RPSC AEn-2024 Main Test Series

MECHANICAL ENGINEERING

Test 2

Test Mode : • Offline • Online

Subjects : Thermal Engineering

(Thermodynamics, Gas & Vapour Power cycles)

DETAILED EXPLANATIONS

1. **Solution:**

Clausius-inequality: For a cyclic process exchanging heat with one or more reservoirs.

$$\oint \frac{đQ}{T} \leq 0$$

Condition for:

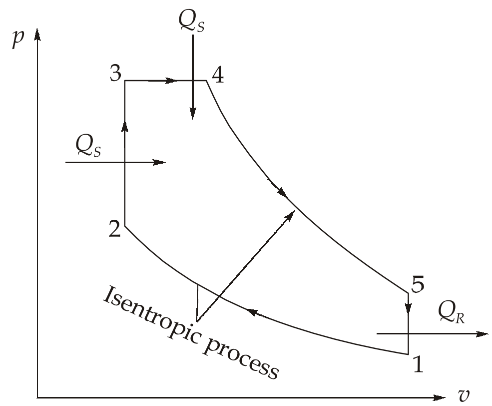
Reversible device $\oint \frac{đQ}{T} = 0$; Irreversible device $\oint \frac{đQ}{T} < 0$; Impossible device $\oint \frac{đQ}{T} > 0$;

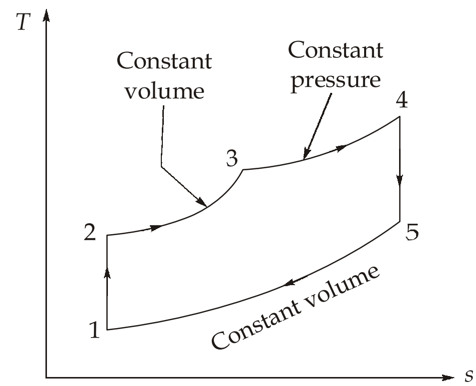
2. **Solution:**

Open system: Turbine, compressor
Closed system: Sealed piston-cylinder system
Adiabatic system: Thermally insulated tank.
Isolated system: Thermos flask, universe

3. Solution:

p-v and T-s diagram for Dual cycle:





4. Solution:

1. The first law of thermodynamics does not differentiate between work and heat. It assumes full convertibility of one with the other. Though full convertibility of work into heat is possible as work is high grade energy, but full convertibility of heat (low grade energy) into work (high grade energy) is not possible.
2. It does not explain the direction of a process.

5. Solution:

Reheat factor: It is defined as the ratio of cumulative heat drop to the adiabatic heat drop in all stages of the turbine. The value of reheat factor depends on the type and efficiency of the turbine. The value of the reheat factor is of the order of 1.1. to 1.5.

6. Solution:

Dryness fraction of steam is defined as the ratio of mass of dry saturated steam to the total mass of mixture (i.e., $m_s + m_w$)

It is generally denoted by x.

$$x = \frac{\text{Mass of dry steam}}{\text{Mass of mixture}} = \frac{m_s}{m_s + m_w}$$

7. Solution:

Bleeding is the process of draining steam from the turbine, at certain points during its expansion and using this steam for heating the feed water supplied to the boiler.

Water in feed pipe has temperature lower than the steam. Due to this difference, steam gives its heat to feed water and gets condensed. By this process, efficiency is increased but at the same time the power developed is decreased.

8. Solution:

Feed water heaters are the devices used for heat exchange between two fluids (i.e. between steam and feed water) either in direct contact or indirect contact.

Types of Feed Water Heaters:

1. Open (Direct contact) Feed Water Heater
2. Closed (Indirect contact) Feed Water Heater

9. Solution:

There are some variables which affect the thermal efficiency of an open cycle gas turbine.

- Pressure ratio
- Turbine inlet temperature
- Compressor inlet temperature
- Efficiencies of turbine and compressor.

10. Solution:

Given: $p_1 = 1$ bar, $p_2 = 12$ bar, $\gamma = 1.4$

$$\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$r_p = \frac{p_2}{p_1} = 12$$

So,

$$\eta = 1 - \frac{1}{(12)^{\frac{1.4-1}{1.4}}} = 50.8\%$$

11. Solution:

Assumptions Made in the Analysis of SFEE:

1. There is no accumulation or decrease of mass in the control volume at any time i.e., there is no other source or sink of mass in the control volume.
2. Rate of mass flow in and out of the control volume is equal and constant with respect to time.
3. State, velocity and elevation of fluid mass entering and leaving the surface do not change with time.
4. Rate of heat and work transfers across the control volume is constant.

12. Solution:

Binary Vapor Power Cycle: A binary vapor power cycle consists of two different working fluids operating in separate but coupled vapor power cycles to improve overall efficiency. Typically, one cycle uses a high-temperature fluid, and the other uses a low-temperature fluid to extract more energy from the heat source.

