GATE PSUs

State Engg. Exams

MADE EASY

Workbook 2024

Detailed Explanations of Try Yourself *Questions*

Chemical Engineering

Thermodynamics

MADE EASY PUBLICATIONS

1 Introduction of Basic Concepts

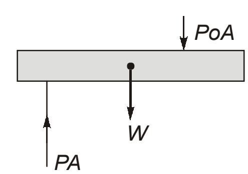
Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans : p_2 = 162.4 kPa; T_2 = 99.34°C]

At the instant, when piston just begins to move;

$$P_0 A + W = P_2 A$$



FBD of piston

$$\Rightarrow \quad P_2 = P_0 + \frac{W}{A}$$

$$P_2 = 100 + \frac{50 \times 9.81 \times 4}{\pi \times 0.1^2 \times 10^3}$$

$$P_2 = 162.45 \text{ kPa}$$

$$\frac{T_2}{P_2} = \frac{T_1}{P_1} \qquad (\because V_1 = V_2)$$

$$\frac{T_2}{162.45} = \frac{300 + 273}{250}$$

$$\Rightarrow \quad T_2 = 372.34 \text{ K or } 99.34°\text{C}$$

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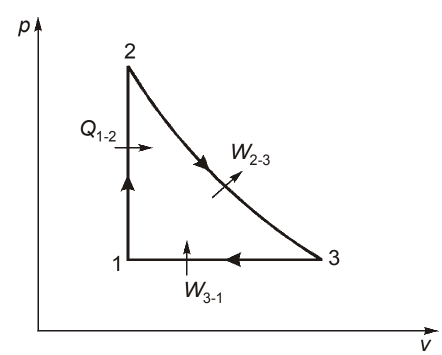
2 First Law of Thermodynamics for Open and Close Systems

Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans : $Q_{3-1} = -250$ kJ, $U_1 - U_3 = -50$ kJ]

Given data: $Q_{1-2} = 50$ kJ; $W_{2-3} = 500$ kJ;
$W_{3-1} = -200$ kJ



First law for process 1-2

$$Q_{1-2} = U_2 - U_1$$

or $$U_2 - U_1 = 50 \text{ kJ}$$

For process 2-3, $T = C$

$$U_3 - U_2 = 0$$

First law for process 2-3

$$Q_{2-3} = (U_3 - U_2) + W_{2-3}$$
$$Q_{2-3} = 0 + 500 = 500 \text{ kJ}$$

First law for cycle 1-2-3-1

$$\oint \delta Q = \oint \delta W$$

$$Q_{1-2} + Q_{2-3} + Q_{3-1} = W_{1-2} + W_{2-3} + W_{3-1}$$
$$50 + 500 + Q_{3-1} = 0 + 500 - 200$$

or $$Q_{3-1} = -250 \text{ kJ}$$

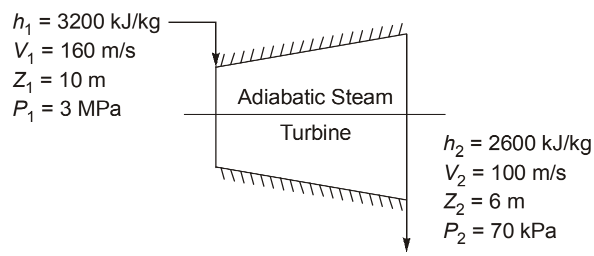
First for process 3-1

$$Q_{3-1} = (U_1 - U_3) + W_{3-1}$$
$$-250 = (U_1 - U_3) - 200$$

or $$U_1 - U_3 = -50 \text{ kJ}$$

T2 : Solution

[Ans : 12.157 MW]



Applying Steady Flow Energy Equation (SFEE)

$$h_1 + \frac{V_1^2}{2} + gZ_1 + Q = h_2 + \frac{V_2^2}{2} + gZ_2 + W$$

$Q = 0$; because it is an adiabatic steam turbine.

$$\Rightarrow \quad 3200 \times 10^3 + \frac{(160)^2}{2} + 9.81 \times 10 + 0$$

$$= 2600 \times 10^3 + \frac{(100)^2}{2} + 9.81 \times 6 + W$$

$\Rightarrow \quad W = 607839.24$ J/kg = 607.84 kJ/kg

Mass flow rate of steam through turbine is 20 kg/s.

The power output of the turbine is

(a) = 20 × 607.84 = 12156.78 kW = 12.157 MW

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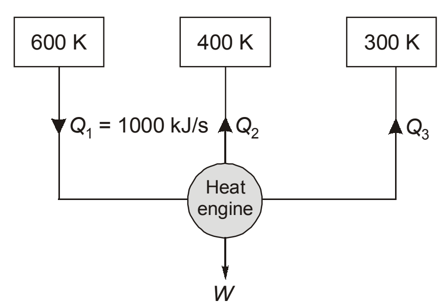
3 Second Law of Thermodynamics Entropy Concepts and Irreversibility

Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans : 2.7%]

A schematic diagram of a reversible heat engine operating with three thermal reservoir is shown in figure.



