EXAM PET 550 — Natural Gas Processing & Transportation

May 10th, 2016

ANSWERS

Ex. 1. a)

I: Const. T ⇒ $dT = 0$

II: $\left(\frac{\partial s}{\partial p}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_p$ (Maxwell-relation)

III: $v = \frac{RT}{p} \Rightarrow \left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{p}$ (ideal gas)

$$\left(\Rightarrow \Delta s^* = \int_{s_1^*}^{s_2^*} ds^* = \int_{p_1}^{p_2} -\frac{R}{p}\, dp = \underline{R \ln \frac{p_1}{p_2}} \right)$$

b) $\Delta s = s_2 - s_1 = (s_1^* - s_1) - (s_2^* - s_2) + (s_2^* - s_1^*)$

$$= -R \ln\left(\frac{v_1 - b}{v_1^*}\right) + R \ln\left(\frac{v_2 - b}{v_2^*}\right) + R \ln\left(\frac{p_1}{p_2}\right)$$

$$= R \cdot \left[\ln\left(\frac{v_1^*}{v_1 - b}\right) + \ln\left(\frac{v_2 - b}{v_2^*}\right) + \ln\left(\frac{p_1}{p_2}\right) \right]$$

$$= R \cdot \ln\left(\underbrace{\frac{RT}{p_1}}_{v_1^*} \cdot \frac{1}{v_1 - b} \cdot (v_2 - b) \cdot \underbrace{\frac{p_2}{RT}}_{1/v_2^*} \cdot \frac{p_1}{p_2} \right) = \underline{\underline{R \ln\left(\frac{v_2 - b}{v_1 - b}\right)}}$$

QED

c) I: $\Delta s = 8.3144 \frac{J}{mol\,K} \cdot \ln\left(\frac{3.898 \cdot 10^{-4} - 4.283 \cdot 10^{-5}}{2.281 \cdot 10^{-3} - 4.283 \cdot 10^{-5}}\right)$

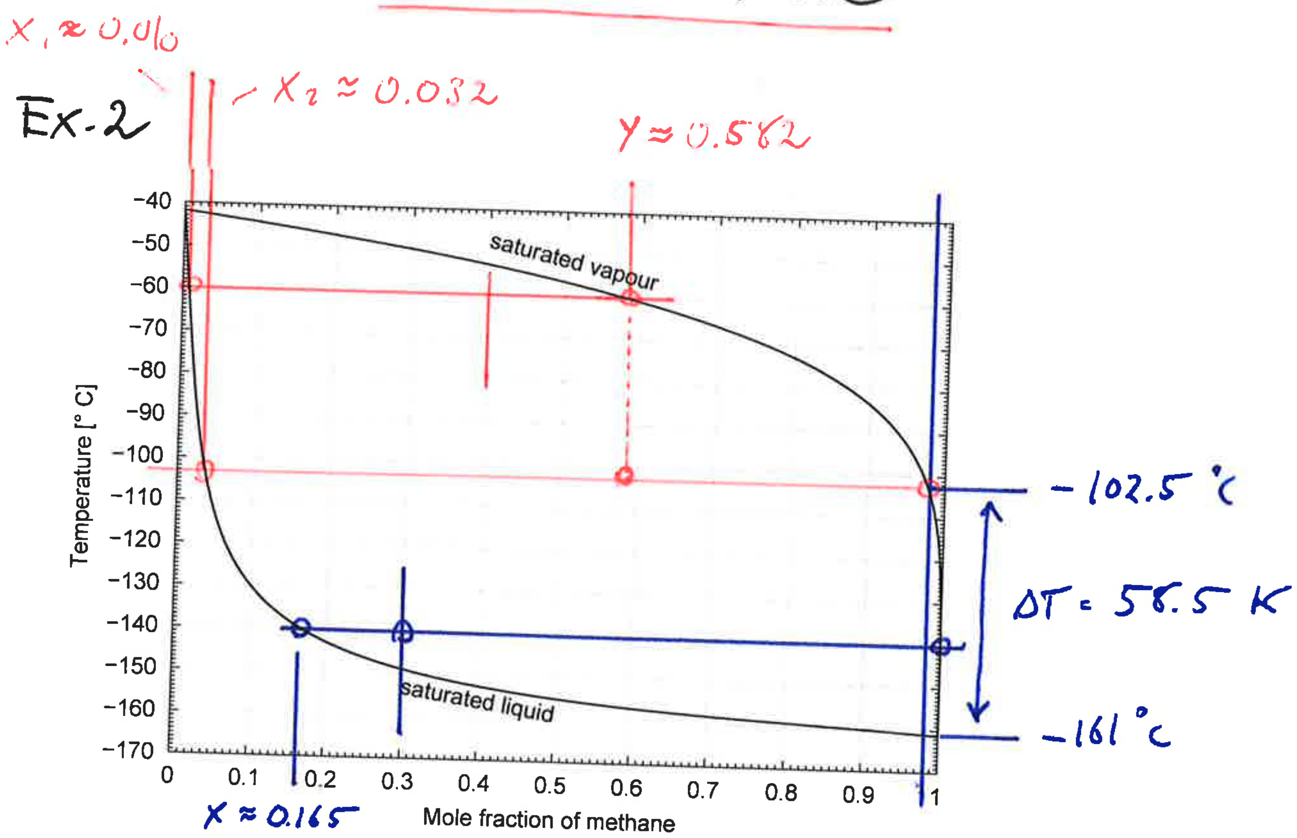
$$= \underline{\underline{-15.5\ J/mol\,K}}$$

