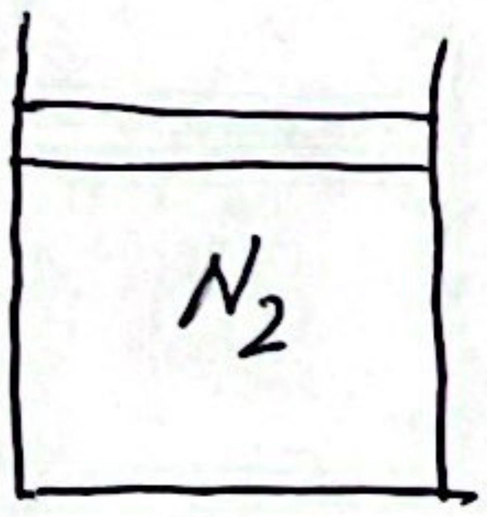
Review Problems for Final Exam

1- A quantity of nitrogen gas in a piston–cylinder assembly undergoes a process at a constant pressure of 80 bar from 220 to 300 K. Determine the work and heat transfer for the process, each in kJ per kmol of nitrogen.



$P = const$
$P_1 = P_2 = 80 bar$
$T_1 = 220K$, $T_2 = 300K$

$$W_{1-2} = \int_{V_1}^{V_2} P\,dV$$

$$W_{1-2}/n = \int_{\bar{v}_1}^{\bar{v}_2} P\,d\bar{v} = P(\bar{v}_2 - \bar{v}_1) = Z_2\bar{R}T_2 - Z_1\bar{R}T_1$$

$$P\bar{v} = Z\bar{R}T$$

$$P_{r_1} = P_{r_2} = \frac{P}{P_c} = \frac{80}{33.9} = 2.36$$

$$T_{r_1} = \frac{T_1}{T_c} = \frac{220}{126} = 1.75, \quad T_{r_2} = \frac{T_2}{T_c} = \frac{300}{126} = 2.38$$

From Fig A.2 $\Rightarrow Z_1 = 0.91$, $Z_2 = 0.99$

$$W_{1-2}/n = (0.99 \times 300 - 0.91 \times 220) \times 8.3144 = 805 \ kJ/kmol$$

$$Q_{1-2} - W_{1-2} = \Delta U \Rightarrow Q_{1-2}/n - W_{1-2}/n = \bar{u}_2 - \bar{u}_1$$

$$u = h - pv \Rightarrow \bar{u}_2 - \bar{u}_1 = (\bar{h}_2 - \bar{h}_1) - (P_2\bar{v}_2 - P_1\bar{v}_1)$$

$$\bar{u}_2 - \bar{u}_1 = \underline{(\bar{h}_2 - \bar{h}_2^*)} + (\bar{h}_2^* - \bar{h}_1^*) + \underline{(\bar{h}_1^* - \bar{h}_1)} - (Z_2\bar{R}T_2 - Z_1\bar{R}T_1)$$

