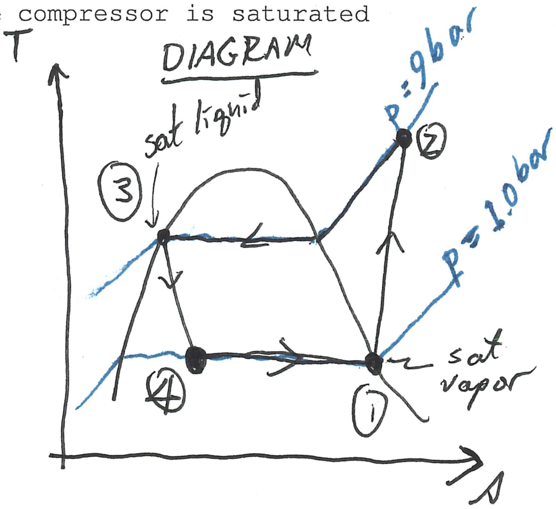
EXAM #2 – ME 3030 – Section 002 – Thermodynamics – Spring 2023
Prof. J. R. Saylor

NAME: SOLUTION

This is a closed book/closed notes exam. Use of a scientific calculator is permitted. Zero credit will be earned for this exam if the honors pledge is not signed.

1. [10 points] R-134a is the working fluid for an ideal vapor-compression refrigerator. If saturated liquid leaves the condenser at 9 bar, and the evaporator pressure is 1.0 bar, determine the heat rejected by the refrigerator in units of kJ per kilogram of refrigerant flowing if the input to the compressor is saturated vapor.

GIVEN: R-134a; P_{hi}; P_{low}; (3) is sat liquid; (1) is sat. vapor; ideal vapor compression refrig.



FIND: $\dot{Q}_H/\dot{m} = ?$ kJ/kg

ASSUME: Assumptions for ideal vapor-compression refrigerator; isentropic compressor

ANALYSIS: $\dot{Q}_H/\dot{m} = h_2 - h_3$

$h_3 = h_f(9\,bar) = 99.56$ kJ/kg

$h_2 = h(9\,bar, s = s_1)$

(1) $s_1 = 0.9395$ kJ/kg·K

$h_2 = h(9\,bar, 0.9395\,\frac{kJ}{kg\cdot K})$

↳ $h_2 = 276.91$ kJ/kg

interpolate p = 9 bar superheated table

$h\left(\frac{kJ}{kg}\right)$	$s\left(\frac{kJ}{kg\cdot K}\right)$
271.25	0.9217
(h_2)	(0.9395)
282.34	0.9566

$h_2 = 276.91$ kJ/kg

$$\frac{\dot{Q}_H}{\dot{m}} = h_2 - h_3$$

$$\frac{\dot{Q}_H}{\dot{m}} = 276.91\,\frac{kJ}{kg} - 99.56\,\frac{kJ}{kg}$$

$$\frac{\dot{Q}_H}{\dot{m}} = 177.35\,\frac{kJ}{kg}$$ ← ANS.

2. [5 points] The equation for the isothermal compressibility κ is:

$$\kappa = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T \tag{1}$$

Develop an equation for κ for an ideal gas. Present your result in its simplest possible form.

GIVEN: κ equation; ideal gas.

FIND: κ in simplest form

ASSUME:

ANALYSIS: $\kappa = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$

$$pv = RT$$

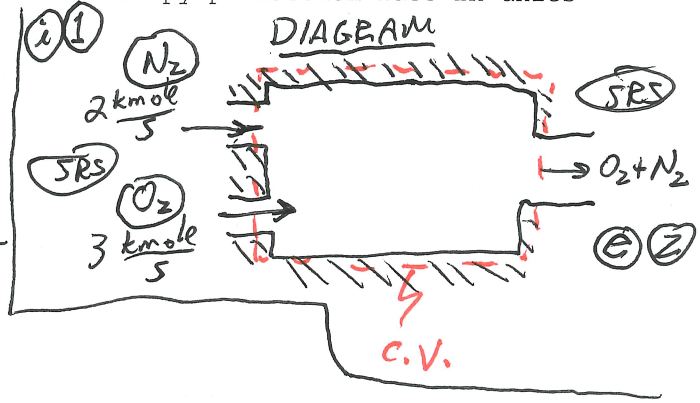
$$v = \frac{RT}{p}$$

$$\left(\frac{\partial v}{\partial p}\right)_T = \frac{-RT}{p^2}$$

$$\kappa = -\left(\frac{p}{RT}\right)\left(-\frac{RT}{p^2}\right)$$

$$\boxed{\kappa = \frac{1}{p}}$$ ← ANS.

