G.W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

ME 3322A: Thermodynamics: Fall 2014
Homework Set # 9
Due Date: November 4, 2014

	Problem # in Textbook		Answer
	7^{th} Ed.	**8^{th} Ed.**	
1	6.83	6.80	- 0.02 kJ/kg.K
2	6.92	6.89	a) 120 kg/min; b) 0.072 kW/K
3	6.101	6.97	σ=-0.12 kW/K
4	6.110	6.106	a) – 131.4 kJ/kg; b) 3.26 (kJ/kg)/K
5	6.112	6.108	b) V_2=55.51 m/s, c) 0.094 kg/s

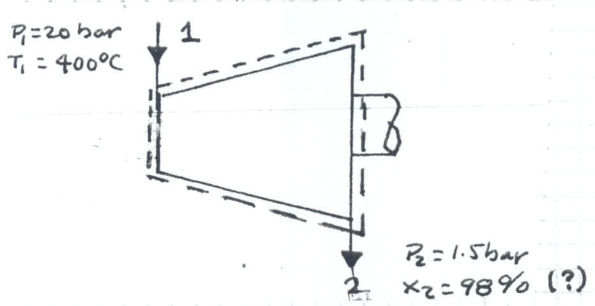
PROBLEM 6.83

Water at 20 bar, 400°C enters a turbine operating at steady state and exits at 1.5 bar. Stray heat transfer and kinetic and potential energy effects are negligible. A hard-to-read data sheet indicates that the quality at the turbine exit is 98%. Can this quality value be correct? If no, explain. If yes, determine the power developed by the turbine, in kJ per kg of water flowing.

KNOWN: Steady-state data are provided for turbine. The quality of the water at the turbine exit is claimed to be 98%

FIND: Determine if the quality value can be correct. If no, explain. If yes, determine the power developed

SCHEMATIC & GIVEN DATA:



ENGINEERING MODEL:

1. The control volume shown in the schematic is at steady state.
2. For the control volume, $\dot{Q}_{cv} = 0$.

ANALYSIS: Applying an entropy rate balance, we get at steady state

$$0 = \cancel{\sum \frac{\dot{Q}_j}{T_j}}^{\,0} + \dot{m}(s_1 - s_2) + \dot{\sigma}$$

$$\Rightarrow \quad \frac{\dot{\sigma}}{\dot{m}} = s_2 - s_1 \qquad (1)$$

From Table A-4,

$$s_1 = 7.1271 \text{ kJ/kg}\cdot\text{K}$$

With data from Table A-3,

$$s_2 = s_f + x_2(s_g - s_f)$$
$$= 1.4336 + 0.98(7.2233 - 1.4336)$$
$$= 7.1075 \text{ kJ/kg}\cdot\text{K}$$

Inserting values in Eq. (1)

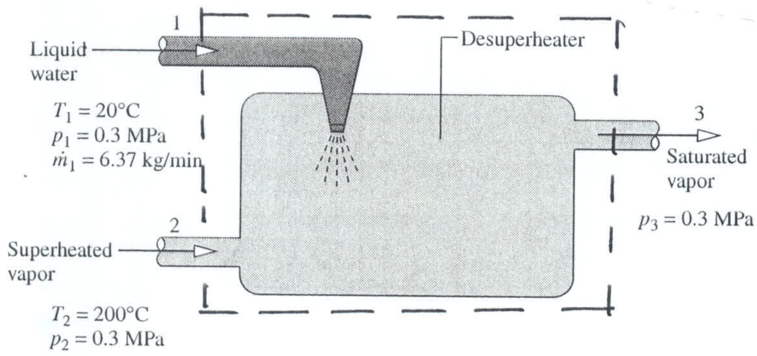
$$\frac{\dot{\sigma}}{\dot{m}} = (7.1075 - 7.1271)\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$
$$= -0.02 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \; *$$

Since $\dot{\sigma}/\dot{m}$ cannot be negative, the claimed value cannot be correct.

PROBLEM 6.92

By injecting liquid water into superheated vapor, the *desuperheater* shown in Fig. P6.92 has a saturated vapor stream at its exit. Steady-state operating data are shown on the figure. Ignoring stray heat transfer and kinetic and potential energy effects, determine (a) the mass flow rate of the superheated vapor stream, in kg/min, and (b) the rate of entropy production within the desuperheater, in kW/K.