II:

Compression usually increases temperature, so heat must leave to compensate for the temp. increase

Entropy is reduced, which requires that heat must leave

Ex-2



a) I: 98% CH_4 : $T_D \approx -102.5\,^\circ C$ → $\Delta T = 58.5\ K$

II: $z = 0.3$, $x \approx 0.165$, $y \approx 1$

$$\Rightarrow z = n^L \cdot x + n^V \cdot y = (1-n^V)x + n^V y$$

$$\Rightarrow n^V = \frac{z - x}{y - x} = \frac{0.3 - 0.165}{1 - 0.165} = 0.162$$

b) I: $y(-60) \approx \underline{\underline{0.582}}$

II: $T = \underline{\underline{-102.5}}$ (The dew point @ $y = 0.98$)

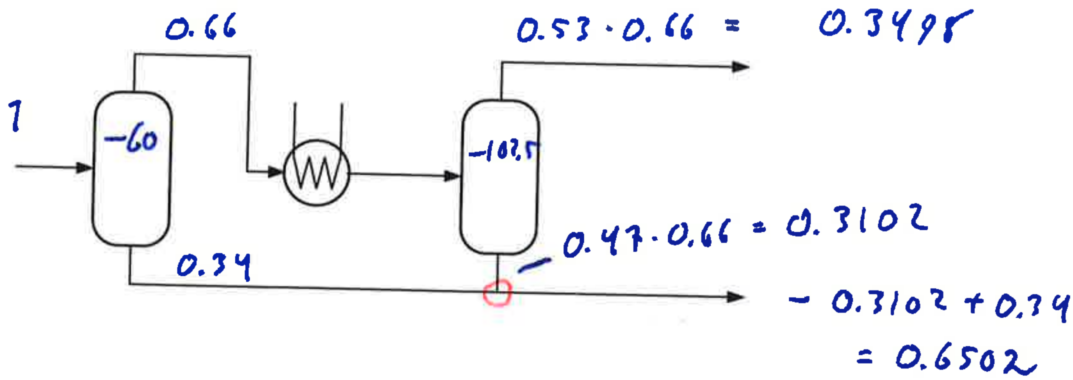
c) Separator @ -60 °C: $n^V = \dfrac{0.4 - 0.01}{0.582 - 0.01} = \underline{0.66}$

$\Rightarrow n^L = 1 - 0.66 = \underline{0.34}$

Separator @ -102.5 °C: $n^V = \dfrac{0.582 - 0.032}{0.98 - 0.032} = \underline{0.53}$

