CHAPTER NO.1
FUNDAMENTALS OF THERMODYNAMICS

SUB: TEN

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CHAPTER 1 FUNDAMENTALS OF THERMODYNAMICS 24MARKS

Q1. What is a pure substance? Give examples.

A pure substance is a substance of constant chemical composition throughout its mass and retains its chemical identity when it undergoes thermodynamic processes.

E.g. i) Oxygen, nitrogen, hydrogen, etc
    ii) Water
    iii) Air

Q2. What is a working substance? Give examples.

Working substance is that essential part of a thermodynamic system which is used to absorb or reject heat or work making thermodynamic processes possible.

E.g. i) Mixture of petrol & air is the working substance in Petrol Engines
    ii) Steam is the working substance in Steam Engines
    iii) Air is the working substance in Air Compressors
    iv) Refrigerant is the working substance in Refrigerators.

Q3. Define the following thermodynamic terms:

i. Thermodynamic system:

A thermodynamic system is defined as a specified quantity of matter or a region in space upon which attention is concentrated in the analysis of a thermodynamic problem.
ii. Surroundings or Environment:
The space and matter external to the thermodynamic system and lying outside system boundary is called its Surroundings or Environment.

iii. System boundary:
The real or imaginary surface enveloping (enclosing) the thermodynamic system and separating it from its surroundings is called its boundary.

iv. Universe:
A thermodynamic system and its surroundings together constitute universe.

Q4. List and explain all the different types of thermodynamic systems.

OR

Give the classification of thermodynamic systems.
Thermodynamic systems are classified into the following three categories:
1. Closed Systems or Non–Flow Systems
2. Open Systems or Flow Systems
3. Isolated Systems

1. Closed Systems or Non–Flow Systems:
A Closed System having no mass transfer across the system boundary, there may be energy (i.e. heat & work) transfer into or out of the system.

E.g. i) A certain quantity of fluid in a cylinder bounded by a piston constitutes a Closed System.

   ii) Refrigeration system is a Closed System.

2. Open Systems or Flow Systems:
An Open System (or Flow System) is a system in which mass as well as energy (i.e. heat & work) may be transferred into or out of the system.

E.g. Air-Compressors, turbines, nozzles, diffusers, etc.
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3. Isolated Systems:
It is a purely theoretical system in which mass as well as energy (i.e. heat & work) cannot be transferred into or out of the system.

E.g. 1. Gas enclosed in a rigid and well insulated vessel
2. Thermos

Q5. Define control volume and control surface.

a) Control Volume:
A fixed volume in space constitutes the control volume upon which interest is focussed for the sake of thermodynamic analysis.

b) Control Surface:
The control volume is bounded by a surface called control surface. Mass as well as energy (i.e. heat & work) can be transferred into or out of the control volume through the control surface.

Q6. Differentiate between open & closed systems.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Open Systems</th>
<th>Closed Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mass of the system do not remain constant</td>
<td>Mass of the system remains constant</td>
</tr>
<tr>
<td>2</td>
<td>Control volume approach is used to deal with open systems</td>
<td>System approach is used to deal with closed systems</td>
</tr>
<tr>
<td>3</td>
<td>Mass as well as energy (i.e. heat &amp; work) may be transferred into or out of the control volume</td>
<td>Only energy (i.e. heat &amp; work) may be transferred into or out of the system through the system boundary</td>
</tr>
<tr>
<td>4</td>
<td>E.g. I.C. Engines, Turbines, Compressors, etc.</td>
<td>E.g. Refrigeration system</td>
</tr>
</tbody>
</table>

Q.7 Define Following Thermodynamic Terms:

i Thermodynamic Cycle
ii Change of State
iii Path
iv Thermodynamic Property
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i. Thermodynamic State:
When the properties of a system have definite values, the system is said to exist at a definite state called thermodynamic state of the system.

ii. Thermodynamic Process:
A system is said to have undergone a thermodynamic process when its state changes from the initial state to final state following a definite path.

iii. Thermodynamic Cycle:
A thermodynamic cycle is defined as a series of state changes such that the final state is identical with the initial state.

iv. Change of State:
A system is said to have undergone a change of state when one or more of the properties of the system changes as a result of some operation.

v. Path:
The succession of states passed through during the change of state of a system is called the path of the change of state.

Thermodynamic Property:
Thermodynamic property is defined as any observable or measurable characteristic of a system which is used to determine or specify the state of a system. E.g. Two thermodynamic properties pressure and volume.
Q8. Differentiate between extensive & intensive properties.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Extensive Properties</th>
<th>Intensive Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The properties which depend on the mass of the system are called extensive properties.</td>
<td>The properties which do not depend on the mass of the system are called intensive properties.</td>
</tr>
<tr>
<td>2</td>
<td>E.g. Volume, energy, enthalpy, entropy, etc.</td>
<td>E.g. Pressure, temperature, density, etc.</td>
</tr>
<tr>
<td>3</td>
<td>If mass is increased, values of extensive properties also increase.</td>
<td>Specific extensive properties i.e., extensive properties per unit mass are intensive properties. E.g. specific volume, specific energy, etc.</td>
</tr>
</tbody>
</table>

Important Thermodynamic Properties & Parameters With Their Units:

<table>
<thead>
<tr>
<th>Thermodynamic Properties &amp; Parameters</th>
<th>Symbol</th>
<th>Definition</th>
<th>Units &amp; Conversion Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>$p$</td>
<td>Pressure is the normal force exerted by a system against unit area of its bounding surface.</td>
<td>S.I. units Pascal or Pa (N/m$^2$)</td>
</tr>
<tr>
<td>Volume</td>
<td>$V$</td>
<td>Volume is the space occupied by a system or substance.</td>
<td>S.I. units Cubic metre (m$^3$)</td>
</tr>
<tr>
<td>Density</td>
<td>$\rho$</td>
<td>Density is defined as the mass contained by unit volume of a system or substance.</td>
<td>S.I. units Kg/m$^3$</td>
</tr>
<tr>
<td>Temperature</td>
<td>$T$</td>
<td>Temperature may be defined as the degree of hotness or coldness of a system or substance. It is indicative of the amount of internal energy contained by a system or substance.</td>
<td>S.I. units Degree Kelvin (or K) M.K.S. units Centigrade or Celsius (°C)</td>
</tr>
</tbody>
</table>
Q.9. Differentiate between Point Function & Path function with the aid of suitable examples.

1. Point Functions:
Any thermodynamic quantity is called a point function if its value is independent of the path followed by the system during the change of state and depends only on the end states of the system.

E.g. Thermodynamic properties like temperature, pressure, volume, etc. are point functions.

2. Path Functions:
Any thermodynamic quantity is called a path function if its value depends on the path passed through by the system during the change of state.

E.g. Heat & work are path functions.

Q10. Give the thermodynamics definition of work. Explain work transfer with examples.

Work:
Work is said to be done by a system if the sole effect on things external to the system (i.e. surroundings) can be reduced to the raising of a weight.

Sign Convention for Work Transfer:
When work is done by a system on its surroundings, it is taken as positive, and when work is done by the surroundings on a system, it is taken as negative.
Examples of Work Transfer:

i) Battery - Motor system driving a fan
ii) Paddle – wheel Work or Stirring Work
iii) Electrical Work


Heat is defined as a form of energy that is transferred across a system boundary by virtue of temperature difference between the system and its surroundings. It is a path function as its value depends on the path of heat transfer.

Sign Convention for Heat Transfer:

Heat flow into a system is taken as positive and heat flow out of the system is taken as negative.

Q12. Differentiate between heat and work transfers.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Heat Transfer</th>
<th>Work Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Heat is the energy interaction between the system and its surroundings due to temperature difference only.</td>
<td>All energy interactions other than that due to temperature difference are considered to be work transfer.</td>
</tr>
<tr>
<td>2.</td>
<td>Heat is low grade form of energy.</td>
<td>Work is high grade form of energy.</td>
</tr>
<tr>
<td>3.</td>
<td>Entire heat cannot be converted into work.</td>
<td>Entire work can be converted into heat.</td>
</tr>
<tr>
<td>4.</td>
<td>Heat transfer is measured in terms of calorie or kilocalorie in M.K.S. units</td>
<td>Work transfer is measured in terms of Kgf - m in M.K.S. units</td>
</tr>
</tbody>
</table>

Q13. Mention the points of similarities between heat and work transfers.

i. Heat and work transfers are energy interactions which bring about property changes in a system.

ii. Both heat and work transfers are boundary phenomenon and represent energy crossing the boundaries of systems.

iii. Both heat and work transfers are path functions and inexact differentials. Their magnitude depends upon the path followed during the change of state.

iv. The same effect in a closed system can be brought about either by heat transfer or by work transfer.
Q14. What is energy? Give its units and hence define specific energy.

1. Energy (E): Energy of a system is its capacity to do work. It is an extensive property of a system. **S.I. units of energy**

   Joule (or J)

2. **Specific Energy:**

   Specific Energy (e) is defined as energy contained per unit mass of the system. It is an intensive property and is measured in terms of J/kg

Q15. List and explain the different forms of stored energy of a system.

There are three forms in which energy can be stored in a system:

   a. Kinetic energy
   b. Potential energy
   c. Internal energy

a. **Kinetic energy:** (K.E.)

   Kinetic energy refers to the energy contained by a system by virtue of the motion of the mass of the system.

   It is the energy that could be recovered when the system is brought to stagnation state in the absence of friction.

   \[ K.E. = \frac{1}{2} m V^2 \]

   Where \( m \) = Mass of the system in ‘kg’

   \( V \) = Velocity of the mass of the system in ‘m/s’

   K.E. = Kinetic energy of the system in ‘J’

b. **Potential energy:** (P.E.)

   Potential energy is the energy possessed by a system by virtue of the position and elevation of the mass of the system with reference to the earth’s surface.

   \[ P.E. = mgh \]

   in Joules

   \( m \) = Mass of the system in ‘kg’

   \( g \) = Acceleration due to gravity in ‘m/s²’

   \( h \) = Height of the system in ‘m’

   P.E. = Potential energy of the system in ‘J’

c. **Internal energy:** (U)

   Internal energy of a system may be defined as that part of the total energy of the system which is stored in the molecular and atomic structure of the system.

   **Components of Internal energy:**

   i. Translational and rotational kinetic energy
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ii Vibrational energy
iii Electronic energy
iv Nuclear energy
v Binding energy, etc.

Q16. What is total energy of a system?

