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MECHANICAL ENGINEERING



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UPSC Engineering Service Examination 2020

**25
YEARS
SOLUTION**

MECHANICAL ENGINEERING
ESE TOPICWISE OBJECTIVE SOLVED
PAPER-I

1995-2019



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Second Edition : 2018

Third Edition : 2019

PREFACE

It is an immense pleasure to present topic wise previous years solved paper of Engineering Services Exam. This booklet has come out after long observation and detailed interaction with the students preparing for Engineering Services Exam and includes detailed explanation to all questions. The approach has been to provide explanation in such a way that just by going through the solutions, students will be able to understand the basic concepts and will apply these concepts in solving other questions that might be asked in future exams.

Engineering Services Exam is a gateway to a immensely satisfying and high exposure job in engineering sector. The exposure to challenges and opportunities of leading the diverse field of engineering has been the main reason for students opting for this service as compared to others. To facilitate selection into these services, availability of arithmetic solution to previous year paper is the need of the day. Towards this end this book becomes indispensable.

Mr. Kanchan Kumar Thakur
Director-IES Master

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UNIT-1

Thermodynamics

SYLLABUS

Thermodynamic systems and processes; properties of pure substances; Zeroth, First and Second Laws of Thermodynamics; Entropy; Irreversibility and availability; analysis of thermodynamic cycles related to energy conversion : Rankine, Otto, Diesel and Dual Cycles; ideal and real gases; compressibility factor; Gas mixtures.

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1

INTRODUCTION AND FIRST LAW

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- A 2 kg of steam occupying 0.3 m^3 at 15 bar is expanded according to the law $pv^{1.3} = \text{constant}$ to a pressure of 1.5 bar. The work done during the expansion will be

(a) 602.9 kJ (b) 606.7 kJ
(c) 612.5 kJ (d) 618.3 kJ
- Certain quantities cannot be located on the graph by a point but are given by a point but are given by the area under the curve corresponding to the process. These quantities in concepts of thermodynamics are called as

(a) cyclic functions (b) point functions
(c) path functions (d) real functions

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- Which one of the following substances has constant specific heat at all pressures and temperature ?

(a) Mono-atomic gas (b) Di-atomic gas
(c) Tri-atomic gas (d) Poly-atomic gas
- When the valve of an evacuated bottle is opened, the atmospheric air rushes into it. If the atmospheric pressure is 101.325 kPa and 0.6 m^3 of air enters into the bottle, then the work done by the air will be

(a) 80.8 kJ (b) 70.8 kJ
(c) 60.8 kJ (d) 50.8 kJ
- A thermodynamic cycle is composed of four processes. The heat added and the work done in each process are as follows :

Process	Heat transfer (J)	Work done (J)
1 – 2	0	50 (by the gas)
2 – 3	50 (from the gas)	0
3 – 4	0	20 (on the gas)
4 – 1	80 (to the gas)	0

The thermal efficiency of the cycle is

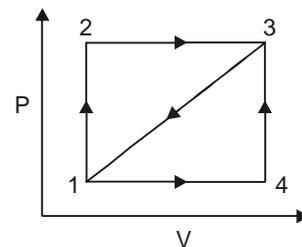
- (a) 20.3% (b) 37.5%
(c) 40.3% (d) 62.5%
- A steel tank placed in hot environment contains 5 kg of air at 4 atm at 30°C . A portion of the air is released till the pressure becomes 2 atm. Later, the temperature of the air in the tank is found to be 150°C . The quantity of air allowed to escape is

(a) 4.72 kg (b) 4.12 kg
(c) 3.71 kg (d) 3.21 kg
 - Consider the following statements :

 - Entropy is related to the first law of thermodynamics.
 - The internal energy of an ideal gas is a function of temperature and pressure.
 - The zeroth law of thermodynamics is the basis for measurement of temperature.

Which of the above statements are correct ?

- (a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3
- A system absorbs 100 kJ as heat and does 60 kJ work along the path 1-2-3. The same system does 20 kJ work along the path 1-4-3. The heat absorbed during the path 1-4-3 is



- (a) -140 kJ (b) -80 kJ
(c) 80 kJ (d) 60 kJ

EXPLANATIONS

Sol-1: (d) $P_1V_1^{1.3} = P_2V_2^{1.3}$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{1.3}$$

$$\Rightarrow V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{1.3}} \times V_1$$

$$\Rightarrow V_2 = \left(\frac{15\text{bar}}{1.5\text{bar}}\right)^{\frac{1}{1.3}} \times 0.3\text{ m}^3 = 1.7634\text{ m}^3$$

$$Pv^{1.3} = \text{constant} = C \text{ (say)}$$

$$\Rightarrow P = \frac{C}{V^{1.3}}$$

$$\text{work done } W = \int_{V_1}^{V_2} Pdv = \int_{V_1}^{V_2} \frac{C}{V^{1.3}} dV$$

$$= \int_{V_1}^{V_2} C V^{-1.3} dV = C \left[\frac{V^{-0.3}}{-0.3} \right]_{V_1}^{V_2}$$

$$= \frac{C}{-0.3} [V_2^{-0.3} - V_1^{-0.3}]$$

$$= \frac{-1}{0.3} [P_2V_2^{1.3} \cdot V_2^{-0.3} - P_1V_1^{1.3} \cdot V_1^{-0.3}]$$

$$= \frac{-1}{0.3} [P_2V_2 - P_1V_1] = \left[\frac{P_1V_1 - P_2V_2}{0.3} \right]$$

$$= [15 \times 10^5 \times 0.3 - 1.5 \times 10^5 \times 1.7634] / 0.3 = 618.3\text{ kJ}$$

Sol-2: (c)

Path functions like heat transfer and work transfer cant be represented by points in the graph, but can be given by the area under the curve.