SCHEMATIC & GIVEN DATA:



ENGR. MODEL:

1. The control volume shown in the figure is at steady state.
2. For the control volume, $\dot{W}_{cv} = 0$. Also, stray heat transfer and kinetic and potential energy effects are ignored.
3. At state 1, $h \approx h_f(T_1)$, $s \approx s_f(T_1)$

ANALYSIS: Property data:

Table A-2: $h_1 \approx h_f(T_1) = 83.96$ kJ/kg; $s_1 \approx s_f(T_1) = 0.2966$ kJ/kg·K	Table A-4: $h_2 = 2865.5$ kJ/kg; $s_2 = 7.3115$ kJ/kg·K	Table A-3: $h_3 = 2725.3$ kJ/kg; $s_3 = 6.9919$ kJ/kg·K

(a) To obtain the value of $\dot{m}_2$, write a mass rate balance: $\dot{m}_3 = \dot{m}_1 + \dot{m}_2$ and an energy rate balance: $0 = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3$, obtaining

$$\dot{m}_2 = \dot{m}_1 \left[\frac{h_3 - h_1}{h_2 - h_3}\right] = 6.37 \frac{kg}{min} \left[\frac{2725.3 - 83.96}{2865.5 - 2725.3}\right] = 120.01 \frac{kg}{min}$$ (a)

(b) To obtain the rate of entropy production, write an entropy rate balance:

$$0 = \cancel{\sum \frac{\dot{Q}_j}{T_j}}^{0} + \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{\sigma}_{cv}$$

$$\Rightarrow \dot{\sigma}_{cv} = \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2$$

$$= (120.01 + 6.37) \frac{kg}{min} \left(6.9919 \frac{kJ}{kg \cdot K}\right) - (6.37)(0.2966) - (120.01)(7.3115)$$

$$= 4.3 \frac{kJ/min}{K} \left|\frac{1\ min}{60 s}\right| \left|\frac{1\ kW}{1\ kJ/s}\right|$$

$$= 0.072 \frac{kW}{K}$$ (b)

PROBLEM 6.101

An inventor has provided the steady-state operating data shown in Fig. P6.101 for a *cogeneration* system producing power and increasing the temperature of a stream of air. The system receives and discharges energy by heat transfer at the rates and temperatures indicated on the figure. All heat transfers are in the directions of the accompanying arrows. The ideal gas model applies to the air. Kinetic and potential energy effects are negligible. Using energy and entropy rate balances, evaluate the thermodynamic performance of the system.

KNOWN: Steady-state operating data are provided for a cogeneration system.

FIND: Evaluate the thermodynamic performance of the system using energy and entropy balances.

SCHEMATIC & GIVEN DATA:

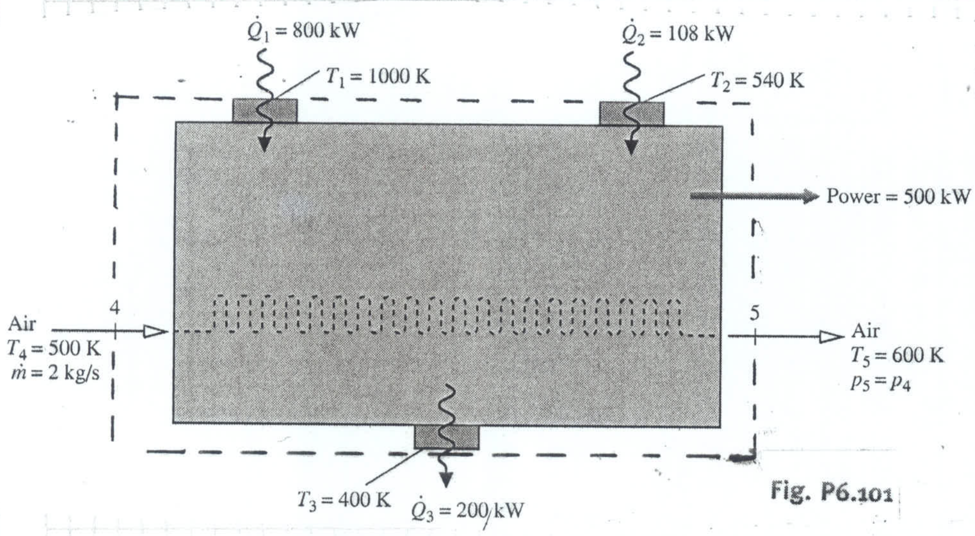


Fig. P6.101

ENGINEERING MODEL:

1. The control volume shown in the schematic is at steady state.
2. The only heat transfers are those shown on the schematic.
3. Kinetic and potential energy effects are negligible.
4. The air is modeled as an ideal gas.

ANALYSIS: For the control volume under consideration, $\dot{m}_4 = \dot{m}_5 = \dot{m}$. An energy rate balance reads, $0 = [\dot{Q}_1 + \dot{Q}_2 - \dot{Q}_3] - \dot{W} + \dot{m}[h_4 - h_5]$. Thus

$$\dot{W} = [\dot{Q}_1 + \dot{Q}_2 - \dot{Q}_3] + \dot{m}[h_4 - h_5]$$, where h_4 and h_5 are obtained from Table A-22.

$$= [800 + 108 - 200]\,\text{kW} + 2\frac{\text{kg}}{\text{s}}[503.02 - 607.02]\frac{\text{kJ}}{\text{kg}}\left|\frac{1\,\text{kW}}{1\,\text{kJ/s}}\right| = 500\,\text{kW}$$

Accordingly, the given data agree with the conservation of energy principle.

