7.11

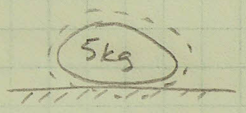
25/25

A system consists of 5 kg of water at 10°C and 1 bar.

Determine the energy in KJ if the system is at rest and zero elevation relative to an energy reference environment for which $T_0 = 20°C$, $p_0 = 1$ bar.

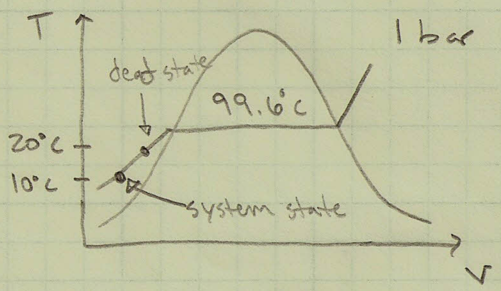
$T = 10°C$

$p = 1$ bar



$T_0 = 20°C$

$P_0 = 1$ bar



$$e = m\left[(u - u_0) + p_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz\right]$$

Table A-2:

$v = v_f(T)$ $\quad$ $v_0 = 1.0018\text{E-}3 \ \frac{m^3}{kg}$ $\quad$ $v = 1.0004\text{E-}3 \ \frac{m^3}{kg}$

$u = u_f(T)$ $\quad$ $u_0 = 83.95 \ \frac{kJ}{kg}$ $\quad$ $u = 42 \ kJ/kg$

$s = s_f(T)$ $\quad$ $s_0 = 0.2966 \ \frac{kJ}{kg \cdot K}$ $\quad$ $s = 0.151 \ kJ/kg$

$$e = 5\,kg\left[(42 - 83.95)\frac{kJ}{kg} + \left(1\,bar\left(\frac{1.0004 - 1.0018}{10^3}\right)\frac{m^3}{kg}\right)\left(\frac{10^5\ \frac{N}{m^2}}{1\,bar}\right)\left(\frac{1\ kJ}{10^3\ N \cdot m}\right) - 293\,K\,(0.1510 - 0.2966)\frac{kJ}{kg \cdot K}\right]$$

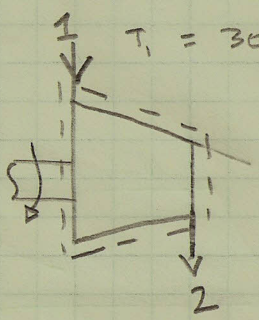
$$= 5\,kg\ (-41.95 - 1.4\text{E-}4 + 42.66)\frac{kJ}{kg}$$

$$\boxed{e = 3.55\ kJ}$$

7.63

Air enters a compressor operating at steady state at $T_1 = 300\,K$, $p_1 = 1$ bar with a velocity of 70 m/s. At the exit, $T_2 = 540\,K$, $p_2 = 5$ bar and the velocity is 150 m/s. The air can be modeled as an ideal gas with $c_p = 10.1$ kJ/kg·K. Stray heat transfer can be ignored.

Determine, in kJ per kg of air flowing
(a) the power required by compressor
(b) the rate of exergy destruction within the compressor.
Let $T_1 = 300\,K$, $p_1 = 1$ bar. Ignore gravity & motion



$T_1 = 300\,K \quad p_1 = 1\text{ bar} \quad V_1 = 70\text{ m/s}$

$T_2 = 540\,K \quad p_2 = 5\text{ bar} \quad V_2 = 150\text{ m/s}$

$c_p = 1.01\text{ kJ/kg·K} \qquad T_0 = 300\,K \qquad p_0 = 1\text{ bar}$

(a) $$0 = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \dot{m}\left[(h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right) + \cancel{g(z_1 - z_2)}\right]$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2}$$

$$= c_p(T_1 - T_2) + \frac{V_1^2 - V_2^2}{2}$$

$$= 1.01\frac{kJ}{kg\cdot K}(-240\,K) + \frac{70^2 - 150^2}{2}\left(\frac{m}{s}\right)^2\left(\frac{1\,N}{1\,kg\cdot\frac{m}{s^2}}\right)\left(\frac{1\,kJ}{10^3\,N\cdot m}\right)$$

$$= -(242.4 + 8.8)\frac{kJ}{kg}$$

$$\boxed{\frac{\dot{W}_{cv}}{\dot{m}} = -251.2\frac{kJ}{kg}}$$

(b) $\dot{e}_d = T_0\dot{\sigma} \qquad \dot{\sigma} = \dot{m}(s_2 - s_1)$

$$\frac{\dot{e}_d}{\dot{m}} = T_0(s_2 - s_1) = T_0\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)$$

$$= 300\,K\left(1.01\frac{kJ}{kg\cdot K}\ln\frac{540\,K}{300\,K} - \frac{8.314}{28.97}\ln\frac{5\text{ bar}}{1\text{ bar}}\right)$$

$$= \boxed{39.5\frac{kJ}{kg}}$$

Pr 3

Refrigerant 22 enters a compressor at steady state at $-5°C$, 3.5 bar and is compressed adiabatically to $75°C$, 14 bar

Calculate (a) First Law (isentropic) efficiency
(b) Second Law (exergic) efficiency

Let $T_0 = 273\ K$ $P_0 = 1$ bar

(a) $\eta_c = \dfrac{h_{2s} - h_1}{h_2 - h_1}$ $h_1 = 249.75\ \frac{kJ}{kg}$ $s_1 = 0.9572\ \frac{kJ}{kg \cdot K}$

$h_2 = ?$ $s_2 = ?$

interpolate @ 75°C, 14 bar

h_2:

x	y
70	290.01
75	h_2
80	298.34

$$h_2 = \frac{(75-70)(298.34 - 290.01)}{(80-70)} + 290.01$$

$$h_2 = 294.18\ \frac{kJ}{kg}$$

s_2:

x	y
70	0.9703
75	s_2
80	0.9942

$$s_2 = \frac{(75-70)(0.9942 - 0.9703)}{(80-70)} + 0.9703$$

$$s_2 = 0.98225\ \frac{kJ}{kg \cdot K}$$

$s_1 = s_{2s} \longrightarrow s_{2s} = 0.9572\ \frac{kJ}{kg \cdot K}$

h_{2s}:

x	y
0.9452	281.53
0.9572	h_{2s}
0.9703	290.01

$$h_{2s} = \frac{(0.9572 - 0.9452)(290.01 - 281.53)}{(0.9703 - 0.9452)} + 281.53$$

$$h_{2s} = 285.58\ \frac{kJ}{kg}$$

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{285.58 - 249.75}{294.175 - 249.75} = 0.8065$$

$\eta_c = 80.7\%$

(b) $$\varepsilon_c = \frac{e_{f_2} - e_{f_1}}{-\frac{\dot{W}_{cv}}{\dot{m}}} = \frac{h_2 - h_1 - T_0(s_2 - s_1)}{h_2 - h_1}$$

$$\varepsilon_c = 1 - \frac{T_0(s_2 - s_1)}{h_2 - h_1} = 1 - \frac{(273\ K)(0.98225 - 0.9572)\ \frac{kJ}{kg \cdot K}}{294.175 - 249.75\ \frac{kJ}{kg}}$$

$\varepsilon_c = 0.846$ = **84.6%**