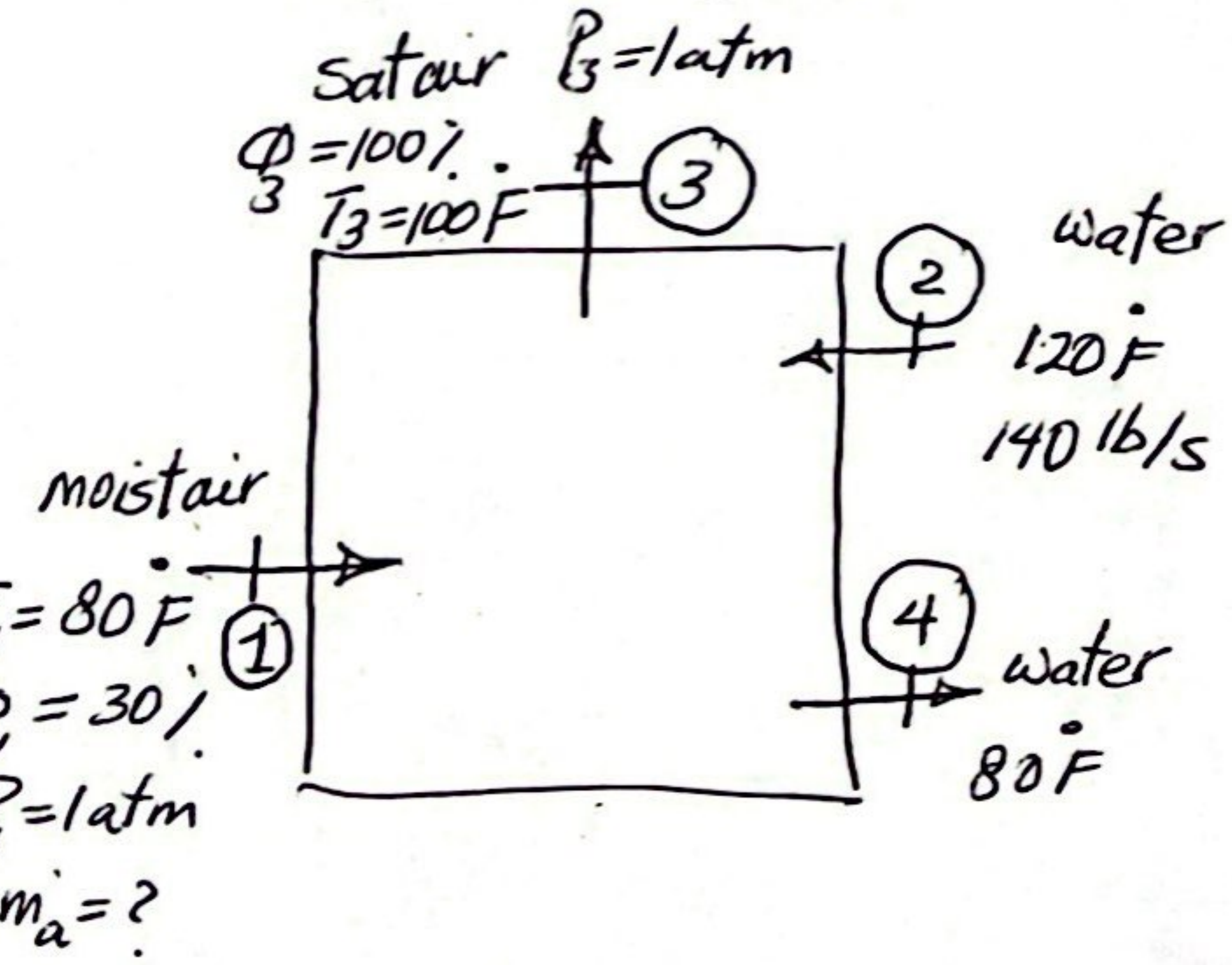
From Fig A.4 $\Rightarrow$ $\dfrac{\bar{h}_1^* - \bar{h}_1}{\bar{R}T_c} = 0.86 \Rightarrow \bar{h}_1^* - \bar{h}_1 = 0.86 \times 8.314 \times 126 = 901.0 \ kJ/kmol$

$\dfrac{\bar{h}_2^* - \bar{h}_2}{\bar{R}T_c} = 0.43 \Rightarrow \bar{h}_2^* - \bar{h}_2 = 0.43 \times 8.314 \times 126 = 405.5 \ kJ/kmol$

$$Q_{1-2}/n = 805 + (-405.5) + (8723 - 6391) + (901.0) - 8.314(0.99 \times 300 - 0.91 \times 220)$$

$$= 2844 \ kJ/kmol$$

2-Liquid water at 120°F enters a cooling tower operating at steady state with a mass flow rate of 140 lb/s. Atmospheric air enters at 80°F, 1 atm, 30% relative humidity. Saturated air exits at 100°F, 1 atm. Makeup water is not provided. Determine the mass flow rate of dry air required, in lb/h, if cooled water exits the tower at (a) 80°F and (b) 60°F. Ignore kinetic and potential energy effects.



