Mechanical Engineering Science

Q&A

Unit: 1 – Principles of Thermodynamics, Fluid Energy, IC Engines and HEVs Dr. MBK

1. A system undergoes the cyclic process abcde. Find the net heat transfer in the cyclic process. The values of Q, W, and Δu for the individual process are as follows:

Process	Q (kJ)	Δu (kJ)	W (kJ)
a–b	–	–510	310
b–c	410	–	–510
c–d	510	610	–
d–e	–	–	810

Answer:

$$\text{Process } a-b: \quad Q = \Delta u + W = -510 + 310 = -200\,\text{kJ (Heat liberated).}$$
$$\text{Process } b-c: \quad Q = \Delta u + W \Rightarrow 410 = \Delta u - 510 \quad \text{or} \quad \Delta u = 920\,\text{kJ}$$
$$\text{Process } c-d: \quad Q = \Delta u + W \Rightarrow W = Q - \Delta u = 510 - 610 = -100\,\text{kJ} \quad \text{(Work done on system)}$$
$$\text{In a cyclic process} \int \Delta u = 0 \Rightarrow \Delta u_{ab} + \Delta u_{bc} + \Delta u_{cd} + \Delta u_{de}$$
$$-510 + 920 + 610 + \Delta u_{de} = 0 \Rightarrow \Delta u_{de} = -1{,}020\,\text{kJ}$$
$$Q = \Delta u + W = -1{,}020 + 810 = -210\,\text{kJ (Heat liberated)}$$

2. Calculate the quantities of work if initial pressure and volume are 15 bar and 15 m^3 and final volume 25 m^3. The process is non-flow reversible as (i) P = constant; (ii) V = constant; (iii) PV = constant; (iv) PV^n = constant, where $n = 1.3$; and (v) PV^{γ} = constant, where $\gamma = 1.4$.

Solution:

(i) $$P = \text{constant}$$
$$W = \int_{V_1}^{V_2} PdV = P(V_2 - V_1) = 15 \times 10^2 (25 - 15) = 15 \times 10^3\ \text{kJ}$$

(ii) $$V = \text{constant}$$
$$W = \int_{V_1}^{V_2} PdV = 0$$

(iii) $$PV = \text{constant} = K$$
$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{K}{V} dv = P_1V_1 \log\frac{25}{15} = 11.49 \times 10^3\ \text{kJ}$$

(iv) $$PV^n = \text{constant} = K$$

$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{K}{V^n} dV = \int_{V_1}^{V_2} KV^{-n} dV = P_1V_1\left[\frac{V^{1-n}}{1-n}\right]_1^2 = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$P_2 = \frac{P_1V_1^n}{V_2^n} = 15 \times \frac{15^{1.3}}{25^{1.3}} = 7.72\,\text{bar}$$

$$W = \frac{15\times10^2\times15 - 7.72\times10^2\times25}{1.3-1} = 10.667\times10^3\ \text{kJ}$$

(v) $$PV^n = \text{constant} = K$$

$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{K}{V^\gamma} dV = \int_{V_1}^{V_2} KV^{-\gamma} dV = P_1V_1\left[\frac{V^{1-\gamma}}{1-\gamma}\right]_1^2 = \frac{P_1V_1 - P_2V_2}{\gamma-1}$$

$$P_2 = \frac{P_1V_1^\gamma}{V_2^\gamma} = 15 \times \frac{15^{1.4}}{25^{1.4}} = 7.336\,\text{bar}$$

$$W = \frac{15\times10^2\times15 - 7.33\times10^2\times25}{1.4-1} = 10.4\times10^3\ \text{kJ}$$

3. In a cyclic process, amount of heat transfers are given as 15J, –27, –4 and 32 kJ. Calculate the net work done in the cyclic process.

Solution:

$$W = Q_1 + Q_2 + Q_3 + Q_4 = 15 - 27 - 4 + 32 = 16\,\text{kJ}$$

4. In a cyclic process, an engine engages in two work interactions: 18 kJ to the fluid and 48 J from the fluid, and two heat interactions out of three are given as: 80 kJ to the fluid and 44 kJ from the fluid. Find the magnitude and direction of the third heat transfer.

Solution:

$$W_1 + W_2 = Q_1 + Q_2 + Q_3$$

$$Q_3 = W_1 + W_2 - Q_1 - Q_2 = -18 + 48 - 80 + 44 = -6\,\text{kJ (Heat rejection)}$$

5. During a certain period of analysis, a refrigerator consuming the energy at the rate of 1.5 kJ/h loses internal energy of its system by 4,500 kJ. Calculate the heat transfer for the system for that period.

