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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Midterm Exam – February 11, 2025

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

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

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 $C_P = 7R$.

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:

$$\Delta \underline{H} \equiv \underline{H}_B - \underline{H}_A = \int_{T_A}^{T_B} C_P dT$$

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

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

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

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

entropy balance:

$$S_{\text{out}} = S_{\text{in}}$$

$$(1 + \alpha)\dot{n}_{\underline{\ }}(T_3, P_3) = \dot{n}_{\underline{\ }}(T_1, P_1) + \alpha\dot{n}_{\underline{\ }}(T_2, P_2)$$

$$_{\underline{\ }}(T_3, P_3) - _{\underline{\ }}(T_1, P_1) + \alpha\left[_{\underline{\ }}(T_3, P_3) - _{\underline{\ }}(T_2, P_2)\right] = 0$$

$$C_{\text{P}}\ln\frac{T_3}{T_1} - R\ln\frac{P_3}{P_1} + \alpha\left[C_{\text{P}}\ln\frac{T_3}{T_2} - R\ln\frac{P_3}{P_2}\right] = 0$$

$$C_{\text{P}}\ln\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right) - R\ln\left(\frac{P_3^{1+\alpha}}{P_1 P_2^{\alpha}}\right) = 0$$

$$\ln\left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right)^{\frac{C_{\text{P}}}{R}}\right] = \ln\left(\frac{P_3^{1+\alpha}}{P_1 P_2^{\alpha}}\right)$$

$$\Rightarrow \ P_3 = \left[\left(\frac{T_3^{1+\alpha}}{T_1 T_2^{\alpha}}\right)^{\frac{C_{\text{P}}}{R}} P_1 P_2^{\alpha}\right]^{\frac{1}{1+\alpha}}$$

$$= \left[\left(\frac{(700)^{(1+0.71)}}{(950)(350)^{0.71}}\right)^7 (13.12)(10.26)^{0.71}\right]^{\frac{1}{1+0.71}}$$

$$= \boxed{25.70 \text{ bar}}.$$

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

<u>F</u> The pope is Freewill Southern Baptist. No, the pope is Catholic.

<u>T</u> A bear shits in the woods. Of course it does.

<u>F</u> Entropy is delicious. You can't taste entropy.

<u>T</u> 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.