An entropy rate balance reads

$$0 = \left[\frac{\dot{Q}_1}{T_1} + \frac{\dot{Q}_2}{T_2} - \frac{\dot{Q}_3}{T_3}\right] + \dot{m}[s_4 - s_5] + \dot{\sigma}$$

$$\Rightarrow \quad \dot{\sigma} = \left[\frac{\dot{Q}_3}{T_3} - \frac{\dot{Q}_1}{T_1} - \frac{\dot{Q}_2}{T_2}\right] + \dot{m}\Big[s_5^\circ - s_4^\circ - \overbrace{R\ln\frac{p_5}{p_4}}^{=0\ (p_5 = p_4)}\Big]$$

$$= \left[\frac{200}{400} - \frac{800}{1000} - \frac{108}{540}\right]\frac{\text{kW}}{\text{K}} + 2\frac{\text{kg}}{\text{s}}[2.40902 - 2.21952]\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\left|\frac{1\,\text{kW}}{1\,\text{kJ/s}}\right|$$

$$= [0.50 - 0.8 - 0.2]\frac{\text{kW}}{\text{K}} + 0.38\frac{\text{kW}}{\text{K}}$$

$$= -0.12\,\frac{\text{kW}}{\text{K}}$$

*

Since the entropy production rate is negative, the given data do not agree with the second law. In sum, the system cannot perform in accordance with the operating data provided.

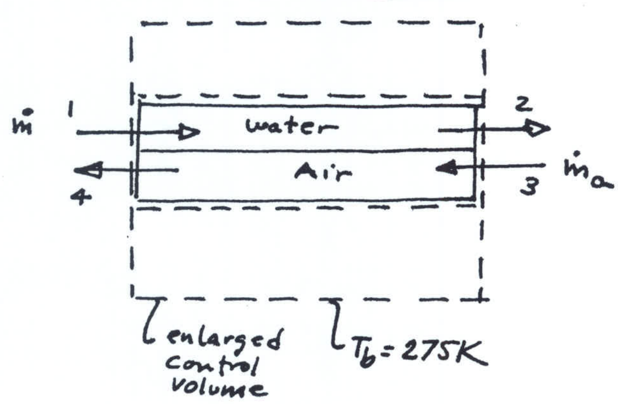
PROBLEM 6.110

Saturated water vapor at 100 kPa enters a counterflow heat exchanger operating at steady state and exits at 20°C with a negligible change in pressure. Ambient air at 275 K, 1 atm enters in a separate stream and exits at 290 K, 1 atm. The air mass flow rate is 170 times that of the water. The air can be modeled as an ideal gas with $c_p = 1.005$ kJ/kg · K. Kinetic and potential energy effects can be ignored.

(a) For a control volume enclosing the heat exchanger, evaluate the rate of heat transfer, in kJ per kg of water flowing.

(b) For an enlarged control volume that includes the heat exchanger and enough of its immediate surroundings that heat transfer from the control volume occurs at the ambient temperature, 275 K, determine the rate of entropy production, in kJ/K per kg of water flowing.

SCHEMATIC & GIVEN DATA:



ENGR. MODEL:

1. The control volumes shown in the sketch are at steady state.
2. Kinetic and potential energy effects are ignored. $\dot{W}_{cv} = 0$.
3. For the enlarged control volume heat transfer occurs at $T_b = 275K$.
4. The air is modeled as an ideal gas with $c_p = 1.005$ kJ/kg·K.
5. For liquid water $h \approx h_f(T)$, $s \approx s_f(T)$.

ANALYSIS:

From Table A-3, $h_1 = h_g$ (at 100 kPa) = 2778.1 kJ/kg, and $s_1 = 6.5863$ kJ/kg·K. From Table A-2, $h_2 \approx h_f(20°C) = 83.96 \frac{kJ}{kg}$, $s_2 \approx s_f(20°C) = 0.2966$ kJ/kg·K.