3. [10 points] 2 kmol/sec of nitrogen gas and 3 kmole/sec of oxygen gas enter an insulated reactor as separate streams. The two streams mix completely and exit as a homogeneous mixture of nitrogen gas and oxygen gas. All inlets and outlets are at one atmosphere and 298K. Determine the entropy production rate in units of kW/K.



GIVEN: $\dot{n}_{N_2}, \dot{n}_{O_2}$, $\dot{Q} = 0$; SRS at i/e

FIND: $\dot{\sigma} = ?$ kW/K

ASSUME: S.S.

ANALYSIS

$$\cancel{\frac{dS}{dt}} = \cancel{\sum_j \frac{\dot{Q}_j}{T_j}} + \sum_i \dot{n}_i \bar{s}_i - \sum_e \dot{n}_e \bar{s}_e + \dot{\sigma}$$

$$\boxed{\dot{\sigma} = \sum_e \dot{n}_e \bar{s}_e - \sum_i \dot{n}_i \bar{s}_i}$$

$$\dot{\sigma} = \left[\dot{n}_{N_2}\bar{s}_{N_2} + \dot{n}_{O_2}\bar{s}_{O_2}\right]_e - \left[\dot{n}_{N_2}\bar{s}_{N_2} + \dot{n}_{O_2}\bar{s}_{O_2}\right] = \dot{n}_{N_2}(\bar{s}_2 - \bar{s}_1)_{N_2} + \dot{n}_{O_2}(\bar{s}_2 - \bar{s}_1)_{O_2}$$

$$\Delta\bar{s} = \cancel{\bar{s}^\circ(T_2) - \bar{s}^\circ(T_1)} - \bar{R}\ln\frac{P_{i,2}}{P_{i,1}} \leftarrow \text{partial pressures}$$

$= 0$ since $T_1 = T_2$

$$\boxed{\dot{\sigma} = \dot{n}_{N_2}\left(-\bar{R}\ln\left(\frac{P_{N_2,2}}{P_{N_2,1}}\right)\right) + \dot{n}_{O_2}\left(-\bar{R}\ln\left(\frac{P_{O_2,2}}{P_{O_2,1}}\right)\right)}$$

$$= -\bar{R}\left[\dot{n}_{N_2}\ln\left(\frac{y_{N_2,2}\cancel{(1\,atm)}}{y_{N_2,1}\cancel{(1\,atm)}}\right) + \dot{n}_{O_2}\ln\left(\frac{y_{O_2,2}\cancel{(1\,atm)}}{y_{O_2,1}\cancel{(1\,atm)}}\right)\right]$$

$$= -\bar{R}\left[\dot{n}_{N_2}\ln\left(\frac{\frac{2}{2+3}}{1}\right) + \dot{n}_{O_2}\ln\left(\frac{\frac{3}{2+3}}{1}\right)\right]$$

$$= -8.314\frac{kJ}{kmole\cdot K}\left[\left(2\frac{kmole}{s}\right)\ln\left(\frac{2}{5}\right) + (3\,kmole/s)\ln\left(\frac{3}{5}\right)\right]$$

$$= \left(-8.314\frac{kJ}{kmole\cdot K}\right)\left[-1.833\frac{kmol}{s} - 1.532\frac{kmol}{s}\right]$$

$$\boxed{\dot{\sigma} = 27.977\frac{kW}{K}} \leftarrow \text{ANS.}$$

I HAVE NEITHER PROVIDED OR RECEIVED HELP DURING THIS EXAM.

SIGNATURE