The total energy of a system is the sum total of all forms of energy possessed by the system; both external and internal.

Total Energy \( (E) = K.E. + P.E. + U \)

Where K.E. = Kinetic energy of the system

P.E. = Potential energy of the system

U = Internal energy of the system

Q17. Differentiate between work and energy.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Work</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Work is done by a system at the expense of the energy of the system and hence the energy of the system reduces.</td>
<td>Energy is the capacity of a system to do work.</td>
</tr>
<tr>
<td>2.</td>
<td>Work is a form of energy in transit and cannot be stored in a system.</td>
<td>Energy is stored in a system.</td>
</tr>
<tr>
<td>3.</td>
<td>Work is a path function.</td>
<td>Energy is point function.</td>
</tr>
</tbody>
</table>

Q18. What is flow work? Where is it applicable?

The flow work is the amount of work that must be done on a system to introduce a unit mass of a fluid into it i.e. it is the work required to cause the flow of mass into the system against the existing pressure.

Flow work \( = p \times v_s \)

Q19. Define enthalpy. Also differentiate between specific enthalpy and total enthalpy and state their units.

Enthalpy :

Enthalpy \( (h) \) of a system is defined as the algebraic sum of its internal energy and flow work associated with the flow of mass into or out of the system.

i.e. \( h = u + pv_s \)
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Where \( h \) = Specific enthalpy or enthalpy of the system in J/kg or kJ/kg

\[ u = \text{Specific internal energy of the system in J/kg or kJ/kg} \]

\[ pv_s = \text{Flow work in J/kg or kJ/kg} \]

\[ p = \text{Pressure in N/m}^2 \]

**Q20. Define entropy. Also differentiate between specific entropy and total entropy and state their units.**

**Entropy:**

1) It is a thermodynamic property of system or substance which increases with the addition of heat and decreases with the removal of heat.

2) Total entropy is an extensive property as it is dependent on the mass of the system.

3) Entropy is introduced to study the behavior of a system which undergoes **reversible processes**.

\[ \Delta S = \frac{dQ}{T} \]

Where \( \Delta S \) = Change in entropy of the system or substance in ‘J/K’

\[ dQ = \text{Heat Transfer in ‘J’ or ‘K J’} \]

\[ T = \text{Absolute Temperature in ‘K’ at which heat transfer takes place} \]

**Q21. State and explain the Zeroth law of thermodynamics.**

**Zeroth law of thermodynamics:**

If two bodies are separately in thermal equilibrium with a third body, then they must be in thermal equilibrium with each other.
e.g: Body A is brought in thermal contact with the third body C and found to be in thermal equilibrium with it. Then the body B is brought in thermal contact with the third body C and also found to be in thermal equilibrium with it. Therefore, bodies A & B must be in thermal equilibrium with each other.

Q22. Define temperature and state its units. Which law of thermodynamics is called the law of temperature measurement?

Temperature may be defined as the degree of hotness or coldness of a system or substance. It is an intensive property.

Units of temperature measurement: Degree Kelvin (or K), Celsius (°C)

Q23. What is thermometry? Explain the basic principle of temperature measurement used in thermometry.

Thermometry is that branch of science which deals with temperature measurement.
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Q24. Define thermometric property and thermometric substance.
1) Thermometric property is that property or physical characteristic of the thermometric substance utilized in the thermometer whose value changes as a function of temperature of the system.
2) Thermometric substance. E.g. Mercury.

Q25. Name the instruments used for temperature measurement.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Thermometer</th>
<th>Thermometric Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mercury – in – glass thermometer</td>
<td>Length of mercury column</td>
</tr>
<tr>
<td>2.</td>
<td>Thermocouple</td>
<td>Thermal e.m.f.</td>
</tr>
<tr>
<td>3.</td>
<td>Electrical Resistance thermometer</td>
<td>Resistance</td>
</tr>
<tr>
<td>4.</td>
<td>Radiation Pyrometer</td>
<td>Thermal radiation</td>
</tr>
<tr>
<td>5.</td>
<td>Constant Volume Gas thermometer</td>
<td>Pressure</td>
</tr>
<tr>
<td>6.</td>
<td>Constant Pressure Gas thermometer</td>
<td>Volume</td>
</tr>
</tbody>
</table>

Q26. State the law of conservation of energy.
The law of conservation of energy states that “Energy can neither be created nor destroyed but it can be converted from one form to another.” In other words, total energy of the universe is conserved i.e. it remains constant.

Q27. State the first law of thermodynamics.
First law of thermodynamics states that in a closed cyclic process heat and work are mutually convertible.

Energy in storage is neither heat nor work, and is given the name stored energy \((E)\) or simply energy of the system.

\[ \text{i.e. } Q - W = \Delta E \]
\[ Q = \Delta E + W \]

Where \(Q\) = Heat Transfer in J or kJ
\(W\) = Work Transfer J or kJ
\(\Delta E\) = Change in energy of the system J or kJ
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Q28. State the limitations of first law of thermodynamics.

Or

State the necessity of second law of thermodynamics.

Limitations of first law of thermodynamics:

1. It is not clear about the direction of heat and work transfer.
2. First law does not help whether or not system will undergo change.
3. No restriction on possibility of conversion energy from one form to another.
4. No clarity that how much percentage of one form of energy converted into another form of Energy.