Ex: heat transfer will be area under curve in T-s diagram work transfer will be area under curve in P-V diagram.

Sol-3: (a)

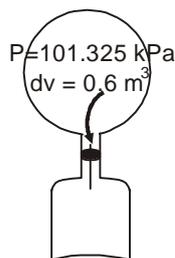
Sol-4: (c)

Work done by air

$$= Pdv$$

$$= 101.325 \times 0.6$$

$$= 60.8\text{ kJ}$$

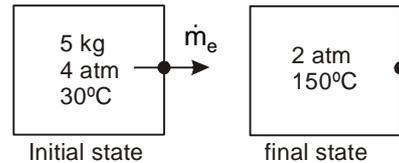


Sol-5: (b)

Thermal efficiency,

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{50}{80} = 37.5\%$$

Sol-6: (d)



From mass conservation,

$$\dot{m}_i - \dot{m}_e = \frac{d}{dt} m_{cv} = m_2 - m_1$$

(1) No inlet, so $\dot{m}_i = 0$

$$\therefore \dot{m}_e = m_1 - m_2 \quad \dots(i)$$

(2) $m_1 = 5\text{kg}$ (given)

$$(P_1V = mRT_1)$$

$$m_2 = \frac{P_2V}{RT_2} = \frac{P_2}{RT_2} \left(\frac{m_1RT_1}{P_1} \right)$$

$$= \frac{2}{423} \times \frac{5 \times 303}{4} = 1.79\text{ kg}$$

$$\text{From equation (i) } \dot{m}_e = 5 - 1.79 = 3.21\text{ kg}$$

Sol-7: (*)

Sol-8: (d)

For process 1 - 2 - 3

$$Q_{123} = U_3 - U_1 + W_{123}$$

$$U_3 - U_1 = Q_{123} - W_{123} = 100 - 60 = 40\text{ kJ}$$

For process 1 - 4 - 3

$$Q_{143} = U_3 - U_1 + W_{143}$$

$$= 40 + 20 = 60\text{ kJ}$$

Sol-9: (a)

The specific heat of ideal gas of constant pressure is the sum of specific heat at constant volume and a constant term. This constant term comes due to work done component. This work done component is missing when heat is added at constant volume.

Sol-10: (d)

The work done during expansion,

$$W = 0.333 Q$$

Because heat added,

$$Q = C_p \Delta T$$

Because work done,

$$W = 0.333 C_p \Delta T$$

$$\therefore \frac{C_p}{W} = \frac{1}{0.333 \times \Delta T} = \frac{1}{0.333 \times 20}$$

$$\frac{C_p}{W} = \frac{100}{0.333 \times 20} = 15\%$$

Sol-11: (c)

A process is reversible if both the system and surroundings are restored to initial condition. Thus, plastic deformation of a material and magnetization of a material exhibiting hysteresis are irreversible processes. The spring after extension will get back to its original position after removal of load, hence it can be considered as reversible.

Sol-12: (a)

Throttling process involves the passage of a higher pressure fluid through a narrow constriction. This process is adiabatic, and there is no work interaction. Hence,

$$Q = 0 \quad \& \quad W = 0$$

$$\Delta PE = 0$$

(Inlet and outlet are at the same level)

$$\Delta KE = 0$$

(KE does not change significantly)

\therefore Applying the SFEE, $h_1 = h_2$

Thus, enthalpy remain constant

Further, the velocity of flow is kept low and any difference between the kinetic energy upstream and downstream is negligible. The effect of the decrease in pressure is an increase in volume.

Sol-13: (b)

Thermodynamic or absolute temperature scale is independent of any working substance. The fact that the efficiency of a reversible heat engine cycle depends only on the temperature of the two reservoirs makes it possible to establish such a scale. If the temperature of a given system is measured with thermometers using different thermoemetric properties, there is considerable difference among the readings.

Sol-14: (c)

Throttling process is a irreversible process as the entropy of the fluid increases during the process. The first law of thermodynamics only gives a quantitative estimate of the heat and work interaction between the system and surroundings, however, it does not state about quality of energy. It is the second law of thermodynamics which deals with the low grade and high grade energy and concepts of availability.

Sol-15: (b)

For charging the tank,

$$m_p h_p = m_2 u_2 - m_1 u_1$$

If the tank is initially empty, then $m_1 = 0$

$$\therefore m_p h_p = m_2 u_2$$

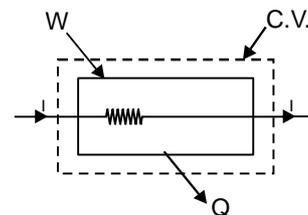
Since $m_p = m_2$, hence, $h_p = u_2$

Sol-16: (c)

The reciprocating compressor can be considered as steady flow system provided the control volume includes the receiver which reduces the fluctuation of flow.

For electric heater, at steady state

$$W = Q$$

**Sol-17: (a)**

A reversible process must be quasi-static and frictionless.

Further, a heat engine cycle in which there is a temperature difference (i) between the source and the working fluid during heat supply, and (ii) between the working fluid and the sink during heat rejection, exhibits external thermal irreversibility. Thus, P and T of the working substance must not differ, appreciably from those of the surroundings at any state in the process.

Sol-18: (b)

The property of a thermodynamic system is a point function, since for a given state, there is a definite value for each property. The change



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