ME 40 Midterm 2 Solutions

① $T_1 = 20°C$ Working fluid = Helium
$P_1 = 100$ kPa
$T_4 = 1400°C$ $\Delta P_{23} = -120$ kPa $r_p = 14.1$
$T_5 = 700°C$ $\dot{V}_1 = 4.0\ m^3/s$ $\eta_c = 0.91$
$P_5 = 100$ kPa

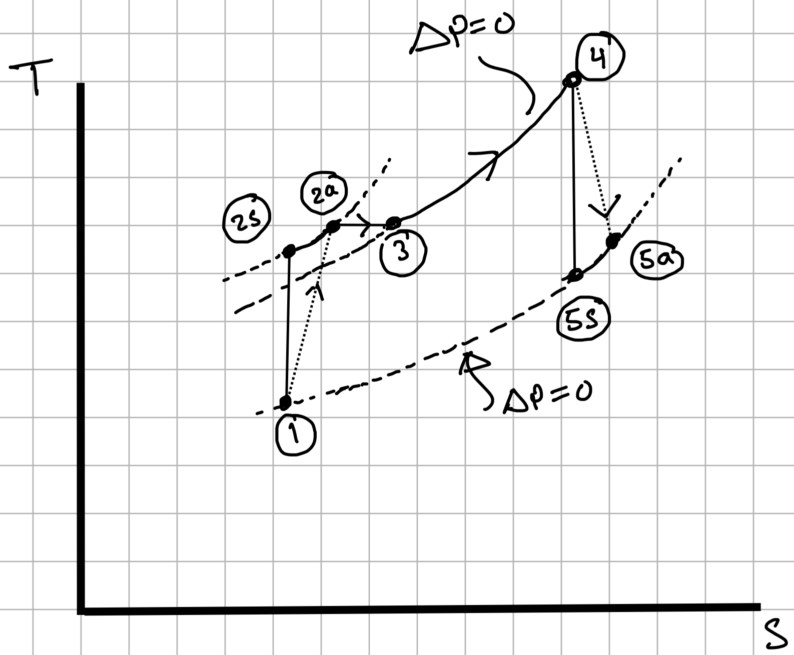


Table A-2: Helium $R = 2.0769$ kJ/kg·K
$C_p = 5.1926$ kJ/kg·K
$k = 1.667$

Find mass flow rate: $\dot{m} = \frac{\dot{V}_1}{v_1}$ Ideal gas Law: $v_1 = \frac{RT_1}{P_1}$

$\dot{m} = \frac{4.0}{6.085} = 0.657$

$v_1 = \frac{(2.0769)(20+273)}{100}$

$v_1 = 6.085\ m^3/kg$

b) Find Isentropic State 2: Use Ideal gas isentropic relations

$$\left(\frac{T_{2s}}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(r_p\right)^{(k-1)/k} \Rightarrow \left(\frac{T_{2s}}{293}\right) = (14.1)^{(1.667-1)/1.667}$$

$\Rightarrow T_{2s} = 844.68$ K

$P_2 = 14.1 P_1 = 1410$ kPa

↳ Find Actual state 2

$$\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1} = \frac{c_p(T_{2s} - T_1)}{c_p(T_{2a} - T_1)} = \frac{844.68 - 293}{T_{2a} - 293} = 0.91$$

$$\boxed{T_{2a} = 899.24\ K}$$

$$\dot{W}_c = \dot{m}(h_{2a} - h_1) = \dot{m} c_p (T_{2a} - T_1)$$

$$= (0.6573)(5.1926)(899.24 - 293)$$

$$\boxed{\dot{W}_c = 2069.16\ \ kW}$$

c) For a throttling valve: $h_3 = h_{2a}$, $P_3 = P_2 - 120 = 1290\ kPa$

↳ $\Delta h = c_p \Delta T \rightarrow \Delta T = 0 \rightarrow \boxed{T_3 = T_{2a} = 899.24\ K}$

d) $\dot{Q}_{in} = \dot{m}(h_4 - h_3) = \dot{m} c_p (T_4 - T_3)$ $\quad T_4 = 1400 + 273 = 1673 K$

$$= (0.6573)(5.1926)(1673 - 899.24)$$

$$\boxed{\dot{Q}_{in} = 2640.9\ kW}$$

e) Find Isentropic state 5: $P_4 = P_3 = 1290\ kPa$

$$\left(\frac{T_{5s}}{T_4}\right) = \left(\frac{P_5}{P_4}\right)^{(k-1)/k} = \left(\frac{100}{1290}\right)^{(1.667-1)/1.667}$$