$$Q_1 = Q_2 + Q_3 + W$$

(As per 1st law of thermodynamics)

$$1000 = Q_2 + Q_3 + 50$$

$$\Rightarrow \quad Q_2 + Q_3 = 950 \text{ kJ/s} \qquad \ldots(i)$$

$$\sum \frac{Q}{T} = 0 \text{ [Claussius inequality]}$$

$$\Rightarrow \quad \frac{1000}{600} - \frac{Q_2}{400} - \frac{Q_3}{300} = 0$$

$$\Rightarrow \quad 3Q_2 + 4Q_3 = 2000 \qquad \ldots(ii)$$

Solving equation (*i*) and (*ii*) we get

$$Q_2 = 1800, \quad Q_3 = -850$$

⇒ Engine rejects 1800 kJ/s to the reservoir at 400 K and absorbs 850 kJ/s from the reservoir at 300 K.

So, Net energy absorbed = 1000 + 850 = 1850 kJ/s

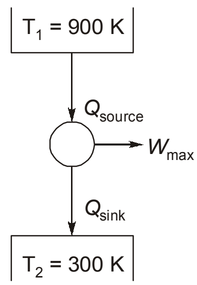
Thermal efficiency of the engine

$$\eta = \frac{\text{Net work done}}{\text{Heat absorbed}} = \frac{50}{1850} = 2.7\%$$

T2 : Solution

[Ans : 5772.72 kJ]

Given: T_1 = 900 K, T_2 = 300 K, m = 50 kg



Final temperature of tank for maximum power production,

$$T_f = \sqrt{T_1 T_2} = \sqrt{900 \times 300} = 519.6\text{K}$$

$$W_{max} = Q_{source} - Q_{sink}$$

$$= mc_v (T_1 - T_f) - mc_v (T_f - T_2)$$

$$= mc_v [T_1 + T_2 - 2T_f]$$

$$= 50 \times 0.718 [900 + 300 - 2 \times 519.6] = 5772.72 \text{ kJ}$$

T3 : Solution

[Ans : 8.65 kJ/K]

The iron block will cool to 285 K from 500 K while the lake temperature remains constant at 285 K.

The entropy change of iron block

$$(\Delta s)_{iron} = \int \frac{mc_v dT}{T} = mc_v \ln\frac{T_2}{T_1}$$

$$= 100 \times 0.45 \times \ln\frac{285}{500}$$

$$= -25.29 \text{ kJ/k}$$

The temperature of the lake water remains constant during this process at 285 K and heat is transferred from iron block to lake water. So entropy change of lake

$$(\Delta s)_{lake} = \frac{Q}{T} = \frac{mc_v (T_2 - T_1)}{T_{lake}}$$

$$= \frac{100 \times 0.45 \times (500 - 285)}{285} = 33.95 \text{ kJ/K}$$

Entropy generated, $(\Delta s)_{gen} = (\Delta s)_{iron} + (\Delta s)_{lake}$

$$= -25.29 + 33.95 = 8.65 \text{ kJ/K}$$

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4 Properties of Pure Substance and Thermodynamic Relation

Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans : 2443.248 kJ/kg]

$$\left(\frac{dP}{dT}\right)_s = 0.189 \text{ kPa/K}$$

Now using Clausius Clapeyron equation,

$$\left(\frac{dP}{dT}\right)_s = \frac{h_{fg}}{T_{sat} v_{fg}} = \frac{h_{fg}}{T_{sat}(v_g - v_f)}$$

$v_g >> v_f$

$$\left(\frac{dP}{dT}\right)_s = \frac{h_{fg}}{T_{sat} \cdot v_g}$$

$$0.189 \times 10^3 = \frac{h_{fg}}{298 \times 43.38}$$

$$h_{fg} = 2443.248 \text{ kJ/kg}$$

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5 Solution Thermodynamics

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$\Delta G = -RT \ln k_{eq}$$
$$-4000 = 8.314 \times 400 \ln k_{eq}$$
$$k_{eq} = 0.3$$

	C_2H_4 +	H_2O $\rightleftharpoons$	C_2H_9OH
Initially	1	1	0
At equilibrium	$1-\epsilon$	$1-\epsilon$	ϵ

Total moles at equilibrium

$$= 1-\epsilon + 1-\epsilon + \epsilon$$
$$= 2-\epsilon$$

$$y_{C_2H_4} = \frac{1-\epsilon}{2-\epsilon} = y_{H_2O},\ y_{C_2H_9OH} = \frac{\epsilon}{2-\epsilon}$$

Now $\quad k_{eq} = k_y\, k_\phi\, k_p$

Where, $\quad k_p = P^{\Sigma v_i} = P^{+1-2} = P^{-1}$

Now,
$$0.3 = \frac{\dfrac{\epsilon}{2-\epsilon}}{\left(\dfrac{1-\epsilon}{2-\epsilon}\right)^2} \times P^{-1}$$

$$\Rightarrow \quad \frac{\epsilon(2-\epsilon)}{(1-\epsilon)^2} \times \frac{1}{3} = 0.3$$

$$\Rightarrow \quad \frac{\epsilon(2-\epsilon)}{(1-\epsilon)^2} - 0.9 = 0$$

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