Q29. What is a heat or thermal reservoir? Differentiate between heat source and heat sink.

1. A heat or thermal reservoir is defined as a body of infinite heat capacity. It is capable of absorbing or rejecting an unlimited quantity of heat without suffering any change in its temperature.

2. The heat or thermal reservoir from which heat is supplied to the system is called heat source; while reservoir to which heat is rejected from the system during a cycle is called heat sink.

Q30. Give the two statements of second law of thermodynamics.

Second law of thermodynamics may be expressed by two different statements:

i  Kelvin – Planck’s statement
ii  Clausius’ statement

Kelvin – Planck’s statement:

It is impossible to construct a heat engine working in a cyclic process (cycle) whose sole effect is to convert all the heat supplied to it into an equivalent amount of work.

Clausius’ statement:

It is impossible to construct a device (heat pump) working in a cyclic process (cycle) whose sole effect is to transfer heat from a body at lower temperature to a body at higher temperature.

Q31. Prove that Kelvin – Planck’s statement and Clausius’ statement are two equivalent statements of second law of thermodynamics.
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**Proof I:**

1. Let us consider a cyclic heat pump (H.P.) which transfers heat from a low temperature or cold reservoir at ‘\( t_2 \)' to a high temperature or hot reservoir at ‘\( t_1 \)' with no other effect, i.e., with no expenditure of work, thereby violating Clausius’ statement.

   ![Diagram of a cyclic heat pump](image)

   - **Fig. (a) Violation of Clausius’ statement**

2. Let us assume a cyclic heat engine (H.E.) operating between the same heat reservoirs, producing net work \( (W_{net}) \) in a cycle.

   ![Diagram of a cyclic heat engine](image)

   - **Fig. (b) Violation of Clausius’ statement**

   The rate of working of heat engine is such that it draws an amount of heat \( Q_1 \) from the hot reservoir equal to that discharged by the pump. Then the hot reservoir may be eliminated, and the heat \( Q_1 \) discharged by the pump is fed directly to the heat engine. So we see that the heat pump (H.P.) and the heat engine (H.E.) acting together constitute a heat engine operating in cycles and producing net work while exchanging heat only with one body at a single fixed temperature ‘\( t_2 \)’.

   This is a violation of Kelvin – Planck’s statement. So, violation of Clausius’ statement implies violation of Kelvin – Planck’s statement.
Proof II:

Consider a cyclic heat engine (H.E.), which producing net work (W) in a cycle by exchanging heat with only one heat reservoir at ‘t₁’ and thus violates the Kelvin – Planck’s statement [Refer fig. (a)].

![Diagram of a cyclic heat engine and a heat pump]

Let us assume a cyclic heat pump (H.P.) which transfers heat ‘Q₂’ from a low temperature or cold reservoir at ‘t₂’ to a high temperature or hot reservoir at ‘t₁’ with expenditure of work equal to what the heat engine (H.E.) delivers in a complete cycle (i.e. \( W = Q₁ \)).

So we see that the heat engine (H.E.) and the heat pump (H.P.) acting together constitute a heat pump operating in cycles and producing the sole effect of transferring heat from a lower temperature body to higher temperature body [fig. (b)]. This is a violation of Clausius’ statement. So, violation of Kelvin – Planck’s statement implies violation of Clausius’ statement.

Q32. What is a perpetual motion machine of the first kind or PMM – 1? Why is it impossible to construct a PMM – 1?

Perpetual motion machine of the first kind or PMM – 1 (fig.2) is a fictitious machine which continuously produces mechanical work without some other form of energy disappearing simultaneously.
PMM – 1 violates the first law of thermodynamics as it continuously develops mechanical work without consuming any energy. So it is impossible to construct PMM – 1.

Q33. What is a perpetual motion machine of the second kind or PMM – 2? Why is it impossible to construct a PMM – 2?

A perpetual motion machine of the second kind or PMM – 2 (fig.) is an imaginary heat engine which operates in a cycle and delivers an amount of work equal to the heat absorbed from a single reservoir.

It follows first law of thermodynamics but violates the second law of thermodynamics.

PMM – 2 violates the second law of thermodynamics as it converts all the heat supplied to it into mechanical work (i.e. it has 100% efficiency) and exchanges heat with only one thermal reservoir. So it is impossible to construct a PMM – 2.

Q34. What is a Heat Engine? How is the performance of Heat Engine measured?

A heat engine is a device which works in a thermodynamic heat engine cycle it converts part of the heat energy supplied into useful mechanical work. Performance of Heat Engine:
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The performance of a heat engine is measured in terms of its thermal efficiency as given below:

\[ \eta_{th} = \frac{\text{Net work done in the cycle/Heat supplied}}{\text{Heat supplied}} = \frac{W_{H.E.}}{Q_1} \]

\[ \eta_{th} = \frac{(Q_1 - Q_2)}{Q_1} = \frac{W_{H.E.}}{Q_1} \]

For Carnot Heat Engine,

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

Where \( T_1 \) = Temperature of source

\( T_2 \) = Temperature of sink

Q35. What is a Heat Pump? How is the performance of a heat pump specified?

Heat pump is a device, which working in a cycle, maintains a body or space (hot body) at a temperature higher than the temperature of the surroundings (cold body). It works on heat pump cycle (or reversed heat engine cycle).