↳ $T_{5s} = 601.35 K$, $T_{5a} = 973 K$

$$\eta_T = \frac{h_4 - h_{5a}}{h_4 - h_{5s}} = \frac{c_p(T_4 - T_{5a})}{c_p(T_4 - T_{5s})} = \frac{(1673 - 973)}{(1673 - 601.35)} = 0.65$$

$$\boxed{\eta_T = 0.65}$$

f) $\dot{W}_{net} = \dot{W}_T - \dot{W}_c$ $\quad$ $\dot{W}_T = \dot{m}(h_4 - h_{5a}) = \dot{m}c_p(T_4 - T_{5a})$

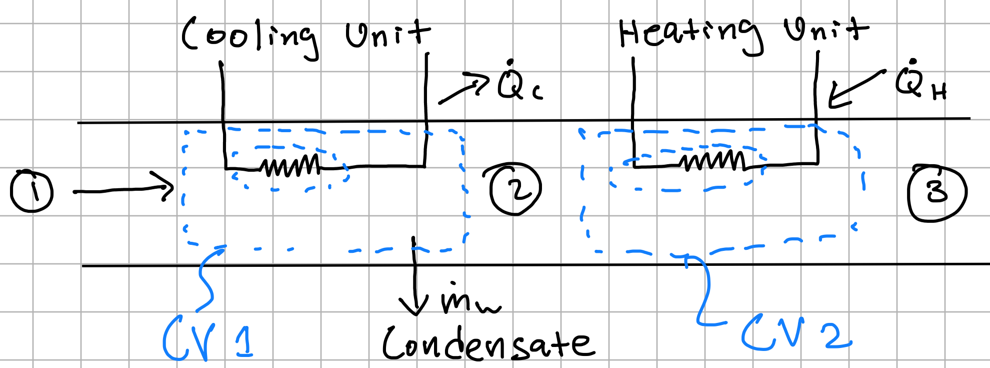
$= 0.6573(5.1926)(1673 - 973)$

$\dot{W}_T = 2389.17\ kW$

$\dot{W}_{net} = 2389.17 - 2069.16 = \boxed{320.01\ kW = \dot{W}_{net}}$

$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{320.01}{2640.9} = 0.121 \rightarrow \boxed{\eta = 12.1\%}$

(2)



$T_{DB,1} = 34°C$ $\quad$ $T_{WB,2} = 6.0°C$ $\quad$ $T_{DB,3} = 21°C$

$\phi_1 = 80\%$

$\dot{V}_1 = 5.0 m^3/min$

a) $\dot{m} = \frac{\dot{V}_1}{v_{da,1}}$ $\quad$ $v_{da,1} = 0.9075$ m^3/kg (approximation from Psych chart)

$$\dot{m} = \frac{5.0/60}{0.9073} = \boxed{0.0918 \ \frac{kg}{s} = \dot{m}}$$

b) To find $\dot{Q}_c$ & $\dot{Q}_H$, set up two control volumes

↳ 1st CV around cooling coil

Mass Conservation: air – $\dot{m}_{da1} = \dot{m}_{da2} = \dot{m}_{da}$

water – $\dot{m}_{da}w_1 = \dot{m}_{da}w_2 + \dot{m}_w$

SSSF: $\dot{m}_{da}h^*_1 = \dot{m}_{da}h^*_2 + \dot{m}_w h_w + \dot{Q}_c$

At Point 2: $\phi = 100\% \rightarrow T_{DB2} = T_{WB2} = 6°C$

↳ $h_w = h_f @ T = 6°C = 25.22$ kJ/kg (Table A-4)

From Psych Chart:

$h^*_1 = 104.5$ kJ/kg $\quad$ $h^*_2 = 20.5$ kJ/kg

$w_1 = 27.3$ g/kg air $\quad$ $w_2 = 5.75$ g/kg air

Water Cons: $(0.0918)(0.0273) = (0.0918)(0.00575) + \dot{m}_w$

↳ $\dot{m}_w = 0.00197$ kg/s

SSSF: $(0.0918)(104.5) = (20.5)(0.0918) + (0.00198)(25.22) + \dot{Q}_c$

↳ $\dot{Q}_c = 7.66$ kW

→ Now set up 2nd Control Volume around the heating coil

Conservation of Mass: air: $\dot{m}_{da2} = \dot{m}_{da3} = \dot{m}_{da}$

Water: $\dot{m}_{da}\omega_2 = \dot{m}_{da}\omega_3 \rightarrow \omega_2 = \omega_3 = 5.75$ g/kg