$\Rightarrow n^L = 1 - 0.53 = \underline{0.47}$

At Liquid mixing point:



$0.34 \cdot 0.01 + 0.3102 \cdot 0.032 = 0.6502 \cdot x$

$\Rightarrow \underline{\underline{x \approx 0.02}}$ (2% CH_4 = 98% C_3H_8, appr. same purity as for CH_4)

Ex. 3 a) Need R on mass basis:

$$\overline{R} = \frac{R}{M_w} = \frac{R}{\gamma_g \cdot M_{wa}} = \frac{8.3144 \ J/mole\ K}{0.67 \cdot 29 \ g/mole}$$

$$= 0.4279 \frac{J}{g\,K} = 427.9 \frac{J}{kg\,K}$$

$$w_{is} = 427.9 \frac{J}{kg\,K} \cdot \underbrace{(50+273.15)}_{323.15} K \cdot \frac{1.6}{0.6} \cdot \left[\left(\frac{393}{170} \right)^{\frac{0.6}{1.6}} - 1 \right]$$

$$= 136151 \frac{J}{kg} = \underline{\underline{136.2 \frac{kJ}{kg}}}$$

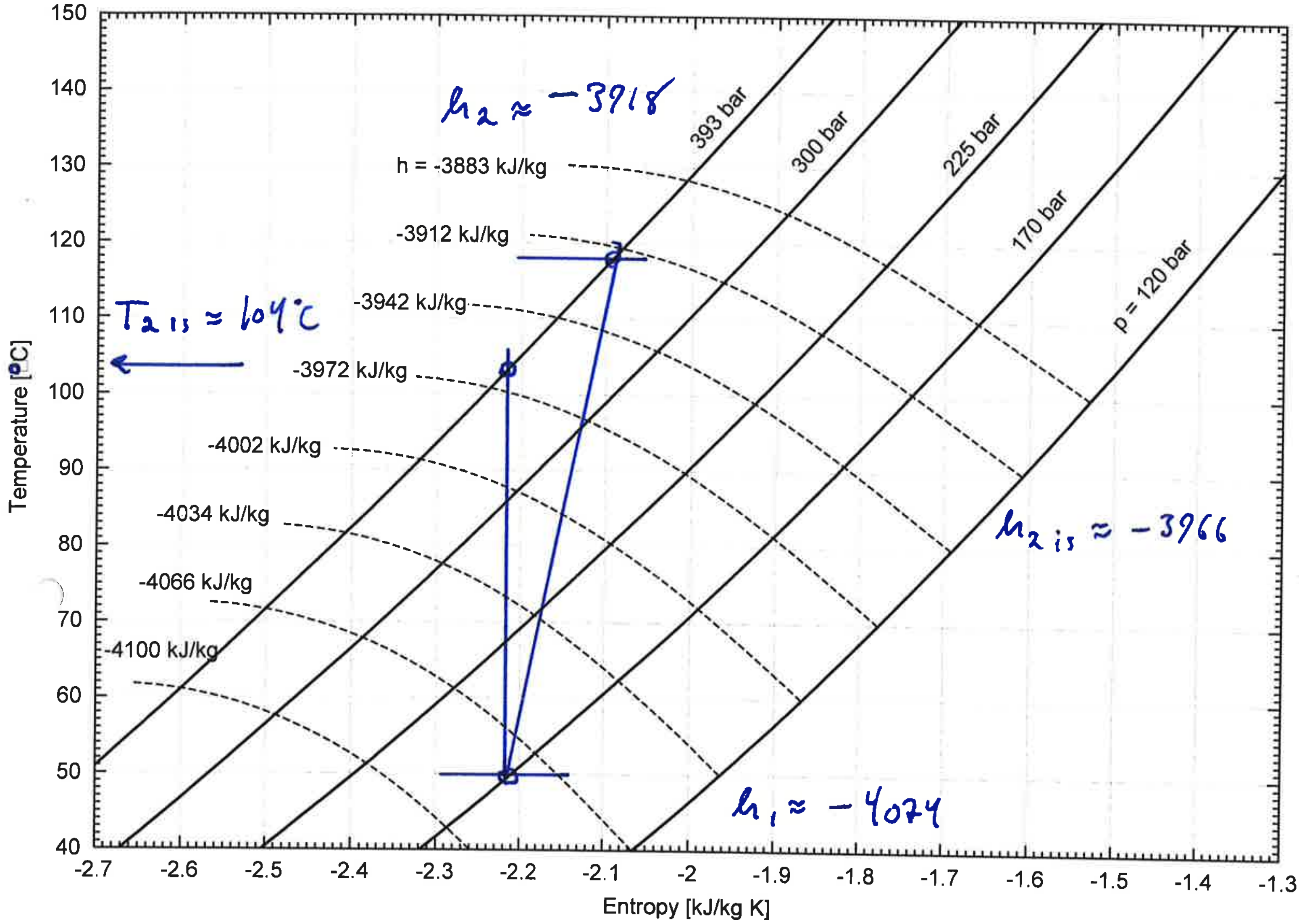
$$T_{2,is} = 323.15 \cdot \left(\frac{393}{170} \right)^{\frac{0.6}{1.6}} = 442.5\ K = \underline{\underline{169.3\ °C}}$$