Combined Gas–Vapor Power Cycle: A combined gas–vapor power cycle (also called a combined cycle) integrates a gas turbine (Brayton cycle) and a steam turbine (Rankine cycle) to improve overall efficiency.

13. Solution:

$$S_2 - S_1 = \bar{c}_p \log\frac{T_2}{T_1} - \bar{R}\log\frac{P_2}{P_1} = -\bar{R}\log\frac{P_2}{P_1}; (\text{as } T_2 = T_1)$$

$$= +8.314\log\frac{0.5}{0.1} = +13.38 \text{ kJ/K}$$

$$(\Delta S)_{universe} = (\Delta S)_{sys} + (\Delta S)_{surr}$$

$$= (\Delta S)_{sys} + 0 = 13.38 \text{ kJ/K}$$

$$(\Delta S)_{universe} = 13.38 \text{ kJ/K}$$

14. Solution:

S.No.	Macroscopic Approach	Microscopic Approach
1	It is used in classical thermodynamics.	It is used in statistical thermodynamics.
2	System is considered as continuum, i.e. continuous distribution of matter without cavities or voids.	System is considered to contain a large number of molecules moving randomly.
3	Properties of system are their average values. Changes can be sensed by human. e.g., pressure, temperature etc.	Properties are defined for each molecule individually. (Properties like velocity, momentum, kinetic energy which describe a molecule) changes in it cannot be sensed by human.
4	Few properties are required to describe the system.	Large number of variables is required to describe the system.

15. Solution:

Specific power or thrust: This is the amount of output power or thrust per unit of mass flow entering the engine. It provides a good first-order indication of the engine weight, frontal area and volume.

Thermal efficiency: Thermal efficiency for aircraft thrust engines is defined as the rate of addition of kinetic energy to the air divided by the rate of fuel energy supplied, usually expressed as a percentage.

Propulsive efficiency: Propulsive efficiency for aircraft thrust engines is defined as the useful propulsive power produced by the engine divided by the rate of kinetic energy addition to the air, again usually expressed as a percentage.

Specific fuel consumption: This is the mass of fuel burnt per unit time per unit of output power or thrust. It is important to minimize SFC for applications where the weight and/or cost of the fuel is significant versus the penalties of doing so.

16. Solution:

Dead State: The dead state of a system is a reference state in which the system is in thermodynamic equilibrium with its surroundings. At this state:

- The system has no potential to do work.
- Temperature, pressure, and other properties are equal to the surrounding environment.

Significance:

It provides a reference point for calculating exergy (available work). Exergy is zero at the dead state. It is used in the second law analysis of energy systems.

Second Law Efficiency: Second law efficiency measures the effectiveness of a real device in converting available energy (exergy) into useful work relative to an ideal reversible device:

Significance:

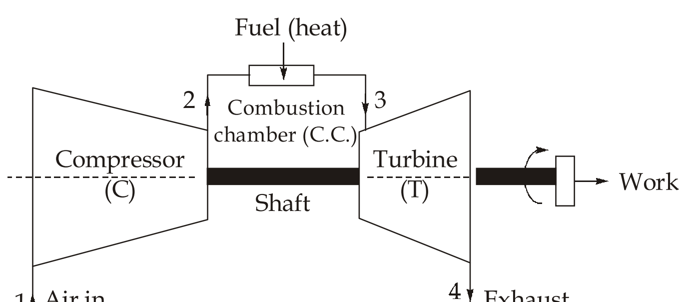
Accounts for irreversibilities in the process.

Indicates how closely a real system approaches ideal performance.

Helps in optimizing energy systems for improved efficiency.

17. Solution:

Constant pressure open cycle gas turbine:



Open cycle gas turbine

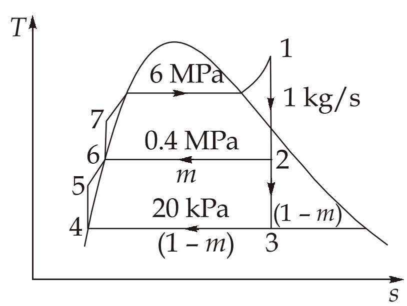
In open cycle gas turbine, a rotary compressor and a turbine are mounted on a common shaft. Air is drawn into the compressor and then compressed air is drawn into the combustion chamber. Here energy is supplied by the spraying fuel into the air stream. After that hot gases expand through the turbine and exhaust to the atmosphere.

18. Solution:

S.No.	Air-Breathing Engine	Rocket Engine
1	There is an altitude limitation	There is no altitude limitation. It can travel in space.
2	Thrust decreases with altitude.	Thrust increases slightly with altitude.
3	Rate of climb decreases with altitude.	Rate of climb increases with altitude.
4	Engine ram drag increases with flight speed.	Engine has no ram drag, so there is a constant thrust with speed.
5	Flight speed always less than jet velocity.	Flight speed can be greater than jet velocity.
6	It has compared less efficiency and reasonable flight duration.	It has low efficiency at extremely high flight speed for small duration.

