Drexel University
Department of Chemical and Biological Engineering
CHE 230 – Chemical Engineering Thermodynamics I
Winter 2024-2025 (202425)
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Midterm Exam – February 11, 2025

S O L U T I O N S

This is an example header named `example_head-33246253.tex`.

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 53.0°C. The unit should produce saturated steam at a rate of 42.0 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: $\hat{H} = 3{,}110.43$ kJ/kg;

   Saturated liquid water at 53.0°C: $\hat{H}^{\mathrm{L}} = 221.87$ kJ/kg; and

   Saturated water vapor at 3 MPa: $\hat{H}^{\mathrm{V}} = 2{,}803.80$ 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

$$\begin{aligned}\dot{m}_1 &= \dot{m}_3\left(\frac{\hat{H}_2 - \hat{H}_3}{\hat{H}_2 - \hat{H}_1}\right)\\ &= (15)\left(\frac{3,110.43 - 2,803.80}{3,110.43 - 221.87}\right) = \boxed{4.46 \text{ kg s}^{-1}}.\end{aligned}$$

2. (21 pts)

A stream of air at 14.14 bar and 1000 K (labeled "stream 1") is to be cooled to 600 K by mixing with another stream of air at 10.08 bar and 450 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 $C_\mathrm{P} = \frac{15}{2}R$.

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:

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

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

$$\begin{aligned}
H_\mathrm{out} &= H_\mathrm{in} \\
(1+\alpha)\dot{n}\underline{H}(T_3, P_3) &= \dot{n}\underline{H}(T_1, P_1) + \alpha\dot{n}\underline{H}(T_2, P_2) \\
(1+\alpha)\int_{T_r}^{T_3} C_\mathrm{P} dT &= \int_{T_r}^{T_1} C_\mathrm{P} dT + \alpha \int_{T_r}^{T_2} C_\mathrm{P} dT \\
(1+\alpha) C_\mathrm{P}(T_3 - T_r) &= C_\mathrm{P}(T_1 - T_r) + \alpha C_\mathrm{P}(T_2 - T_r) \\
(1+\alpha)T_3 &= T_1 + \alpha T_2 \\
\Rightarrow T_3 &= \frac{T_1 + \alpha T_2}{1+\alpha}, \text{ or} \\
\alpha &= \frac{T_1 - T_3}{T_3 - T_2} \\
&= \frac{900 - 500}{500 - 400} = \frac{400}{100} = \boxed{2.7}.
\end{aligned}$$

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

$$
\begin{aligned}
S_{\text{out}} &= S_{\text{in}} \\
(1+\alpha)\dot{n}_(T_3, P_3) &= \dot{n}_(T_1, P_1) + \alpha\dot{n}_(T_2, P_2) \\
{}_(T_3, P_3) -{}_(T_1, P_1) + \alpha\left[{}_(T_3, P_3) -{}_(T_2, P_2)\right] &= 0 \\
C_\text{P} \ln \frac{T_3}{T_1} - R \ln \frac{P_3}{P_1} + \alpha \left[C_\text{P} \ln \frac{T_3}{T_2} - R \ln \frac{P_3}{P_2} \right] &= 0 \\
C_\text{P} \ln \left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right) - R \ln \left(\frac{P_3^{1+\alpha}}{P_1 P_2^\alpha} \right) &= 0 \\
\ln \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right)^{\frac{C_\text{P}}{R}} \right] &= \ln \left(\frac{P_3^{1+\alpha}}{P_1 P_2^\alpha} \right) \\
\Rightarrow \;\; P_3 &= \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^\alpha} \right)^{\frac{C_\text{P}}{R}} P_1 P_2^\alpha \right]^{\frac{1}{1+\alpha}} \\
&= \left[\left(\frac{(600)^{(1+2.67)}}{(1000)(450)^{2.67}} \right)^{\frac{15}{2}} (14.14)(10.08)^{2.67} \right]^{\frac{1}{1+2.67}} \\
&= \boxed{18.67 \text{ bar}}.
\end{aligned}
$$

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 Entropy is delicious. You can’t taste entropy.

    T The sky is blue. Of course it is.

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

This is an example tail named `example_tail-33246253.tex`.

Answers are compiled in `solutions-33246253.yaml`.