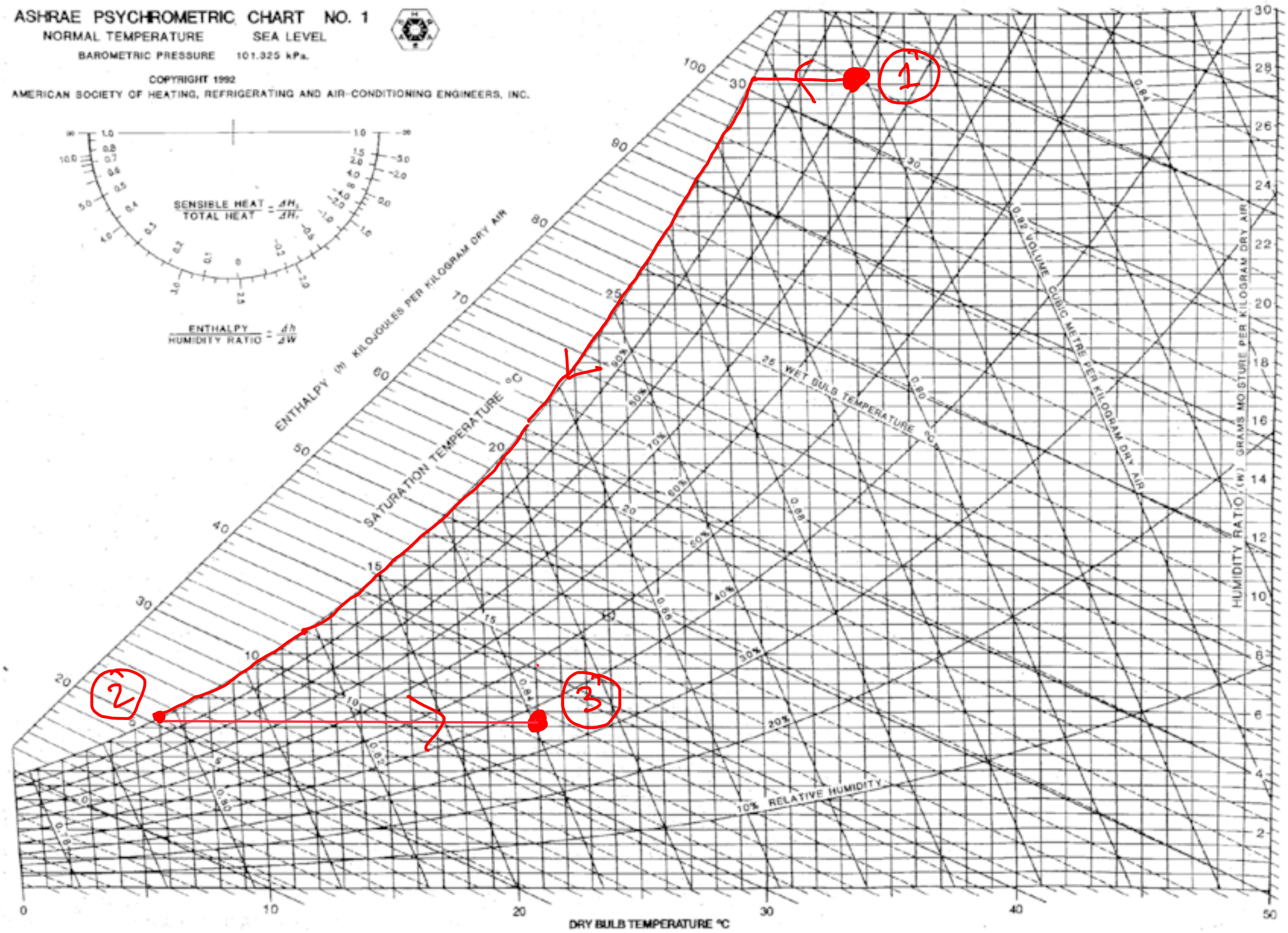
SSSF: $\dot{m}_{da}h^*_2 + \dot{Q}_H = \dot{m}_{da}h^*_3$

↳ $\dot{Q}_H = \dot{m}_{da}(h^*_3 - h^*_2)$

From Psych Chart: $h^*_3 = 36.0$ kJ/kg

↳ $\dot{Q}_H = (0.0918)(36.0 - 20.5) = 1.423 \text{ kW} = \dot{Q}_H$

c) $T_{DB,2} = T_{WB,2} = 6.0°C$


ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa.
COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
1
2
3