Performance of a heat pump: The performance of a heat pump is specified in terms of Coefficient of Performance (C.O.P PUMP) which is defined as given below:

\[ C.O.P_{\text{PUMP}} = \frac{\text{Heat delivered to the body or space (hot body) in the cycle}}{\text{Work supplied}} = \frac{Q_1}{W_{\text{PUMP}}} \]

i.e. \( C.O.P_{\text{PUMP}} = \frac{Q_1}{(Q_1 - Q_2)} \)

\[ C.O.P._{\text{CARNOT (for Heat Pump)}} = \frac{T_1}{(T_1 - T_2)} \]
Where \( T_1 \) = Hot Body Temperature
\[ T_2 = \text{Cold Body Temperature} \]

**Q.36. Why is the value of C.O.P. of a heat pump always greater than unity?**

The value of C.O.P. of a heat pump is always greater than unity (i.e. \( \text{C.O.P. pump} > 1 \)) because it is the reciprocal of the efficiency of a heat engine (which is always less than unity) operating within the same temperature limits.

\[
\text{C.O.P. pump} = \frac{Q_1}{Q_1 - Q_2} = \frac{1}{(Q_1 - Q_2)/Q_1} = 1/\eta_{H.E.}
\]

**Q.37. What is a refrigerator? How is the performance of a refrigerator specified?**

A refrigerator is a device, which working in a cycle, maintains a body or space at a temperature lower than the temperature of the surroundings. It works on heat pump cycle (or reversed heat engine cycle).
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Performance of a refrigerator:
The performance of a refrigerating unit is specified in terms of its **Coefficient of Performance (C.O.P.)** and is defined as given below:

Coefficient of Performance (C.O.P.) of a refrigerating unit may be defined as the ratio of heat extracted (or refrigerating effect produced) to the work done on the refrigerant.

\[
(C.O.P.)_{REF} = \frac{\text{Refrigerating effect produced}}{\text{Work Required}} = \frac{Q_2}{W_{REF}} = \frac{Q_2}{Q_1 - Q_2}
\]

**Work Required**

\[
(C.O.P.)_{CARNOT} = \frac{T_2}{T_1 - T_2}
\]

Where \(T_1\) = Hot Body Temperature

\(T_2\) = Cold Body Temperature

Q.37. What is a reversible or ideal process? How does it differ from irreversible (natural or actual) processes?

i Reversible or ideal processes

ii Irreversible (natural or actual) processes
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1. Reversible or ideal processes:

1) A system is said to have undergone a reversible or ideal process if it is performed in such a way at the conclusion of the process, both the system and the surroundings may be restored to their initial states.

2) A reversible process does not leave any trace to show that the process had ever occurred.

3) A reversible process is carried out infinitely slowly with an infinitesimal gradient, so that every state passed through by the system is a thermodynamic equilibrium.

4) A reversible process is an idealized hypothetical process which is practically not feasible.

5) E.g. Frictionless isothermal expansion or compression of an ideal gas.

2) Irreversible or natural or actual processes:

1) A process is rendered irreversible if it is carried out with a finite gradient (i.e. lack of equilibrium) or if it involves internal or external dissipative effects.

E.g. i) Heat transfer through a finite temperature difference. (Process is carried out with a finite gradient and so there is lack of equilibrium)

ii) All processes involving dissipative effects (like friction, electrical resistance, etc.) are irreversible because the energy once lost due to dissipative effects cannot be recovered.

Difference between reversible process & irreversible process:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Reversible process</th>
<th>Irreversible process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The system as well as the surroundings is restored to their initial states at the conclusion of the process.</td>
<td>The system and the surroundings cannot be restored to their initial states at the conclusion of the process.</td>
</tr>
<tr>
<td>2.</td>
<td>This is an ideal process which is practically not feasible.</td>
<td>All real processes are irreversible and take place spontaneously.</td>
</tr>
<tr>
<td>3.</td>
<td>A reversible process is carried out infinitely slowly with an infinitesimal gradient.</td>
<td>Irreversible processes are carried out with a finite gradient.</td>
</tr>
<tr>
<td>4.</td>
<td>E.g. Frictionless isothermal expansion or compression of an ideal gas.</td>
<td>E.g. All real processes involving dissipative effects (like friction, electrical resistance, etc.) are irreversible.</td>
</tr>
</tbody>
</table>

Q.38. State and explain all the causes of irreversibility.

Causes of irreversibility:

i  Lack of equilibrium during the process (mechanical, thermal or chemical).
ii  Involvement of dissipative effects (internal or external).
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Flow process can be classified into:

i. Steady flow processes
ii. Unsteady flow processes

Q.40. Differentiate between steady flow processes and unsteady flow processes?

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Steady Flow Processes</th>
<th>Unsteady Flow Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The state of the system at any point within the control volume is invariant with time.</td>
<td>The state of the system at any point within the control volume varies with time.</td>
</tr>
<tr>
<td>2.</td>
<td>There is no accumulation of mass within the control volume.</td>
<td>There is accumulation of mass within the control volume.</td>
</tr>
<tr>
<td>3.</td>
<td>There is no accumulation of energy within the control volume.</td>
<td>There is accumulation of energy within the control volume.</td>
</tr>
<tr>
<td>3.</td>
<td>There is no change in the chemical composition of the system.</td>
<td>There may be change in the chemical composition of the system.</td>
</tr>
<tr>
<td>4.</td>
<td>E.g. Engineering devices and applications like air compressors, turbines, engines, heat exchangers, etc.</td>
<td>E.g. Unsteady flow processes are seen in bottle filling process.</td>
</tr>
</tbody>
</table>

Q.41. What is a steady flow process? State the assumptions made in steady flow process.