$$\dot m_{a_1} = \dot m_{a_3} = \dot m_a$$

$$\dot m_{v_1} + \dot m_{w_2} = \dot m_{v_3} + \dot m_{w_4}$$

$$\cancel{\dot Q_{c.v}}^{\,0} + \dot m_a h_{a_1} + \dot m_{v_1} h_{v_1} + \dot m_{w_2} h_{w_2} = \dot m_{a_3} h_{a_3} + \dot m_{v_3} h_{v_3} + \dot m_{w_4} h_{w_4}$$

$$\dot m_a \omega_1 + \dot m_{w_2} = \dot m_a \omega_3 + \dot m_{w_4}$$

$$\dot m_{w_4} = \dot m_{w_2} + \dot m_a(\omega_1 - \omega_3)$$

$$\dot m_a h_{a_1} + \dot m_a \omega_1 h_{v_1} + \dot m_{w_2} h_{w_2} = \dot m_a h_{a_3} + \dot m_a \omega_3 h_{v_3} + \left[\dot m_{w_2} + \dot m_a(\omega_1 - \omega_3)\right] h_{w_4}$$

$$\dot m_a = \frac{\dot m_{w_2}(h_{w_2} - h_{w_4})}{\underbrace{(h_{a_3} - h_{a_1})}_{c_p(T_3 - T_1)} + (\omega_3 h_{v_3} - \omega_1 h_{v_1}) + (\omega_1 - \omega_3) h_{w_4}} \qquad 1$$

$$\varphi_1 = \frac{P_{v_1}}{P_{g_1}} \Rightarrow P_{v_1} = \varphi_1 \times P_{sat\,at\,80F} = 0.3 \times (0.5073) = 0.15219\ Psi$$

$$\omega_1 = 0.622 \frac{P_{v_1}}{P - P_{v_1}} = 0.622 \frac{0.15219}{14.7 - 0.15219} = 0.0065 \frac{lb\ of\ H_2O}{lb\ of\ dry\ air}$$

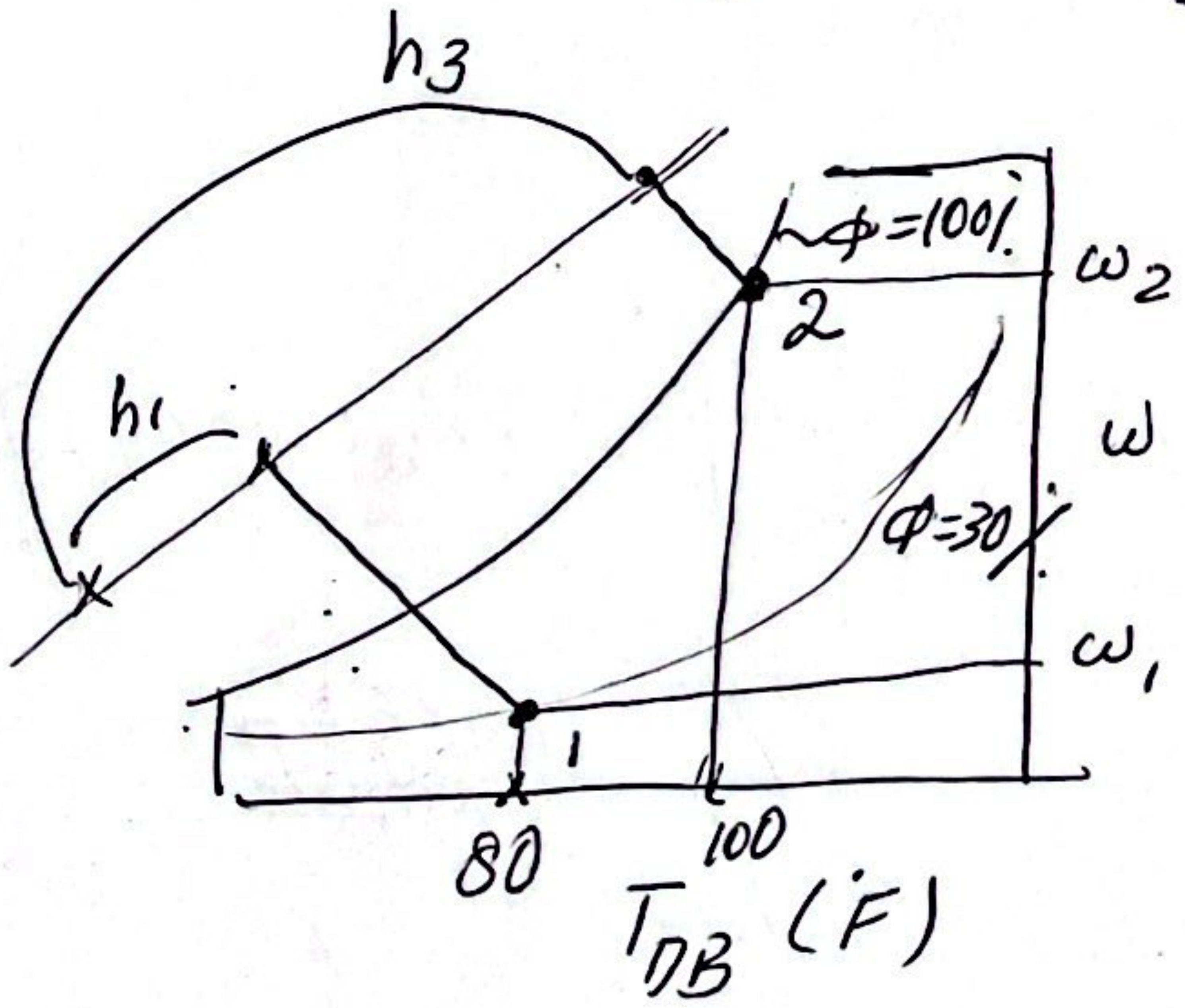
$$\varphi_3 = \frac{P_{v_3}}{P_{g_3}} \Rightarrow P_{v_3} = \varphi_3 \times P_{sat\,at\,100F} = 1 \times 0.9503 = 0.9503\ Psi$$

