ME40: Thermodynamics

Mock Final Exam

December 5th, 2024

Name of the Examinee: ______________________________

ID number: ______________________

Problem and Point Summary:

Remarks:

- Do not spend time interpolating property values. Just select the value that's closest to the one you need.
- Allowed aids are 3 letter-sized sheets (6-pages) and an electronic calculator.
- To get full credit you must:
  - indicate what the equations you use represent, and why they apply
  - if terms in the full equations are neglected, indicate why
  - state any idealizations about processes
  - indicate how properties are evaluated, i.e., indicate table number if relevant
  - show units on properties and final answer

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1. Heat pump (15 pts)

A heat pump, which operates on the ideal vapor-compression cycle with the refrigerant R-134a, is used to heat a house. The mass flow rate of the refrigerant is 0.25 kg/s. The condenser and evaporator pressures are 1400 kPa and 320 kPa, respectively.

a. Show the cycle on a *T*-*s* diagram with respect to saturation lines.

b. Determine the rate of heat supply to the house.

c. Determine the volume flow rate of the refrigerant at the compressor inlet.

d. Determine the coefficient of performance (COP) of this heat pump.

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2. Clausius-Clapeyron equation (15 pts)

A long vertical column of a particular liquid is kept isothermal at temperature – 5°C. The material below a certain point in the column is found to be a solid; that above this point is a liquid.

The temperature is now changed to –5.2°C, and the solid-liquid interface is observed to shift upward by 1.03 m. The latent heat is 8,368 J/kg, and the density of the liquid phase is 1000 kg/m^3.

What is the density of the solid phase?

Hint: Note that the pressure at the original position of the interface remains constant.

Note: The height value has been increased. The previous value produced an incorrect value for the solid density.

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3. Free Expansion (15 pts)

Imagine a system where there is a rigid container of volume V_i filled with van der Waals gas of mass m separated from another rigid container that is evacuated by a membrane. If this membrane is suddenly fractured, the gas expands and fills the volume of both containers, V_f.

We would like to determine the change in entropy during this process. The change in entropy can be described as:

$$dS = \left(\frac{\partial S}{\partial V}\right)_U dV$$

a. Can you express $\left(\frac{\partial S}{\partial V}\right)_U$ as a function of p, T, n, c_V, c_p, α, and/or β?

Hints:

$$\left(\frac{\partial X}{\partial Y}\right)_Z = -\left(\frac{\partial Z}{\partial Y}\right)_X / \left(\frac{\partial Z}{\partial X}\right)_Y ;$$

$$dU = \left(\frac{\partial U}{\partial S}\right)_V dS + \left(\frac{\partial U}{\partial V}\right)_S dV = TdS - pdV$$

b. A van der Waals gas has the following equation of state:

$$p = \frac{RT}{v-b} - \frac{a}{v^2}$$

What is the change in entropy, $S_f - S_i$? Please provide a formula.

c. We now replace the van der Waals gas with an ideal gas and repeat the expansion process. What is the change in entropy, $S_f - S_i$?