(a) An energy rate balance for a control volume enclosing just the heat exchanger reads,

$$0 = \dot{Q}_{cv} - \cancel{\dot{W}_{cv}} + \dot{m}(h_1 - h_2) + \dot{m}_a(h_3 - h_4) \Rightarrow \dot{Q}_{cv} = \dot{m}(h_2 - h_1) + \dot{m}_a(h_4 - h_3).$$

Since $\dot{m}_a/\dot{m} = 170$, and using assumption 4,

$$\frac{\dot{Q}_{cv}}{\dot{m}} = (h_2 - h_1) + 170\left(c_{pa}(T_4 - T_3)\right) = \left[(83.96 - 2778.1) + 170(1.005)(290 - 275)\right] \frac{kJ}{kg(w)}$$

water

$$= -131.4 \text{ kJ/kg(w)}$$

(a)

(b) An entropy rate balance for the enlarged control volume reads,

$$0 = \frac{\dot{Q}_{cv}}{T_b} + \dot{m}(s_1 - s_2) + \dot{m}_a(s_3 - s_4) + \dot{\sigma}_{cv}$$

$$\Rightarrow \dot{\sigma}_{cv}/\dot{m} = \frac{(-\dot{Q}_{cv}/\dot{m})}{T_b} + (s_2 - s_1) + 170\left[c_p \ln\frac{T_4}{T_3} - \cancel{R \ln\frac{P_4}{P_3}}\right] \quad 0\ (P_4 = P_3)$$

$$= \left[\frac{131.4}{275} + (0.2966 - 6.5863) + 170(1.005)\ln\frac{290}{275}\right] \frac{kJ/kg(w)}{K}$$

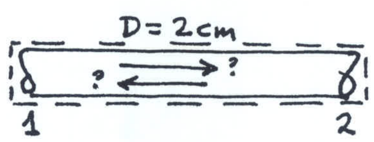
$$= 3.26 \ \frac{kJ/kg(w)}{K}$$

(b)

PROBLEM 6.112

-- Air flows through an insulated circular duct having a diameter of 2 cm. Steady-state pressure and temperature data obtained by measurements at two locations, denoted as 1 and 2, are given in the accompanying table. Modeling air as an ideal gas with $c_p = 1.005$ kJ/kg · K, determine (a) the direction of the flow, (b) the velocity of the air, in m/s, at each of the two locations, and (c) the mass flow rate of the air, in kg/s.

Measurement location	1	2
Pressure (kPa)	100	500
Temperature (°C)	20	50



ENGR. MODEL:

1. The control volume shown in the sketch is at steady state.
2. For the control volume, $\dot{Q}_{cv} = 0$, $\dot{W}_{cv} = 0$ and potential energy effects are negligible.
3. The air is modeled as an ideal gas with $c_p = 1.005$ kJ/kg·K.

ANALYSIS: As discussed in Secs. 5.1 and 6.8, directionality normally can be established using the 2nd law. Here, a direction is assumed and the associated entropy production is evaluated. Taking the inlet at 1 and the exit at 2, an entropy rate balance reads, $0 = \cancel{\sum_j \frac{\dot{Q}_j}{T_j}}^{\,0} + \dot{m}(s_1 - s_2) + \dot{\sigma}_{cv}$

$$\Rightarrow \frac{\dot{\sigma}_{cv}}{\dot{m}} = s_2 - s_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} = 1.005 \ln \frac{323}{293} - \frac{8.314}{28.97} \ln \frac{500}{100} = -0.364 \frac{kJ}{kg \cdot K}$$

Since $\dot{\sigma}_{cv}/\dot{m}$ cannot be negative, the flow direction can only be from 2 to 1. ← (a)

A mass rate balance reads, $\dot{m}_1 = \dot{m}_2 \Rightarrow \frac{AV_1}{\underbrace{v_1}_{RT_1/P_1}} = \frac{AV_2}{\underbrace{v_2}_{RT_2/P_2}} \Rightarrow \frac{V_2}{V_1} = \frac{P_1}{P_2}\frac{T_2}{T_1}$.

Inserting values, $V_2 = \left(\frac{100}{500}\right)\left(\frac{323}{293}\right) V_1 = 0.2205 V_1$.

An energy rate balance reads, $0 = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right]$. Or

$$0 = c_p(T_2 - T_1) + \frac{(0.2205 V_1)^2 - V_1^2}{2} \Rightarrow 0 = c_p(T_2 - T_1) - \frac{0.9514 V_1^2}{2}.$$ Solving, we get

$$V_1 = \left[\frac{2\left(1.005 \frac{kJ}{kg \cdot K}\right)(30 K)}{0.9514} \left|\frac{10^3 N \cdot m}{1 kJ}\right| \left|\frac{1 kg \cdot m/s^2}{1 N}\right|\right]^{\frac{1}{2}} = 251.75 \text{ m/s}$$

And

$$V_2 = 0.2205 V_1 = 55.51 \text{ m/s}$$ ← (b)

(c) $$\dot{m} = \frac{AV_1}{\underbrace{v_1}_{RT_1/P_1}} = \frac{P_1(\pi D^2/4) V_1}{RT_1} = \frac{(10^5 N/m^2)\left(\frac{\pi}{4}(.02 m)^2\right) 251.75 m/s}{\left(\frac{8314}{28.97} \frac{N \cdot m}{kg \cdot K}\right)(293 K)} = 0.094 \frac{kg}{s}$$ ← (c)