$$\omega_3 = 0.622 \frac{P_{v_3}}{P - P_{v_3}} = 0.622 \frac{0.9503}{14.7 - 0.9503} = 0.0430 \frac{lb\ of\ H_2O}{lb\ of\ dry\ air}$$

$$① \rightarrow \dot{m}_a = \frac{140(88-48.08)}{0.24(100-80)+0.0430\times(1105)-0.0065(1096.4)+(0.0065-0.0430)\times 48.08}$$

$$= 128.675\ lb/s\left(\frac{3600s}{1h}\right) = 4.63\times 10^{5}\ lb/h$$

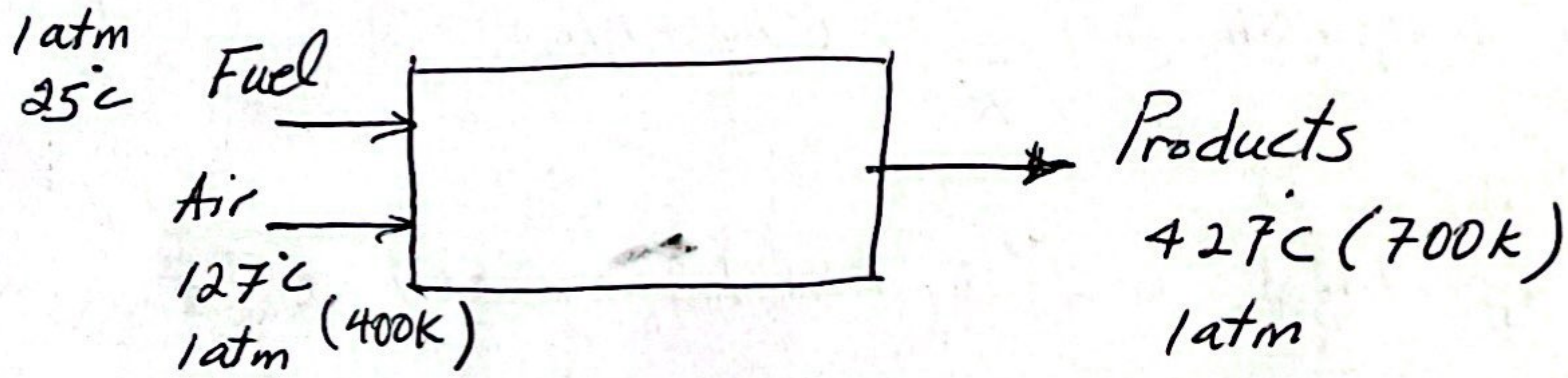
$$① \rightarrow \dot{m}_a = \frac{\dot{m}_{w_2}(h_{w_4}-h_{w_2})}{\underbrace{(h_{a_1}+\omega_1 h_{v_1})}_{h_1}-\underbrace{(h_{a_3}+\omega_3 h_{v_3})}_{h_3}-(\omega_1-\omega_3)h_{w_4}}$$



