mK}$

$K$ for cork $= 0.043 \text{ W/mK}$

$K$ for cement $= 0.294 \text{ W/mK}$

Given data:

$L_3 = 20\text{ cm}$

$L_2 = 10\text{ cm}$

$L_1 = 5 \text{ cm}$

$T_b = 25^\circ\text{C}$

$T_a = -20^\circ\text{C}$

$h_b = 45.4 \text{ W/m}^2\text{K}$.

$h_a = 17 \text{ W/m}^2\text{K}$

$K_3 = 3/45 \text{ W/m K}$

$K_2 = 0.043 \text{ W/mK}$

$K_1 = 0.294 \text{ W/mK}$

To find

Heat flow rate

Thermal resistance of the wall
\[ Q = \frac{\Delta T_{\text{overall}}}{R} \]

\[ \Delta T = T_a - T_b \]

\[ R = \frac{1}{h_oA} + \frac{L_1}{K_1A} + \frac{L_2}{K_2A} + \frac{L_3}{K_3A} + \frac{1}{h_bA} \]

\[ Q/A = -17.081 \text{ W/m}^2. \]

3. A furnace wall is made up of three layers, inside surface with thermal conductivity 8.5W/mK, the middle layer with conductivity 0.25W/mK, the outer layer with conductivity 0.08W/mK. The respective thickness of the inner, middle and outer layer are 25cm, 5cm and 3cm respectively. The inside and outside wall temperatures are 600°C and 50°C respectively. Draw the equivalent electrical circuit for conduction of heat through the wall find thermal resistance, heat flow/m² and interface temperature.

**Given data:**

- \( K1 = 8.5 \text{ W/mK} \)
- \( K2 = 0.25 \text{ W/mK} \)
- \( K3 = 0.08 \text{ W/mK} \)
- \( L1 = 25 \text{ cm} \)
- \( L2 = 5 \text{ cm} \)
- \( L3 = 3 \text{ cm} \)
- \( T1 = 600^\circ\text{C} \)
- \( T4 = 50^\circ\text{C} \)

**To find**
- The heat flow rate
- Thermal resistance
- Interface Temperature

**Solution:**
\[ Q = \frac{\Delta T_{\text{overall}}}{R} \]
\[ \Delta T = T_a = T_b \]
\[ R = \frac{1}{h_a A} + \frac{L_4}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_i A} \]

\[ \frac{Q}{A} = 909.97 \text{ W/m}^2. \]

(ii) Thermal resistance ,
\[ R = 0.604 \text{ K/W} \]

(iii) Interface Temperature
\[ \frac{Q}{A} = \frac{T_1 - T_2}{R_1} \]
\[ T_2 = 846.23 \text{ K} \]

\[ \frac{Q}{A} = \frac{T_2 - T_3}{R_2} \]
\[ T_3 = 664.23 \text{ K} \]

4. A pipe of inside diameter 100mm and outside diameter 120mm carries steam at 110°C. The thermal conductivity of pipe material is 185 W/m°C. The pipe is located in a room where the ambient air temperature is 30°C and the convective heat transfer co-efficient between the pipe and air is 15 W/m²°C. Determine heat transfer rate per meter length of pipe. Find the percentage reduction in heat transfer rate if the pipe is covered with a 50mm thick layer of insulation having thermal conductivity of 0.20 W/m°C.

Given data :
\[ D_1 = 100 \text{ mm} \]
\[ r_1 = 50 \text{ mm} \]
\[ D_2 = 120 \text{ mm} \]
\[ r_2 = 60 \text{ mm} \]
\[ T_a = 110 \text{ °C} \]
\[ K_1 = 185 \text{ W/m°C} \]
\( T_b = 30^\circ C \)
\( h_b = 15 \text{ W/m}^2{\circ C} \)

to find:
The heat transfer rate per meter length of pipe.

Solution:
Case(a)
Heat transfer through composite cylinder is given by

\[
Q = \frac{\Delta T_{\text{overall}}}{R}
\]

\[
\Delta T = T_a = T_b
\]

\[
R = \frac{1}{2\pi L} \left[ \frac{1}{h_a r_1} \ln \left( \frac{r_2}{r_1} \right) + \frac{1}{r_1 K_1} + \frac{1}{r_2 K_2} + \frac{1}{h_b r_3} \ln \left( \frac{r_2}{r_3} \right) \right]
\]

Neglecting \( h_a, r_3, K_2 \)
\( Q/L = 451.0 \text{ W/m} \)

5. Derive an expression for heat loss through a composite wall of layers, considering the convective heat transfer coefficient. Refer: Heat transfer ; Sachdeva

6. Calculate the net radiant interchange per sq. m for two large planes at temperature of 700K and 300K respectively. Assume that the emissivity of hot plane is 0.9 and that of cold plane is 0.7

given data:
\( T_1 = 900K \)
\( T_2 = 400K \)
\( \varepsilon_1 = 0.9 \)
\( \varepsilon_2 = 0.7 \)

To find:
The net radiant exchange per square meter

Solution:
The heat exchange between two large parallel plate is given by

\[ Q = A \sigma \bar{\varepsilon} (T_1^4 - T_2^4) \]

\[ \bar{\varepsilon} = \frac{1}{\left( \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} \right) - 1} \]

\[ \frac{Q}{A} = 23.218 \text{ kW/m}^2. \]

7. A block body at 3000K emits radiation. Calculate the following
   b. Monochromatic emissive power at 1\( \mu \)m wave length K.
   c. Wave length at which the emission is maximum.
   d. Maximum emissive power.
   e. Total emissive power.

Given data:
\( T = 3000K \)

To find:
\( E_{b\lambda} \) at \( \lambda \mu m \)
\( \lambda_{\text{max}} \)
\( (E_{b\lambda})_{\text{max}} \)
\( E_b \)

Solution

\[ E_{b\lambda} = \frac{2\pi C_1}{\lambda^5 \left[ \exp \left( \frac{C_2}{\lambda T} \right) - 1 \right]} \]

\( C_1 = 0.595 \times 10^{-8} \text{ Wm}^2. \)
\( C_2 = 1.428 \times 10^{-2} \text{ mK} \)

\[ E_{b\lambda} = 5.281 \times 10^{13} \text{ W/m}^2. \]
From wien’s displacement law, 
\[ \lambda_{\text{max}} T = C_3. \]

\[ C_3 = 0.289 \times 10^{-2} \text{ mK} \]

\[ \lambda_{\text{max}} = 9.63 \times 10^{-7} \text{ m} \]

\[ E_{b\lambda,\text{max}} = C_4 T^5. \]

\[ C = 1.307 \times 10^{-5} \text{ W/ m}^2 \text{ K}^5. \]

\[ E_{b\lambda,\text{max}} = 3.17 \times 10^{12} \text{ W/m}^2. \]

From Stefan Boltzmann law;

\[ E_b = \sigma T^4 \]

\[ E_b = 4.59 \times 10^6 \text{ W/m}^2. \]

8. Assuming sun to be a black body emitting radiation with maximum intensity at \( \tau = 0.5 \mu\text{m} \), calculate the temperature of the surface of the sun and the heat flux at its surface.

Given data:

\[ \lambda_{\text{max}} = 0.5 \mu\text{m} \]

To find:

The surface temperature, \( T \)

Heat flux, \( q \)

\[ \lambda_{\text{max}} T = C_2. \]

\[ T = 5780 \text{ K} \]

Heat flux, \( q \)

\[ q = Q / A = E_b = \sigma T^4. \]

\[ q = 63.28 \times 10^6 \text{ W/m}^2. \]