19. Solution:

Given: h_1 = 3301.8 kJ/kg, s_1 = 6.7193 kJ/kgK = $s_2 = s_3$



$$s_1 = s_2 = 6.7193 = s_f + x_2\, s_{fg}$$

$$6.7193 = 1.7766 + x_2\,(5.1193)$$

$\Rightarrow$ $x_2 = 0.965$

As, $h_2 = h_f + x_2\, h_{fg}$

$\Rightarrow$ $h_2 = 604.74 + 0.965\,(2133.8)$

$= 2664.9$ kJ/kg

Also, $s_1 = s_3 = 6.7193 = 0.832 + x_3\,(7.0766)$

$x_3 = 0.83$

$h_3 = h_f + x_3\, h_{fg} = 251.4 + (0.83 \times 2358.3) = 2208.78$ kJ/kg

Neglecting pump work (w_p is very small)

Assuming, $h_4 = h_5 = (h_f)_{20\text{ kPa}} = 251.4$ kJ/kg

$h_6 = (h_f)_{0.4\text{ MPa}} = 604.74$ kJ/kg

Energy balance for the heater gives,

$$m(h_2 - h_6) = (1 - m)(h_6 - h_5)$$
$$m(2664.9 - 604.74) = (1 - m)(604.74 - 251.4)$$
$$(2060.16)m = (1 - m)(353.34)$$
$$2413.5\, m = 353.34$$
$$m = 0.15 \text{ kg}$$
$$w_T = (h_1 - h_2) + (1 - m)(h_2 - h_3)$$
$$= (3301.8 - 2664.9) + (1 - 0.15)(2664.9 - 2208.78)$$
$$= 1024.602 \text{ kJ/kg}$$

As pump work is neglected.

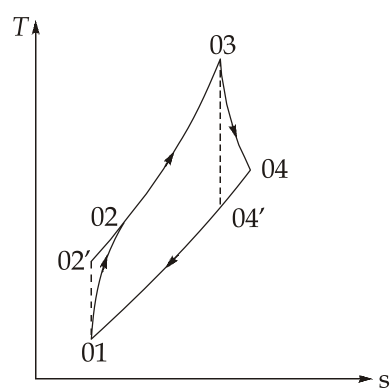
∴ $$w_{net} = w_T = 1024.602 \text{ kJ/kg}$$

Heat supplied, $$Q_1 = (h_1 - h_7)$$
$$Q_1 = (3301.8 - 604.74) \text{ kJ/kg} = 2697.06 \text{ kJ/kg [As } h_6 = h_7]$$

$$\eta_{cycle} = \frac{w_{net}}{Q_1} = \frac{1024.602}{2697.05} = 0.3798 \text{ or } 37.98\%$$

20. Solution:

Given: $T_{01} = 288$ K, $\eta_C = 0.85$, $\eta_T = 0.9$, $C_{pg} = C_{pa} = 1.005$ kJ/kgK, $r = 7$, $\gamma = 1.4$, $P = 750$ kW



$$T_{02} = T_{01}\left[1 + \frac{1}{\eta_C}\left(r^{\frac{\gamma-1}{\gamma}} - 1\right)\right]$$
$$= 288 \times \left[1 + \frac{1}{0.85}\left(7^{0.286} - 1\right)\right] = 540.29 \text{ K}$$

$$T_{04} = T_{03}\left[1 - \eta_T\left(1 - \frac{1}{r^{\frac{\gamma-1}{\gamma}}}\right)\right] = 1000 \times \left[1 - 0.9\left(1 - \frac{1}{7^{0.286}}\right)\right] = 615.87 \text{ K}$$

$$W_N = C_{pg}(T_{03} - T_{04}) - C_{pa}(T_{02} - T_{01})$$
$$= 1.005 \times (1000 - 615.87) - 1.005 \times (540.29 - 288)$$
$$= 132.499 \text{ kJ/kg}$$

$$\eta_{th} = \frac{W_N}{C_{pg}(T_{03} - T_{02})} = \frac{132.499}{1.005 \times (1000 - 540.29)}$$
$$= 0.2867 = 28.68\%$$

Ideal Joule cycle,
$$W_N = C_P\left[T_{03}\left(1 - \frac{1}{r^{\frac{\gamma-1}{\gamma}}}\right) - T_{01}\left(r^{\frac{\gamma-1}{\gamma}} - 1\right)\right]$$
$$= 1.005 \times \left[1000 \times \left(1 - \frac{1}{7^{0.286}}\right) - 288 \times \left(7^{0.286} - 1\right)\right] = 213.42 \text{ kJ/kg}$$
$$\eta_{th} = 1 - \frac{1}{r^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{7^{0.286}} = 0.427 = 42.7\%$$
$$\dot{m}_a = \frac{P}{W_N} = \frac{750}{132.499} = 5.60 \text{ kg/s}$$

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