b) $$w_{is} = h_{2\,is} - h_1 = -3966 - (-4074) = \underline{\underline{108\ kJ/kg}}$$

$$T_{2\,is} = \underline{\underline{104\ °C}}$$

c) $T_2 = 118\ °C \Rightarrow h_2 = -3918\ kJ/kg$

$$\rightarrow \eta_{is} = \frac{\Delta h_{is}}{\Delta h} = \frac{108}{\underbrace{-3918-(-4074)}_{w\ =\ \underline{\underline{156\ kJ/kg}}}} = \underline{\underline{0.69}}$$



Ex.4 a) I: $p = 1.013$ bar $\Rightarrow$ $T \approx -42°C$

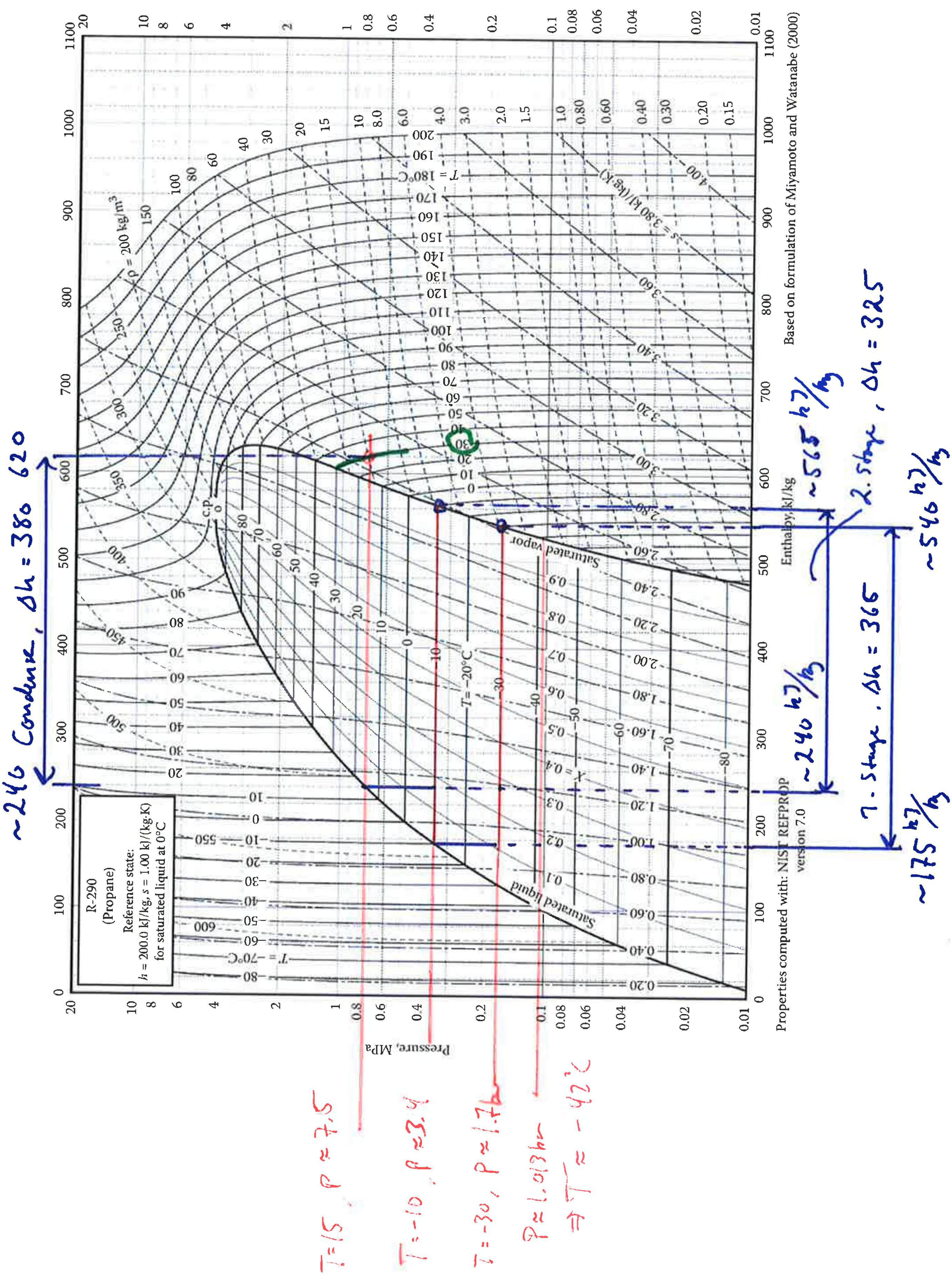
II: $T = -30°C$ $\Rightarrow$ $p_1 \approx 1.7$ bar

