

ESE

GATE

State Engg. Exams

MADE EASY
WORKBOOK 2027



**Detailed Explanations of
Try Yourself *Questions***

Mechanical Engineering
Thermodynamics



1

Basic Concepts and Zeroth Law of Thermodynamics



Detailed Explanation of Try Yourself Questions

T1 : Solution (a)

$$0^{\circ}\text{C} \quad \underline{\hspace{2cm}} \quad 5^{\circ}\text{C}$$

$$t^{\circ}\text{C} \quad \underline{\hspace{2cm}} \quad 52^{\circ}\text{C}$$

$$100^{\circ}\text{C} \quad \underline{\hspace{2cm}} \quad 99^{\circ}\text{C}$$

$$\frac{0-t}{0-100} = \frac{5-52}{5-99}$$

$$t = 50^{\circ}\text{C}$$

$$t = 50 \times \frac{9}{5} + 32 = 122^{\circ}\text{F}$$

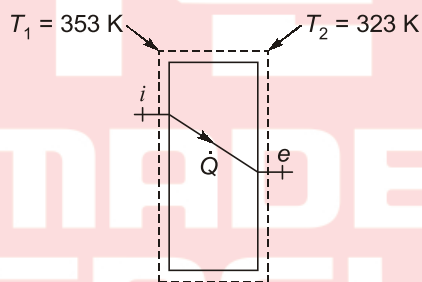
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Energy Interactions (Heat & Work)



Detailed Explanation of Try Yourself Questions

T1 : Solution



$$\dot{Q} = KA \frac{dT}{dx}$$

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$$4500 = 15 \times 1 \times \frac{(353 - T_2)}{0.1}$$

$$30 = 353 - T_2$$

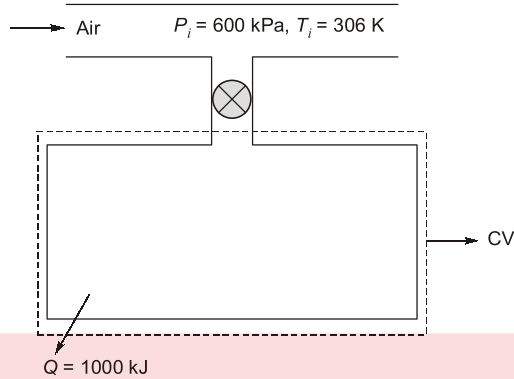
$$T_2 = 323 \text{ K}$$

$$\left(\frac{ds}{dt} \right)_{\text{C.V.}}^0 = \dot{S}_i + \dot{S}_{\text{gen}} - \dot{S}_e$$

$$\begin{aligned} \dot{S}_{\text{gen}} &= \dot{S}_e - \dot{S}_i = \frac{\dot{Q}}{T_e} - \frac{\dot{Q}}{T_i} = \frac{4500}{323} - \frac{4500}{353} \\ &= 1.184 \text{ W/k.m}^2 \end{aligned}$$

T2 : Solution (395.388)

Here, i = Inlet, e = Exit,
Initial condition of CV \Rightarrow 1
Final condition of CV \Rightarrow 2



From conservation of mass:

$$m_2 - m_1^0 = m_i - m_e^0$$

$$m_2 = m_e$$

Conservation of energy:

$$U_2 - U_1^0 = m_i h_i + Q - m_e h_e^0 - W_{CV}^0$$

$$m_2 u_2 = m_2 \times C_p T_i + (-1000)$$

[$\because u_2 = C_V T_2$ and $m_i = m_2$]

$$m_2 C_V T_2 = m_2 C_V T_i - 1000$$

$$\frac{P_2 V}{RT_2} \times C_V \times T_2 = \frac{P_2 V}{RT_2} \times C_V \times T_i - 1000$$