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Property tables

TABLE A–12 Saturated refrigerant-134a—Pressure table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, $kJ/kg \cdot K$		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
60	−36.95	0.0007097	0.31108	3.795	205.34	209.13	3.837	223.96	227.80	0.01633	0.94812	0.96445
70	−33.87	0.0007143	0.26921	7.672	203.23	210.90	7.722	222.02	229.74	0.03264	0.92783	0.96047
80	−31.13	0.0007184	0.23749	11.14	201.33	212.48	11.20	220.27	231.47	0.04707	0.91009	0.95716
90	−28.65	0.0007222	0.21261	14.30	199.60	213.90	14.36	218.67	233.04	0.06003	0.89431	0.95434
100	−26.37	0.0007258	0.19255	17.19	198.01	215.21	17.27	217.19	234.46	0.07182	0.88008	0.95191
120	−22.32	0.0007323	0.16216	22.38	195.15	217.53	22.47	214.52	236.99	0.09269	0.85520	0.94789
140	−18.77	0.0007381	0.14020	26.96	192.60	219.56	27.06	212.13	239.19	0.11080	0.83387	0.94467
160	−15.60	0.0007435	0.12355	31.06	190.31	221.37	31.18	209.96	241.14	0.12686	0.81517	0.94202
180	−12.73	0.0007485	0.11049	34.81	188.20	223.01	34.94	207.95	242.90	0.14131	0.79848	0.93979
200	−10.09	0.0007532	0.099951	38.26	186.25	224.51	38.41	206.09	244.50	0.15449	0.78339	0.93788
240	−5.38	0.0007618	0.083983	44.46	182.71	227.17	44.64	202.68	247.32	0.17786	0.75689	0.93475
280	−1.25	0.0007697	0.072434	49.95	179.54	229.49	50.16	199.61	249.77	0.19822	0.73406	0.93228
320	2.46	0.0007771	0.063681	54.90	176.65	231.55	55.14	196.78	251.93	0.21631	0.71395	0.93026
360	5.82	0.0007840	0.056809	59.42	173.99	233.41	59.70	194.15	253.86	0.23265	0.69591	0.92856
400	8.91	0.0007905	0.051266	63.61	171.49	235.10	63.92	191.68	255.61	0.24757	0.67954	0.92711
450	12.46	0.0007983	0.045677	68.44	168.58	237.03	68.80	188.78	257.58	0.26462	0.66093	0.92555
500	15.71	0.0008058	0.041168	72.92	165.86	238.77	73.32	186.04	259.36	0.28021	0.64399	0.92420
550	18.73	0.0008129	0.037452	77.09	163.29	240.38	77.54	183.44	260.98	0.29460	0.62842	0.92302
600	21.55	0.0008198	0.034335	81.01	160.84	241.86	81.50	180.95	262.46	0.30799	0.61398	0.92196
650	24.20	0.0008265	0.031680	84.72	158.51	243.23	85.26	178.56	263.82	0.32052	0.60048	0.92100
700	26.69	0.0008331	0.029392	88.24	156.27	244.51	88.82	176.26	265.08	0.33232	0.58780	0.92012
750	29.06	0.0008395	0.027398	91.59	154.11	245.70	92.22	174.03	266.25	0.34348	0.57582	0.91930
800	31.31	0.0008457	0.025645	94.80	152.02	246.82	95.48	171.86	267.34	0.35408	0.56445	0.91853
850	33.45	0.0008519	0.024091	97.88	150.00	247.88	98.61	169.75	268.36	0.36417	0.55362	0.91779
900	35.51	0.0008580	0.022703	100.84	148.03	248.88	101.62	167.69	269.31	0.37383	0.54326	0.91709
950	37.48	0.0008640	0.021456	103.70	146.11	249.82	104.52	165.68	270.20	0.38307	0.53333	0.91641
1000	39.37	0.0008700	0.020329	106.47	144.24	250.71	107.34	163.70	271.04	0.39196	0.52378	0.91574
1200	46.29	0.0008935	0.016728	116.72	137.12	253.84	117.79	156.12	273.92	0.42449	0.48870	0.91320
1400	52.40	0.0009167	0.014119	125.96	130.44	256.40	127.25	148.92	276.17	0.45325	0.45742	0.91067

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TABLE A–13 Superheated refrigerant-134a

	P = 1.20 MPa (T_{sat} = 46.29°C)				P = 1.40 MPa (T_{sat} = 52.40°C)			
Sat.	0.016728	253.84	273.92	0.9132	0.014119	256.40	276.17	0.9107
50	0.017201	257.64	278.28	0.9268				
60	0.018404	267.57	289.66	0.9615	0.015005	264.46	285.47	0.9389
70	0.019502	277.23	300.63	0.9939	0.016060	274.62	297.10	0.9733
80	0.020529	286.77	311.40	1.0249	0.017023	284.51	308.34	1.0056
90	0.021506	296.28	322.09	1.0547	0.017923	294.28	319.37	1.0364
100	0.022442	305.81	332.74	1.0836	0.018778	304.01	330.30	1.0661
110	0.023348	315.40	343.41	1.1119	0.019597	313.76	341.19	1.0949
120	0.024228	325.05	354.12	1.1395	0.020388	323.55	352.09	1.1230
130	0.025086	334.79	364.90	1.1665	0.021155	333.41	363.02	1.1504
140	0.025927	344.63	375.74	1.1931	0.021904	343.34	374.01	1.1773
150	0.026753	354.57	386.68	1.2192	0.022636	353.37	385.07	1.2038
160	0.027566	364.63	397.71	1.2450	0.023355	363.51	396.20	1.2298
170	0.028367	374.80	408.84	1.2704	0.024061	373.75	407.43	1.2554
180	0.029158	385.10	420.09	1.2955	0.024757	384.12	418.78	1.2808