4200:225 EQUILIBRIUM THERMODYNAMICS SPRING 87

TEST 2 SSN________

1) True or false.

____The compressibility factor Z is always less than or equal to unity.

____The critical properties T_c and P_c are constants for a given compound.

____A closed system is one of constant volume.

____A steady-state flow process is one for which the velocities of all streams may be assumed negligible.

____Gravitational potential-energy terms may be ignored in the steady-state energy equation if all streams entering and leaving the control volume are at the same elevation.

____In an adiabatic flow process, the entropy of the fluid must increase as the result of any irreversibilities within the system.

____The temperature of a gas undergoing a continuous throttling process may either increase or decrease across the throttling device, depending on conditions.

____When an ideal gas is compressed adiabatically in a flow process and is then cooled to the initial temperature, the heat removed in the cooler is equal to the work done by the compressor. (Assume potential and kinetic energy effects are negligible.)

____In the limit as $P \rightarrow 0$, the ratio f/P for a gas goes to infinity, where f is the fugacity.

____The residual Gibbs function is related to f/P by (G-Gid)/(nRT)=ln(f/p).

2) Reduce $(\partial H/\partial S)$ to a form involving p, V, T, Cp, Cv, and their derivatives.

3) A house has an effective heat loss of 100,000 Btu/hr. During the heating season of 160 days the average inside temperature should be 70°F while that outside is 45 F. Freon-12 is the working fluid and an ordinary vapor-compression cycle is used. A 10 F approach on each side may be assumed. Electricity costs $0.14/KW-hr = $0.00004/Btu.
   a) What is the cost in $/hr if the compressor is 100% efficient?
   b) What is the cost if the compressor is 80% efficient?

4) Determine the horsepower required to continuously compress reversibly and adiabatically 1 lbm/min of ethylene oxide from 70°F and 1 atm to 250 psia. Cp = 12.8 cal/gmol-K; Tc = 469 K; Pc = 70.1 atm; ω= 0.200.

5) Propylene vapor is processed from 325 K and 21.35 atm to 225 K and 1 atm. Compute the change in entropy. Suppose saturated propylene vapor at 325 K is expanded reversibly and adiabatically to 1 atm. What is the final quality?
   Tc = 364.8 K; Pc = 45.5 atm; ω= 0.142; Cp = 14.6cal/mol-K;
   $\ln(p^{vap})$ = -2238 + 9.953 where p^{vap} is in atm and T is in K.
   1.FTFFTTTTFT 2.$T(1+V/Cv(dp/dT)_V)$ 3.a.0.44.b.0.55 4.1.96 5.19.8cal/mol-K,90%

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TEST 2 SSN________

1. Short Answer
   a) In an ordinary vapor-compression cycle, what is the entropy after the throttle relative to the entropy before the throttle (higher, lower or equal) and why?
   b) Estimate the vapor pressure of sulfur dioxide at room temperature (298K). Tc=430.8 K; p =7.78 MPa; ω=0.251
   c) What is the change in entropy for an ideal gas (Cp=7 cal/mol-K) when it is raised from a temperature of 300K and pressure of .1 MPa to 320K and 5MPa?
   d) After reacting $H_2+½O_2$, H_2O vapor at 1500 K and 11 MPa is expanded reversibly and adiabatically through a nozzle to 0.1 MPa. Estimate the outlet temperature of this exhaust stream.

e) A two-stage compressor operates adiabatically during each stage with intercooling to 60°F between stages. We would like to compress helium (C_P = 5cal/mol-K) from 1 atm to 16 atm. What pressure between stages minimizes the reversible work for the compression of this gas?

f) Develop an expression for $(G-G^{id})/RT$ as a function of $b\rho$ for a gas that can be described by:
$Z = 1 + 2b\rho/(1-2b\rho)$

2. Evaluate $(\partial H/\partial P)_V$ in terms of only P, V, T, C_P, and C_V and their derivatives. Describe a physical situation to which this quantity relates.
3. Estimate the enthalpy of 1,3, butadiene at 125 atm and 530°F relative to its saturated liquid at 60F.
T = 425.4 K; P = 4.33 MPa; ω = 0.193; C_P =23 cal/mol-K;

4. It is desired to design a Rankine cycle using a 70% efficient turbine and expanding the steam to saturated vapor at 224°F. The boiler operates at 500 psia. Compute the thermodynamic efficiency for conversion of heat into work.(hint: neglect the pump work). Compare this to the thermodynamic efficiency of the Carnot cycle operating between the same temperatures.
5. By holding the can upside down at room temperature (298K), liquid freon-22 (*MW*=85.5) can be dispensed from a can through 1 ft of stainless tubing (100 g, C_P =.12 cal/g-K). (a) Estimate the heat of vaporization (in cal/g) of freon-22 at its normal boiling temperature (-42°C). (b) Estimate the number of moles of freon-22 that must be wasted before the first drop of liquid comes out of the pipe if the pipe is insulated. Velocity of the vapor freon coming out of the tube may be neglected.
T_c = 369.8; P = 4.97 MPa; ω= 0.221

Answers: 1)a.higher, throttling irreversible b.0.389MPa c.-7.32cal/mol-K d.585K e.4atm
f.$-\ln(1-2b\rho)+Z-1-\ln Z$ (2)$C_v(\partial T/\partial P)_v+V$ (3)9443cal/mol (4)21%vs46%