Steady flow process is defined as a process in which the conditions within the control volume do not vary with time i.e. any thermodynamic property will have a fixed value at a particular location.

E.g. air compressors, turbines, engines, heat exchangers, etc. make use of steady flow processes.

Assumptions made in Steady Flow Processes:

i. The mass flow rates at the entrance and exit of the control volume are the same and do not vary with time.
ii. The energy (i.e. heat & work) flow rates at the entrance and exit of the control volume are the same and do not vary with time.
iii. The state of the system at any point within the control volume is invariant with time.
iv. There is no change in the chemical composition of the system.

Q.42. What is steady flow energy equation (S.F.E.E.)? Derive the steady flow energy equation.

When first law of thermodynamics is applied to determine the energy balance of an open system in steady state, it results in steady flow energy equation (S.F.E.E.). This equation finds application in steady flow devices like air compressors, turbines, engines, etc.
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Derivation of Steady Flow Energy Equation (S.F.E.E.):

Consider a steady flow system with the control volume and control surface as shown in the fig. below. Section 1-1 and section 2-2 indicate, respectively, the entrance and exit of the fluid.

![Diagram of steady flow system]

\[ \text{A}_1 \text{ & A}_2 = \text{Cross – section of stream, m}^2 \]

\[ \text{m}_1 \text{ & m}_2 = \text{Mass flow rate, kg/s} \]

\[ p_1 \text{ & p}_2 = \text{Absolute pressure, N/m}^2 \]

\[ v_{s1} \text{ & v}_{s2} = \text{Specific volume or volume per unit mass of the fluid, m}^3/\text{kg} \]

\[ u_1 \text{ & u}_2 = \text{Specific internal energy or internal energy per unit mass of the fluid, J/kg} \]

\[ V_1 \text{ & V}_2 = \text{Velocity of the fluid, m/s} \]

\[ Z_1 \text{ & Z}_2 = \text{Elevations above an arbitrary datum, m} \]

\[ e_1 \text{ & e}_2 = \text{Specific energy or energy carried per unit mass of the fluid, J/kg} \]

\[ \frac{dQ}{dt} = \text{Net rate of heat transfer through the control surface, J/s} \]

\[ \frac{dW}{dt} = \text{Net rate of work transfer through the control surface, J/s} \]

\[ p_1 v_{s1} = \text{Flow work at the inlet, J/kg} \]

\[ p_1 v_{s1} = \text{Flow work at the outlet, J/kg} \]
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Since there is no accumulation of energy in a steady flow system as per first law of thermodynamics or law of conservation of energy,

i.e. Total energy entering the C.V. = Total energy leaving the C.V.

\[ m_1 e_1 + m_1 p_1 v_{s1} + \frac{dQ}{dt} = m_2 e_2 + m_2 p_2 v_{s2} + \frac{dW}{dt} \]  \hspace{1cm} I

Specific energy is given by

\[ e = e_{K,E} + e_{P,E} + u \]

\[ e = \frac{V^2}{2} + Z g + u \]

Where \( e_{K,E} = \) K.E. per unit mass

\( e_{P,E} = \) K.E. per unit mass

\( u = \) Internal energy per unit mass

Substituting the expression for ‘e’ in the equation I, we have

\[ m_1 (\frac{V_1^2}{2} + Z_1 g + u_1) + m_1 p_1 v_{s1} + \frac{dQ}{dt} = m_2 (\frac{V_2^2}{2} + Z_2 g + u_2) + m_2 p_2 v_{s2} + \frac{dW}{dt} \]

Or, \( m_1 (h_1 + V_1^2/2 + Z_1 g) + \frac{dQ}{dt} = m_2 (h_2 + V_2^2/2 + Z_2 g) + \frac{dW}{dt} \) \hspace{1cm} II

(Since \( h = u + pv_s \))

Equation II represents Steady Flow Energy Equation (S.F.E.E.) on time basis.

For unit mass, i.e. \( m = 1kg \), we have

\[ h_1 + \frac{V_1^2}{2} + Z_1 g + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + Z_2 g + \frac{dW}{dm} \] \hspace{1cm} III

\[ h_1 + \frac{V_1^2}{2} + Z_1 g + Q = h_2 + \frac{V_2^2}{2} + Z_2 g + W \]

Equation III represents Steady Flow Energy Equation (S.F.E.E.) on mass basis.

In general,

\[ Q - W = (\frac{V_2^2 - V_1^2}{2}) + (Z_2 - Z_1) g + (h_2 - h_1) \]

Where \( Q = \frac{dQ}{dm} = \) Net rate of heat transfer in J/kg

\( W = \frac{dW}{dm} = \) Net rate of work transfer in J/kg

\( (V_2^2 - V_1^2)/2 = \) Change in K.E. in J/kg

\( (Z_2 - Z_1) g = \) Change in P.E. in J/kg

\( h_2 - h_1 = \) Change in enthalpy in J/kg
Q.42. Apply Steady Flow Energy Equation (S.F.E.E.) to the following engineering devices

i) Boiler
ii) Engine
iii) Nozzle
iv) Turbine
v) Compressor
vi) Condenser

i) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO BOILER:

**Boiler** is a device which utilizes heat released from the combustion of fuel to convert incoming water into steam. It is a steady flow system. This system is shown in fig. 2.28 with its control volume and control surface.