$T = -10°C$ $\Rightarrow$ $p_2 \approx 3.4$ bar

$\rightarrow R = \frac{p_2}{p_1} = \frac{3.4}{1.7} = 2.0$

III: $T = +15°C$ $\Rightarrow$ $p_c \approx 7.5$ bar

Attachment 3: log$p$-h diagram for propane (for Exercise 4)



b) The propane refrigerant is assumed to be saturated liquid before the JT-valves:

1st stage: $h_{in} = 175\ \text{kJ/kg}$, $h_{out} = 540\ \text{kJ/kg}$

2nd stage: $h_{in} = 240\ \text{kJ/kg}$, $h_{out} = 565\ \text{kJ/kg}$

$\rightarrow \Delta h_1 = 540 - 175 = 365\ \text{kJ/kg}$

$\Delta h_2 = 565 - 240 = 325$ "

$\Rightarrow \dot{Q}_0 = \dot{m}\,\Delta h \quad \rightarrow \quad \dot{m}_1 = \dfrac{20.000\ \text{kW}}{365\ \text{kJ/kg}} = \underline{54.8\ \text{kg/s}}$

↙ mass evaporated

$\dot{m}_2 = \dfrac{20.000\ \text{kW}}{325\ \text{kJ/kg}} = \underline{61.5\ \text{kg/s}}$

Compr. 1: $\dot{m} = \dot{m}_1 = \underline{\underline{54.8\ \text{kg/s}}}$

Compr. 2: $\dot{m} = \dot{m}_1 + \dot{m}_2 = \underline{\underline{116.3\ \text{kg/s}}}$

c) Condenser: $h_{in} = 620\ \text{kJ/kg}$, $h_{out} = 240\ \text{kJ/kg}$

$\rightarrow \Delta h = 620 - 240 = 380\ \text{kJ/kg}$

$\dot{Q}_C = \dot{m} \cdot \Delta h = 116.3\ \text{kg/s} \cdot 380\ \text{kJ/kg} = \underline{\underline{44.194\ \text{kW}}}$

($\dot{m}$ from Compr. 2)