[By Ideal gas equation]

$$\frac{600 \times 8}{0.287} \times 0.718 = \frac{600 \times 8}{0.287 \times T_2} \times 1.005 \times 306 - 1000$$

$$\Rightarrow T_2 = 395.388 \text{ K}$$



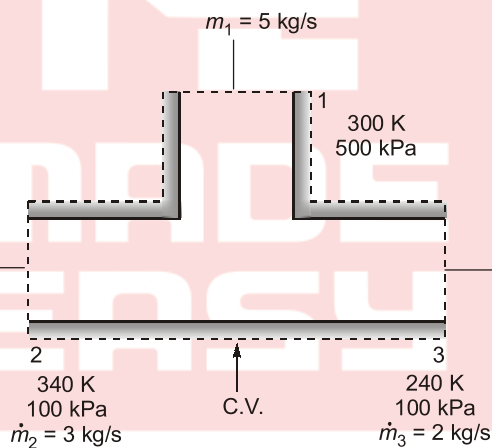
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First Law of Thermodynamics



Detailed Explanation of Try Yourself Questions

T1 : Solution



$$\left(\frac{dS}{dt}\right)_{C.V.} = \dot{S}_i + \dot{S}_{gen} - \dot{S}_e$$

∴

$$\left(\frac{dS}{dt}\right)_{C.V.} = 0 \text{ [Steady state]}$$

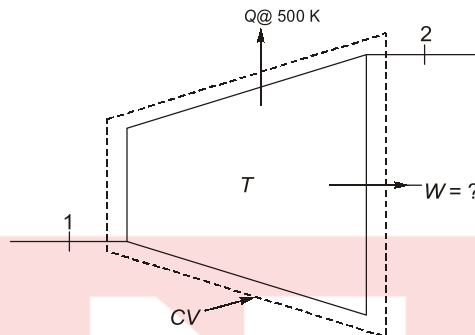
$$\begin{aligned} \dot{S}_{gen} &= \dot{S}_e - \dot{S}_i \\ &= \underbrace{\dot{m}_2}_{\downarrow 3} s_2 + \underbrace{\dot{m}_3}_{\downarrow 2} s_3 - \underbrace{\dot{m}_1}_{\downarrow 5} s_1 \\ &= 3(s_2 - s_1) + 2(s_3 - s_1) \\ &= 3 \times 0.587 + 2(0.237) \\ &= 2.235 \text{ kW/K} \approx 2.2 \text{ kW/K} \end{aligned}$$

T2 : Solution

For reversible process

$$\dot{S}_{\text{gen}} = 0$$

$$\left(\frac{dS}{dt}\right)_{\text{CV}} \underset{0(\text{Steady state})}{=} \dot{S}_i + \overset{0(\text{Reversible})}{\dot{S}_{\text{gen}}} - \dot{S}_e$$



$$0 = \dot{m}s_1 - \left\{ \dot{m}s_2 + \frac{\dot{Q}}{500} \right\}$$

$$0 = 500 \times \{6.5 - 6.3\} - \frac{\dot{Q}}{500}$$

$$\dot{Q} = 50000 \text{ kW}$$

$$\dot{Q} = 50 \text{ MW}$$

Conservation of energy:

$$\dot{E}_{\text{in}} = \dot{E}_{\text{exit}}$$

$$\dot{m}h_1 = \dot{m}h_2 + \dot{Q} + \dot{W}$$

$$\dot{m}(h_1 - h_2) = \dot{Q} + \dot{W}$$

$$500(3500 - 2500) = 50000 + \dot{W}$$

$$\dot{W} = 450000 \text{ kW}$$

$$\dot{W} = 450 \text{ MW}$$



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Second Law of Thermodynamics



Detailed Explanation of Try Yourself Questions

T1 : Solution

$$T_L = 2 + 273 = 275\text{K}$$

$$T_H = 300\text{K}$$

$$(\text{COP})_{\text{ideal}} = \frac{T_L}{T_H - T_L} = \frac{275}{300 - 275} = 11$$

$$\begin{aligned}(\text{COP})_{\text{actual}} &= 20 \text{ percent of } (\text{COP})_{\text{ideal}} \\ &= 0.2 \times 11 = 2.2\end{aligned}$$

Let the electricity consumed per day is x

$x \times (\text{Number of days}) \times (\text{Rate of electricity}) = \text{Monthly bill}$

$$\Rightarrow x \times 30 \times 3 = 200$$

$$\Rightarrow x = 2.22 \text{ kWh} \simeq 8000 \text{ kJ}$$

$$Q_{\text{in}} \text{ per day} = x \times (\text{COP})_{\text{actual}} = 17600 \text{ kJ}$$

$$n \times 400 = 17600$$

$$\Rightarrow n = \frac{17600}{400} = 44$$



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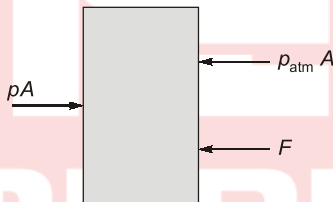
Entropy, Availability and Irreversibility



