T6 SOLUTIONS BY WAITZ

a)

	Q	W	PROCESS
LEG 1-2	0	−	ADIABATIC COMPRESSION
LEG 2-3	+	+	CONST. PRESSURE EXPANSION
LEG 3-4	+	+	ISOTHERMAL EXPANSION
LEG 4 1	−	0	CONST VOLUME COOLING

b) LEG 1-2 ADIABATIC COMPRESSION, $pv^{\gamma} = \text{CONSTANT} \Rightarrow \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\gamma/\gamma-1}$

$$\frac{P_2}{P_1} = 20 = \left(\frac{T_2}{300}\right)^{1.4/0.4} \Rightarrow T_2 = 706\,K$$

$$\Delta u = \cancel{q} - w \qquad -w = C_v (T_2 - T_1) \Rightarrow W = -291\,kJ/kg$$

$$\Delta h = C_p (T_2 - T_1) = 1003.5\,(706-300)$$

$$\boxed{W = -291\,kJ/kg,\quad q = 0,\quad \Delta u = 291\,kJ/kg,\quad \Delta h = 407\,\frac{kJ}{kg}}$$

LEG 2-3 CONSTANT PRESSURE EXPANSION, $p = \text{const.}$

$$dh = \delta q + v\cancel{dp}$$

$$\therefore \Delta h = C_p (T_3 - T_2) = q = 1003.5\,(1800 - 706) = 1098\,\frac{kJ}{kg}$$

$$\Delta u = C_v (T_3 - T_2) = 716.5\,(1800 - 706) = 784\,\frac{kJ}{kg}$$

$$\Delta u = q - w \quad \therefore w = q - \Delta u = 1098 - 784 = 314\,\frac{kJ}{kg}$$

$$\boxed{W = 314\,\frac{kJ}{kg},\quad q = 1098\,\frac{kJ}{kg},\quad \Delta u = 784\,\frac{kJ}{kg},\quad \Delta h = 1098\,\frac{kJ}{kg}}$$

LEG 3-4 ISOTHERMAL EXPANSION, $T = \text{const.} \;\therefore \Delta u = 0$

$$\cancel{\Delta u} = q - w \quad \therefore q = w \quad ; \quad W = RT_3 \ln \frac{V_4}{V_3}$$

$$P_3 = 20 \cdot 100 \times 10^3\,Pa,\; P_3 = 2 \times 10^6\,Pa$$

$$T_3 = 1800\,K \qquad V_3 = \frac{RT_3}{P_3} = 0.258\,\frac{m^3}{kg}$$

$$V_4 = V_1 = \frac{RT_1}{P_1} = \frac{287 \cdot 300}{100 \times 10^3} = 0.861\,\frac{m^3}{kg}$$

$$W = 287\,(1800) \ln\left(\frac{0.861}{0.258}\right) = 623\,kJ/kg$$

$$\boxed{W = 623\,\frac{kJ}{kg},\quad q = 623\,\frac{kJ}{kg},\quad \Delta u = 0,\quad \Delta h = 0}$$

LEG 4-1 CONSTANT VOLUME COOLING, $V = \text{const.}$

$du = \delta q - \cancel{\delta w}^{0}$ const volume $\therefore \Delta u = C_V(T_1 - T_4) = q$

$\Delta u = 716.5(300-1800) = -1075 \text{ kJ/kg} = q$

$\Delta h = 1003.5(300-1800) = -1505 \text{ kJ/kg}$

$$\boxed{W=0,\ q = -1075 \frac{\text{kJ}}{\text{kg}},\ \Delta u = -1075 \text{ kJ/kg},\ \Delta h = -1505 \text{ kJ/kg}}$$

c) $\boxed{\text{WORK OF CYCLE} = -291 + 314 + 623 = 646 \text{ kJ/kg}}$

d) $$\eta = \frac{W_{cycle}}{Q_{ADDED}} = \frac{646}{1098 + 623} \boxed{= 0.375}$$

e) IN REVERSE, WORK CYCLE = -646 kJ/kg AND ALL SIGNS ON HEAT ARE REVERSED. SO THE HEAT FLOWS INTO THE SYSTEM (FROM FOOD), HEAT IN WOULD BE $1075 \frac{\text{kJ}}{\text{kg}}$.

SO FOR EACH JOULE OF WORK IN COULD REMOVE $\frac{1075}{646} = 1.66$ J OF HEAT FROM FOOD.