For a boiler,

There is no work transfer i.e. \( W = 0 \)

Change in K.E. & P.E. is negligible i.e. \( (V_2^2 - V_1^2)/2 = 0 \) & \( (Z_2 - Z_1) \) \( g = 0 \)

The heat transfer (Q) is positive since heat is supplied to the system by the combustion of fuel.

Applying Steady Flow Energy Equation (S.F.E.E.) to the boiler, we have

\[
Q - W = (V_2^2 - V_1^2)/2 + (Z_2 - Z_1) \ g + (h_2 - h_1)
\]

\[
Q - 0 = 0 + 0 + (h_2 - h_1)
\]
Q = h₂ – h₁  

Equation ‘i’ shows that the heat supplied to a boiler is utilized to increase the enthalpy of the fluid.

**ii) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO ENGINE:**

Heat engine is a device which converts part of the heat released from the combustion of fuel to mechanical work. It is a steady flow system. This system is shown in fig. with its control volume and control surface.

For a Heat Engine,

Change in K.E. is negligible i.e. \( \frac{V_2^2 - V_1^2}{2} = 0 \)

Change in P.E. is negligible i.e. \( Z_2 - Z_1 \) g = 0

The heat transfer \( (Q) \) is negative since heat is lost from the system

The work transfer \( (W) \) is positive since work is developed by the system

Applying Steady Flow Energy Equation (S.F.E.E.) to the Engine, we have

\[ Q - W = \frac{V_2^2 - V_1^2}{2} + (Z_2 - Z_1) g + (h_2 - h_1) \]

\[ Q - W = 0 + 0 + (h_2 - h_1) \]  \( \text{--------} \) (Q is negative because heat is lost)

\[ h_2 - h_1 = - Q - W \]

\[ h_1 - h_2 - Q = W \]  \( \text{--------} \) ii
iii) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO NOZZLE:

**Nozzle** is a device which increases the velocity or K.E. of a fluid at the expense of its enthalpy drop. It is a steady flow system. This system is shown in fig. with its control volume and control surface.

**For an insulated nozzle as shown in fig,**

There is no work transfer i.e. \( W = 0 \)

There is no heat transfer i.e. \( Q = 0 \) (if Nozzle is well-insulated)

Change in P.E. is zero i.e. \( (Z_2 - Z_1) \) \( g = 0 \)

Applying Steady Flow Energy Equation (S.F.E.E.) to the Nozzle, we have

\[
Q - W = (V_2^2 - V_1^2)/2 + (Z_2 - Z_1) \ g + (h_2 - h_1)
\]

\[
0 - 0 = (V_2^2 - V_1^2)/2 + 0 + (h_2 - h_1)
\]

\[
0 = (V_2^2 - V_1^2)/2 + (h_2 - h_1)
\]

\[
2 (h_2 - h_1) = (V_2^2 - V_1^2)
\]

\[
V_2^2 = 2 (h_2 - h_1) + V_1^2
\]

\[
V_2 = \sqrt{2 (h_2 - h_1) + V_1^2} \quad iii
\]

\[
V_2 = \sqrt{2 (h_2 - h_1)}
\]
iv) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO TURBINE:

Turbine is a device which converts part of the heat energy (or enthalpy) of fluid to mechanical work. It is a steady flow system. This system is shown in fig. with its control volume and control surface.

For a well insulated turbine as shown in fig,

The work transfer (W) is positive since work is developed by the system

There is no heat transfer i.e. \( Q = 0 \) (if turbine is well-insulated)

Change in P.E. is negligible i.e. \( (Z_2 - Z_1) \ g = 0 \)

Change in K.E. is negligible i.e. \( (V_2^2 - V_1^2)/2 = 0 \)

Applying Steady Flow Energy Equation (S.F.E.E.) to the Turbine, we have

\[ Q - W = (V_2^2 - V_1^2)/2 + (Z_2 - Z_1) \ g + (h_2 - h_1) \]

\[ 0 - W = 0 + 0 + (h_2 - h_1) \]

\[ - W = h_2 - h_1 \]

\[ h_1 - h_2 = W \]
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V) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO COMPRESSOR:

Compressor is a device in which the pressure (or enthalpy) of air is increased at the expense of work supplied to the compressor

a. Centrifugal Compressor
b. Reciprocating Compressor

c) Application of Steady Flow Energy Equation (S.F.E.E.) to Centrifugal Compressor:

Centrifugal compressor compresses atmospheric air and supplies the same continuously at moderate pressure and in large quantities.

