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 4 MPa and 349.0°C is to be converted to saturated steam at 3 MPa in a desuperheater. This desuperheater is supplied with inlet liquid water at 52.0°C. The unit should produce saturated steam at a rate of 13.0 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 349.0°C and 4 MPa: $\hat{H} = 3{,}099.15$ kJ/kg;

   Saturated liquid water at 52.0°C: $\hat{H}^{\mathrm{L}} = 217.69$ kJ/kg; and

   Saturated water vapor at 3 MPa: $\hat{H}^{\mathrm{V}} = 2{,}803.60$ 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 $\dot{m}_2$:

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$
$$\dot{m}_1\hat{H}_1 + \dot{m}_2\hat{H}_2 = \dot{m}_3\hat{H}_3$$

   Solving these two simultaneously yields

$$\begin{aligned}\dot{m}_1 &= \dot{m}_3\left(\frac{\hat{H}_2 - \hat{H}_3}{\hat{H}_2 - \hat{H}_1}\right)\\ &= (15)\left(\frac{3,099.15 - 2,803.60}{3,099.15 - 217.69}\right) = \boxed{1.33\text{ kg s}^{-1}}.\end{aligned}$$

2. (21 pts)

A stream of air at 13.12 bar and 950 K (labeled "stream 1") is to be cooled to 700 K by mixing with another stream of air at 10.26 bar and 350 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 $C_\mathrm{P} = 7R$.

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:

$$\Delta \underline{H} \equiv \underline{H}_B - \underline{H}_A = \int_{T_A}^{T_B} C_\mathrm{P} dT$$
$$\Delta \underline{S} \equiv \underline{S}_B - \underline{S}_A = \int_{T_A}^{T_B} \frac{C_\mathrm{P}}{T} dT - R \ln \frac{P_B}{P_A}.$$

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

$$\begin{aligned}
H_\mathrm{out} &= H_\mathrm{in} \\
(1+\alpha)\dot{n}\underline{H}(T_3, P_3) &= \dot{n}\underline{H}(T_1, P_1) + \alpha\dot{n}\underline{H}(T_2, P_2) \\
(1+\alpha)\int_{T_r}^{T_3} C_\mathrm{P} dT &= \int_{T_r}^{T_1} C_\mathrm{P} dT + \alpha \int_{T_r}^{T_2} C_\mathrm{P} dT \\
(1+\alpha)C_\mathrm{P}(T_3 - T_r) &= C_\mathrm{P}(T_1 - T_r) + \alpha C_\mathrm{P}(T_2 - T_r) \\
(1+\alpha)T_3 &= T_1 + \alpha T_2 \\
\Rightarrow T_3 &= \frac{T_1 + \alpha T_2}{1+\alpha}, \text{ or} \\
\alpha &= \frac{T_1 - T_3}{T_3 - T_2} \\
&= \frac{900 - 500}{500 - 400} = \frac{400}{100} = \boxed{0.7}.
\end{aligned}$$

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

$$
\begin{aligned}
S_{\text{out}} &= S_{\text{in}} \\
(1+\alpha)\dot{n}_{(}T_3, P_3) &= \dot{n}_{(}T_1, P_1) + \alpha\dot{n}_{(}T_2, P_2) \\
{}_{(}T_3, P_3) -_{(}\, T_1, P_1) + \alpha\left[{}_{(}T_3, P_3) -_{(}\, T_2, P_2)\right] &= 0 \\
C_{\text{P}} \ln\frac{T_3}{T_1} - R\ln\frac{P_3}{P_1} + \alpha\left[C_{\text{P}}\ln\frac{T_3}{T_2} - R\ln\frac{P_3}{P_2}\right] &= 0 \\
C_{\text{P}} \ln\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right) - R\ln\left(\frac{P_3^{1+\alpha}}{P_1 P_2^{\alpha}}\right) &= 0 \\
\ln\left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right)^{\frac{C_{\text{P}}}{R}}\right] &= \ln\left(\frac{P_3^{1+\alpha}}{P_1 P_2^{\alpha}}\right) \\
\Rightarrow\ P_3 &= \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right)^{\frac{C_{\text{P}}}{R}} P_1 P_2^{\alpha}\right]^{\frac{1}{1+\alpha}} \\
&= \left[\left(\frac{(700)^{(1+0.71)}}{(950)(350)^{0.71}}\right)^{7} (13.12)(10.26)^{0.71}\right]^{\frac{1}{1+0.71}} \\
&= \boxed{25.70 \text{ bar}}.
\end{aligned}
$$

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

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

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

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

   T The sky is blue. Of course it is.

This is an example tail named example_tail-95002171.tex.

Answers are compiled in solutions-95002171.yaml.