
D R E X E L U N I V E R S I T Y
Department of Chemical and Biological Engineering
CHE 230 – Chemical Engineering Thermodynamics I
Winter 2024-2025 (202425)
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S O L U T I O N S

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1. (17 pts)

Superheated steam at 3 MPa and 348.0°C is to be converted to saturated steam at 3 MPa in a desuperheater. This desuperheater is supplied with inlet liquid water at 50.0°C. The unit should produce saturated steam at a rate of 34.0 kg s⁻¹. Assuming adiabatic operation, and assuming the liquid inlet is saturated, what is the mass flowrate of the inlet water?

The following enthalpies will be useful:

Superheated steam at 348.0°C and 3 MPa: $\hat{H} = 3,105.83$ kJ/kg;

Saturated liquid water at 50.0°C: $\hat{H}^L = 209.33$ kJ/kg; and

Saturated water vapor at 3 MPa: $\hat{H}^V = 2,803.63$ kJ/kg.

SOLUTION

Let stream 1 be the liquid water stream, which we assume is saturated liquid, stream 2 be the superheated steam inlet, and stream 3 be the saturated steam outlet. Hence, $\dot{m}_3 = 15$ kg s⁻¹ as given. The mass and energy balance yield the two unknowns \dot{m}_1 and \dot{m}_2 :

$$\begin{aligned}\dot{m}_1 + \dot{m}_2 &= \dot{m}_3 \\ \dot{m}_1 \hat{H}_1 + \dot{m}_2 \hat{H}_2 &= \dot{m}_3 \hat{H}_3\end{aligned}$$

Solving these two simultaneously yields

$$\begin{aligned}\dot{m}_1 &= \dot{m}_3 \left(\frac{\hat{H}_2 - \hat{H}_3}{\hat{H}_2 - \hat{H}_1} \right) \\ &= (15) \left(\frac{3,105.83 - 2,803.63}{3,105.83 - 209.33} \right) = \boxed{3.55 \text{ kg s}^{-1}}.\end{aligned}$$

2. (21 pts)

A stream of air at 14 bar and 1000 K (labeled “stream 1”) is to be cooled to 600 K by mixing with another stream of air at 12 bar and 400 K (labeled “stream 2”). Let α be the ratio of the molar flow rate of the hotter stream to that of the cooler stream. Compute (1) α , and (2) the pressure P of the mixed stream (labeled “stream 3”). You may assume this is carried out adiabatically and that air is an ideal gas for which $C_P = \frac{7}{2}R$.

It may be helpful for you to remember, **for the ideal gas**, that a change of state from (T_A, P_A) to (T_B, P_B) results in the following enthalpy and entropy changes, respectively:

$$\Delta H \equiv H_B - H_A = \int_{T_A}^{T_B} C_P dT$$
$$\Delta S \equiv S_B - S_A = \int_{T_A}^{T_B} \frac{C_P}{T} dT - R \ln \frac{P_B}{P_A}.$$

SOLUTION

Let \dot{n} be the unknown molar flow rate of stream 1. This means the outlet stream (3) has a flow rate of $\alpha\dot{n}$. An energy balance here resolves to

$$\begin{aligned} H_{\text{out}} &= H_{\text{in}} \\ (1 + \alpha)\dot{n}H(T_3, P_3) &= \dot{n}H(T_1, P_1) + \alpha\dot{n}H(T_2, P_2) \\ (1 + \alpha) \int_{T_r}^{T_3} C_P dT &= \int_{T_r}^{T_1} C_P dT + \alpha \int_{T_r}^{T_2} C_P dT \\ (1 + \alpha)C_P(T_3 - T_r) &= C_P(T_1 - T_r) + \alpha C_P(T_2 - T_r) \\ (1 + \alpha)T_3 &= T_1 + \alpha T_2 \\ \Rightarrow T_3 &= \frac{T_1 + \alpha T_2}{1 + \alpha}, \text{ or} \\ \alpha &= \frac{T_1 - T_3}{T_3 - T_2} \\ &= \frac{900 - 500}{500 - 400} = \frac{400}{100} = \boxed{2.0}. \end{aligned}$$

(Note all terms involving T_r cancel and C_P divides out.). We can get P_3 from an

entropy balance:

$$\begin{aligned}S_{\text{out}} &= S_{\text{in}} \\(1 + \alpha)\dot{n}(T_3, P_3) &= \dot{n}(T_1, P_1) + \alpha\dot{n}(T_2, P_2) \\(T_3, P_3) - (T_1, P_1) + \alpha[(T_3, P_3) - (T_2, P_2)] &= 0 \\C_P \ln \frac{T_3}{T_1} - R \ln \frac{P_3}{P_1} + \alpha \left[C_P \ln \frac{T_3}{T_2} - R \ln \frac{P_3}{P_2} \right] &= 0 \\C_P \ln \left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right) - R \ln \left(\frac{P_3^{1+\alpha}}{P_1 P_2^\alpha} \right) &= 0 \\\ln \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right)^{\frac{C_P}{R}} \right] &= \ln \left(\frac{P_3^{1+\alpha}}{P_1 P_2^\alpha} \right) \\\Rightarrow P_3 &= \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right)^{\frac{C_P}{R}} P_1 P_2^\alpha \right]^{\frac{1}{1+\alpha}} \\&= \left[\left(\frac{(600)^{(1+2.00)}}{(1000)(400)^{2.00}} \right)^{\frac{7}{2}} (14)(12)^{2.00} \right]^{\frac{1}{1+2.00}} \\&= \boxed{17.93 \text{ bar}}.\end{aligned}$$

3. (19 pts) True/False questions. Write “T” for “True” or “F” for “False” in the blank space.

T A bear shits in the woods. Of course it does.

F The pope is Freewill Southern Baptist. No, the pope is Catholic.

T The sky is blue. Of course it is.

F Entropy is delicious. You can't taste entropy.

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