Detailed Explanation of Try Yourself Questions

T1 : Solution

The initial and final pressure of the air are calculated from a free-body diagram of the piston, as follows



$$pA = p_{\text{atm}} A + F$$

$$pA = p_{\text{atm}} A + kx$$

$$pA = p_{\text{atm}} A + \frac{k(V_2 - V_1)}{A}$$

$$p = p_{\text{atm}} + \frac{k(V_2 - V_1)}{A^2}$$

or

Initially, spring force,

$$F = 0$$

∴

$$p_1 = p_{\text{atm}} = 100 \text{ kPa}$$

Final pressure,

$$p_2 = p_{\text{atm}} + \frac{k(V_2 - V_1)}{A^2} = 100 + \frac{10 \times (0.003 - 0.002)}{(0.02)^2}$$

$$= 100 + 25 = 125 \text{ kPa}$$

$$s_2 - s_1 = c_v \log_e \frac{p_2}{p_1} + c_p \log_e \frac{V_2}{V_1}$$

$$= 0.718 \log_e \frac{125}{100} + 1.005 \log_e \frac{0.003}{0.002}$$

$$= 0.16017 + 0.40749$$

$$= 0.56766 \text{ kJ/kgK}$$



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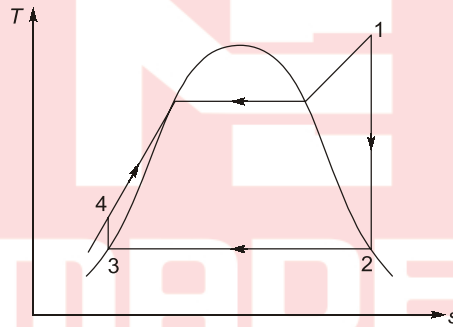
Properties of Pure Substance



Detailed Explanation of Try Yourself Questions

T1 : Solution (b)

For minimum possible dryness fraction at the exit of the adiabatic turbine, the process must be reversible



$$\begin{aligned}
 s_1 &= s_2 \\
 6.9362 &= s_f + x_2 s_{fg} \text{ at } 50 \text{ kPa} \\
 6.9362 &= 1.091 + x_2 (7.5939 - 1.091) \\
 x_2 &= 0.899 \text{ or } 89.9\%
 \end{aligned}$$



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Thermodynamic Relations and Clapeyron Equation



Detailed Explanation of Try Yourself Questions

T1 : Solution (b)

$$\beta = \frac{1}{v} \left(\frac{\partial v}{\partial T} \right)_P$$

$$5 \times 10^{-5} = \frac{1}{0.000114} \left(\frac{\partial V}{\partial T} \right)_P$$

$$\left(\frac{\partial V}{\partial T} \right)_P = 570 \times 10^{-11} \text{ m}^3/\text{kgK}$$

Now,

$$k = -\frac{1}{v} \left(\frac{\partial V}{\partial P} \right)_T$$

$$8.6 \times 10^{-12} = -\frac{1}{0.000114} \left(\frac{\partial V}{\partial T} \right)_T$$

$$\left(\frac{\partial V}{\partial P} \right)_T = -980 \times 10^{-18} \text{ m}^3/\text{kgPa}$$

$$\begin{aligned} C_P - C_V &= -T \left(\frac{\partial P}{\partial V} \right)_T \left[\left(\frac{\partial V}{\partial T} \right)_P \right]^2 - (273 + 25) \left(\frac{1}{-980 \times 10^{-18}} \right) (570 \times 10^{-11})^2 \\ &= 9.8755 \text{ J/kgK} \end{aligned}$$

$$\begin{aligned} C_P &= \frac{\gamma}{\gamma - 1} (C_P - C_V) = \frac{1.024}{1.024 - 1} \times 9.8755 \\ &= 421.35 \text{ J/kgK} \end{aligned}$$

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