Solution:

$$W = -1.5\,\text{kW h}, \quad \Delta u = -4{,}500\,\text{kJ}$$

$$Q = \Delta u + W = -4{,}500\,\text{kJ} - 1.5\times3{,}600 = -9{,}900\,\text{kJ} = -9.9\ \text{MJ (Heat rejection)}$$

6. A single cylinder engine operating at 2000 rpm develops a torque of 8 N-m. The indicated power of the engine is 2.0 kW. Find loss due to friction as the percentage of brake power.

Ans:

$$\text{Brake power } = \frac{2\pi\, NT}{60000} = \frac{2 \times \pi \times 2000 \times 8}{60000}$$

$$= 1.6746 \text{ kW}$$

$$\text{Friction power} = 2.0 - 1.6746$$

$$= 0.3253$$

$$\%\text{ loss } = \frac{0.3253}{2} \times 100$$

$$\%\text{ loss} = 16.2667\%$$

7. A single cylinder engine running at 180 rpm develops a torque of 8 Nm. The indicated power of the engine 1.8 kW. Find the loss due to friction power as the percentage of brake power.

Solution

Given Data : Single cylinder engine

Speed of engine $= N = 1800$ rpm

Torque $= T = 8$ Nm

$I.P. = 1.8$ kW

$$\text{Brake power } = B.P. = \frac{2\pi NT}{60} = \frac{2\pi \times 1800 \times 8}{60}$$

$$= 1507.96 \text{ W} = 1.50796 \text{ kW}$$

$$\text{Friction power} = F.P. = I.P. - B.P.$$

$$= 1.8 - 1.50796$$

$$= 0.29204 \text{ kW}$$

Loss due to friction power as the percentage of brake power

$$= \frac{0.29204}{1.50796} \times 100$$

$$= 19.37\% \text{ of brake power.}$$

8. A 4-cylinder, 4-stroke SI engine runs at 3000 rpm with a brake torque of 120 Nm. Calculate the brake power.

Solution:

$$BP = \frac{2\pi NT}{60}$$

$$BP = \frac{2\pi \times 3000 \times 120}{60} = 37,699.1 \text{ W} \approx \boxed{37.7 \text{ kW}}$$

9. Define Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV).

Solution:

- **Electric Vehicle (EV):** A vehicle powered entirely by an electric motor using energy stored in batteries. It does not use any internal combustion engine.
- **Hybrid Electric Vehicle (HEV):** A vehicle that combines an internal combustion engine (ICE) with one or more electric motors. It uses both fuel and electricity for propulsion.

10. What do you understand by quasi-static process? How it is achieved?

Ans:

A quasi-static process (also called a quasi-equilibrium process) is a thermodynamic process that happens very slowly such that the system remains nearly in equilibrium at all times during the process. Because the process proceeds gradually, the system's properties (pressure, temperature, volume) change infinitesimally between states, allowing it to be treated as a series of equilibrium states. By making the process extremely slow so that pressure and temperature differences within the system are negligible. By applying forces or heat gradually to avoid sudden changes or turbulence. Examples include very slow compression or expansion of gas in a piston-cylinder arrangement.

11. Why do EVs have better energy efficiency than ICE vehicles?

Solution:

EVs convert over 85-90% of electrical energy into motion, while ICE vehicles convert only about 25-30% of fuel energy into motion. The rest is lost as heat and friction in ICE vehicles, whereas EVs have:

- Regenerative braking
- Fewer moving parts
- Minimal idling losses

12. Explain the basic working principle of electric and hybrid vehicles, highlighting the differences between them.

Ans:

Working Principle of Electric Vehicles (EVs):

Electric vehicles (EVs) operate solely on electricity stored in rechargeable batteries. The electric motor in the vehicle uses this electrical energy to power the wheels, converting electrical energy directly into mechanical energy. The vehicle is charged via an external power source, typically through a charging station or wall outlet. EVs do not use gasoline or diesel, making them environmentally friendly and reducing reliance on fossil fuels.

Working Principle of Hybrid Vehicles (HEVs):

Hybrid electric vehicles (HEVs) combine both a traditional internal combustion engine (ICE) and an electric motor. The vehicle can run on either the gasoline engine, the electric motor, or both, depending on driving conditions and the level of battery charge. The system uses regenerative braking to recharge the battery and optimize fuel efficiency. When more power is needed, the gasoline engine kicks in, and when efficiency is prioritized, the electric motor is used.

Feature	**Electric Vehicle (EV)**	**Hybrid Vehicle (HEV)**
Power Source	Runs solely on electricity from batteries	Uses both an internal combustion engine and an electric motor
Emissions	Zero tailpipe emissions	Lower emissions than conventional vehicles, but still produces some
Fuel Efficiency	100% electric, no fuel required	More fuel-efficient than standard gasoline vehicles
Charging/Fueling	Requires charging from an electric outlet	Gasoline engine provides backup when battery is low
Maintenance	Fewer moving parts, lower maintenance	More complex due to both electric and combustion systems