For a well insulated Centrifugal Compressor as shown in fig. ,

The work transfer (W) is negative since work is supplied to the system i.e. the Compressor

There is no heat transfer i.e. Q = 0 (if the Compressor is well - insulated)

Change in P.E. is negligible i.e. \((Z_2 - Z_1) \cdot g = 0\)

Change in K.E. is negligible i.e. \((V_2^2 - V_1^2)/2 = 0\)

Applying Steady Flow Energy Equation (S.F.E.E.) to the Centrifugal Compressor, we have

\[
Q - W = (V_2^2 - V_1^2)/2 + (Z_2 - Z_1) \cdot g + (h_2 - h_1)
\]

0 - (- W) = 0 + 0 + (h_2 - h_1) -------------- (W is negative because work is supplied to the system)

\[
W = h_2 - h_1 ------------------------------- v
\]
b) Application of Steady Flow Energy Equation (S.F.E.E.) to Reciprocating Compressor:

Reciprocating compressor compresses atmospheric air and supplies the same at considerably high pressure and in small quantities (compared to Centrifugal Compressor). The heat lost to the surroundings is considerable due to large surface area in contact with the surroundings and low flow rate.

For a Reciprocating Compressor (with its receiver within the control volume) as shown in fig. 2.33,

The work transfer (W) is negative,

There is heat loss to the surroundings. So heat transfer (Q) is negative.

Change in P.E. is negligible i.e. \( (Z_2 - Z_1) g = 0 \)

Change in K.E. is negligible i.e. \( (V_2^2 - V_1^2)/2 = 0 \)

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

\[ Q - W = (V_2^2 - V_1^2)/2 + (Z_2 - Z_1) g + (h_2 - h_1) \]

- \( Q - (-W) = 0 + 0 + (h_2 - h_1) \)

(W & Q are negative because heat is lost to the surroundings and work is supplied to the system)

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

\[ W = (h_2 - h_1) + Q \]
vi) APPLICATION OF STEADY FLOW ENERGY EQUATION (S.F.E.E.) TO CONDENSER (HEAT EXCHANGER):

Condenser is a Heat Exchanger used to condense a fluid (e.g. steam is condensed to water) using a suitable coolant (water or air). Heat lost by the fluid being condensed is gained by the coolant. Thus, there are two streams of fluids, viz. fluid being condensed and the coolant between which energy interactions take place.

For a Condenser as shown in fig. ,

There is no work transfer i.e. \( W = 0 \)

There is no heat transfer i.e. \( Q = 0 \) (Since there is no external heat interaction)

Change in P.E. is negligible i.e. \((Z_2 - Z_1) \ g = 0\)

Change in K.E. is negligible i.e. \((V_2^2 - V_1^2)/2 = 0\)

Applying Steady Flow Energy Equation (S.F.E.E.) on time basis to the Condenser considering the two flow streams, we have

\[
m_s \ (h_{s1} + V_{s1}^2/2 + Z_{s1} \ g) + m_w \ (h_{w1} + V_{w1}^2/2 + Z_{w1} \ g) + Q = \]

\[
m_s \ (h_{s2} + V_{s2}^2/2 + Z_{s2} \ g) + m_w \ (h_{w2} + V_{w2}^2/2 + Z_{w2} \ g) + W
\]
Neglecting the K.E. & P.E. terms and putting \( Q = 0 \) & \( W = 0 \) in the above equation, we have

\[
m_s \hs_1 + m_w \hw_1 = m_s \hs_2 + m_w \hw_2
\]

\[
m_s (\hs_1 - \hs_2) = m_w (\hw_2 - \hw_1)
\]

i.e. Heat lost by the steam = Heat gained by the coolant (water)

Where,

\[
m_{s1} = \text{Mass of steam at the inlet to condenser}
\]

\[
m_{s2} = \text{Mass of steam at the outlet of condenser}
\]

\[
m_{w1} = \text{Mass of cooling water at the inlet to condenser}
\]

\[
m_{w2} = \text{Mass of cooling water at the outlet of condenser}
\]

**Q. Difference between heat engine and heat Pump.**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Heat engine</th>
<th>Heat pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heat engine is device in which heat energy is converted into work.</td>
<td>Heat pump is a device in which to maintain the temperature of system above the atmospheric temperature (surrounding)</td>
</tr>
<tr>
<td>2</td>
<td>It is measured in term of efficiency</td>
<td>It is measured in term of co-efficient of performance (cop)</td>
</tr>
<tr>
<td>3</td>
<td>Efficiency of heat engine is always less than one.</td>
<td>Cop of heat pump is always greater than one.</td>
</tr>
</tbody>
</table>
| 4 | \[
\text{efficiency} = \frac{\text{work done}}{\text{heat supplied}}
\] | \[
\text{cop} = \frac{\text{Desired heating effect}}{\text{work supplied}}
\] |
Q. What is boiler draught? State various types of boiler draughts with meaning.

Boiler draught is the pressure difference, which is necessary to draw the required quantity of air for combustion and to remove the flue gases out of the boiler combustion chamber.

**Necessity of boiler draught:**

1. To provide sufficient quantity of air for combustion.
2. To expel out the hot gases to flow through the boiler.
3. To discharge these gases to atmosphere through chimney.

**Boiler draught is classified as:**

1. **Natural or chimney draught:** draught is produced with the help of chimney alone by using pressure difference between hot flue gases inside the chimney and cold air outside the chimney.

2. **Artificial draught**
   - a) Fan draught (Produced by mechanical fan): draught is produced with the help of fan
     - i) Forced draught: fan is kept before boiler furnace.
     - ii) Induced draught: fan is kept after boiler furnace and before the chimney.
     - iii) Balanced draught
   - b) Steam jet draught (Produced by steam jet)
     - i) Induced draught