3- Methane gas (CH4) at 25°C, 1 atm and a volumetric flow rate of 27 m^3/h enters a heat-treating furnace operating at steady state. The methane burns completely with 140% of theoretical air entering at 127°C, 1 atm. Products of combustion exit at 427°C, 1 atm. Determine

a. the volumetric flow rate of the air, in m^3/h.

b. the rate of heat transfer from the furnace, in kJ/h.



$$v_a = \frac{RT}{P} = \frac{0.287 \times (127+273)}{101.325} = 1.133\ m^3/kg$$

$$\dot{n}_{air} = \frac{\dot{m}}{M} = \frac{(AV/v)}{M} = \frac{AV}{\bar{v}}$$

$$(AV)_{air} = \dot{n}_{air} \times \bar{v} = \dot{n}_{air} \times \frac{\bar{R}T}{P}$$

$$R_{CH_4} = \frac{\bar{R}}{M} = \frac{8.3144}{16.04} = 0.5183$$

$$v_f = \frac{RT}{P} = \frac{0.5183 \times 298}{101.325} = 1.5245\ m^3/kg$$

$$\dot{n}_f = \frac{\dot{m}_f}{M} = \frac{27\ m^3/h \,/\, 1.5245\ m^3/kg}{16.04\ kg/kmol} = 1.104\ \frac{kmol\ CH_4}{h}$$

$$CH_4 + 2(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 7.52N_2$$

$$CH_4 + 2\times1.4(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 0.8O_2 + 10.528N_2$$

$$\dot{n}_{air} = 1.104 \times 2.8 \times 4.76 = 14.714\ kmol/h$$

$$\overline{AF} = \frac{\dot{n}_a}{\dot{n}_f} \Rightarrow \dot{n}_{air} = \dot{n}_f \times \overline{AF} = 1.104 \times \frac{2\times1.4\times4.76}{1} = 14.714\ \frac{kmol}{h}$$

$$(AV)_{air} = 14.717 \times \frac{8.3144 \times 400}{101.325} = 483 \ m^3/h .$$

$$PV = n\bar{R}T \Rightarrow P(AV) = \dot{n}\bar{R}T \Rightarrow (AV)_{air} = \frac{\dot{n}_{air}\bar{R}T}{P}$$

$$\frac{\dot{Q}_{c.v}}{\dot{n}_{CH4}} = \bar{h}_P - \bar{h}_R$$

$$= \sum_P n_e(\bar{h}_f + \Delta\bar{h})_e - \sum_R n_i(\bar{h}_f + \Delta\bar{h})_i$$

$$= \Big[(\bar{h}_f + \Delta\bar{h})_{CO_2} + 2(\bar{h}_f + \Delta\bar{h})_{H_2O} + 0.8(\cancelto{0}{\bar{h}_f} + \Delta\bar{h})_{O_2}$$

$$+ 10.528(\cancelto{0}{\bar{h}_f} + \Delta\bar{h})_{N_2}\Big]_P - \Big[1\times(\bar{h}_f + \cancelto{0}{\Delta\bar{h}})_{CH_4} + 2.8(\cancelto{0}{\bar{h}_f} + \Delta\bar{h})_{O_2}$$

$$+ 10.528(\cancelto{0}{\bar{h}_f} + \Delta\bar{h})_{N_2}\Big]_R$$

$$\frac{\dot{Q}_{c.v}}{\dot{n}_{CH4}} = \Big[(-393520) + (27125 - 9364)\Big]_{CO_2} + 2\Big[-241820 + (24088 - 9904)\Big]_{H_2O}$$

$$+ 0.8(21184 - 8682)_{O_2} + 10.528(20604 - 8669)_{N_2}$$

$$- 1(-74850)_{CH_4} - 2.8(11711 - 8682)_{O_2} - 10.528(11640 - 8669)_{N_2}$$

$$= -670297.62 \ kJ/kmol \text{ of } CH_4$$

$$\dot{Q}_{c.v} = -670297.62 \times 1.104$$

$$= -740008.6 \ kJ/h$$