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TEST 2 SSN________

1. Estimate the entropy of 1 gmol of propane at 150°F and 200 psia. The entropy is to be taken as zero at 1 atm ideal gas and 0F.T_c =369.8 K; P_c =4.249 MPa; ω =0.152
2. Estimate the vapor pressure of isobutane at 300 K. T_c =408K; P_c =3.65MPa; ω=0.177
3. Argon (C_P =5 cal/mol-K) is compressed reversibly and adiabatically in a continuous single stage process from 0.15 MPa and 300 K to 0.90 Mpa. Estimate the work done by the compressor.
4. Suppose the argon from the preceding problem was compressed from 0.15 MPa to 0.90 MPa in a two-stage process with intercooling back to 300 K. What would be the optimum interstage pressure and the work done in that case?
5. Express in terms of in terms of only P, V, T, C_P, C_V and their derivatives. Your answer may include absolute values of S if it is not associated with a derivative.
$(\partial G/\partial H)_P$
6. The compressibility factor for a certain fluid is well-represented by:
$Z = 1 + ab\rho/(1+b\rho)^2$
Develop an expression for the Helmholtz energy departure function.
7. Saturated vapor propane at -40°C is to be compressed to 55 atm. Estimate the work required if the compressor is adiabatic but only 50% efficient.
T_c =369.8 K; P_c =4.249 MPa; ω =0.152
8. An ordinary vapor-compression cycle is to be designed for superconductor application using N2 as refrigerant. The expansion will be to atmospheric pressure. A heat sink is available at 105 K. A 5 K approach should be sufficient. Roughly 100 Btu/hr must be removed. Compute the coefficient of performance (COP) and compare it to the Carnot COP. Also, estimate the power requirement (hp) of the compressor assuming it is adiabatic and reversible.

1.-.7246cal/mol-K 2.0.3746MPa 3.-1572cal/mol 4.-1293cal/mol 5. $-S/P$ 6. $ab\rho/(1+b\rho)$
7.-3563cal/mol 8.1.33,0.30hp

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TEST 2 SSN________

1.a. List in the space below all the differences between a Rankine cycle and a Carnot cycle. Order the list from most important to least important.

1.b. An inventor proposes to have developed a small power plant that operates at 70% efficiency. It operates between temperature extremes of 1000°F and 100°F. Develop your own analysis of the maximum possible efficiency. (Choose the power cycle that gives the highest possible value for the efficiency.)

1.c. Estimate the vapor pressure of CO_2 at 14°C. (T_c=304.2K; P_c=7.381Mpa; ω=.228).

2. Estimate the quality of Freon-12 after the throttle in an ordinary vapor-compression cycle operating between -20F and 114.3F.

3. A simple Rankine cycle operates between superheated steam at 1000xF and 400 psia entering the turbine and 2 psia entering the pump. What is the maximum possible efficiency for this Rankine cycle?

4. Express in terms of in terms of only P, V, T, C_P, C_V and their derivatives. Your answer may include absolute values of S if it is not associated with a derivative.

$(\partial S/\partial P)_G$

5. Suppose an ideal gas was continuously compressed adiabatically and reversibly from 45 psia and 70°F to 1500 psia in two stages with intercooling to 70°F between stages. What would be the optimal pressure between stages (for minimum work) and the temperature coming out of the second stage before it is cooled. (C_P =13 cal/gmol-K).

6. Estimate the change in enthalpy (Btu/lbmole) when ethane at 70°F and 400 psia is compressed to 1500 psia and 120°F (T_c =305.4K; P_c =4.880MPa; ω=.099; C_P =13 Btu/lbmol-R).

7. Suppose ethane was compressed adiabatically in a 70% efficient continuous compressor. The downstream pressure is specified to be 1500 psia at a temperature not to exceed 350°F. What is the highest that the upstream temperature could be if the upstream pressure is 200 psia? (Hint: neglect the departure function for the upstream thermodynamics.)

Answers: 1b) 62% 1c) 5MPa 2) 42% 3) 29% 4) $C_pV/TS-(dV/dT)_p$ 5) 260psia 6) -2300Btu/mol 7) 269K

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TEST 2 SSN________

1.a. The conditions of a fluid encountered in some process calculations are at a high reduced pressure and a low reduced temperature. Would this fluid have density and enthalpy similar to a gas, a vapor, a supercritical fluid or a liquid? Why?

1.b. Why does the compressibility factor increase sharply at high density?

1.c. Estimate the value of the compressibility factor, Z, for neon at P_r=30 and T_r=15.

1.d. Estimate the density of neon at P_r=30 and T_r=15.(1.2,0.26g/cc)

2. Freon-12 is used in a heat pump operating on an ordinary vapor compression cycle with a 100% efficient compressor. The average outdoor temperature is 90°F and the desired indoor temperature is 70°F. The design is such that a 40°F approach temperature is used on each side. Compute the Q /W for this process and compare it to the value you would expect for a Carnot cycle operating at the same conditions. What would be the power requirement of the compressor motor (in hp) to provide 12,000 Btu/hr of heating capacity?(1 hp=0.7074 Btu/s)

3. Propane is compressed from 1 bar and 0xC to 64 bar and 100°C. Compute the change in molar entropy, S.

4. As part of a liquefaction process, ammonia is throttled to 80% quality at atmospheric pressure. If the upstream pressure is 100 bar, what must be the upstream temperature? (Assume Cp=8.8 cal/mol-K).

5.a. For certain fluids, the equation of state is given by

$Z = 1 - b\rho/T_r$

Develop an expression for the enthalpy departure function for fluids of this type.

($-2b\rho/T_r$)

5.b. Evaluate $(dS/dT)_G$ in terms of only p, v, T, C , C and their derivatives. Your answer may include absolute values of S if is not associated with a derivative.

Answers: 1a.liquid 1b) close packed 1c)1.2 1d).26g/cc 2).95hp 3)-8.7cal/mol-K 4)358K 5a) 5b)Cp/T-S(dv/dT)p/V

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TEST 2 SSN_______

1.a. Sketch the radial distribution function vs. radial distance for a low density hard sphere fluid. Describe in words why it looks like that.

1.b. The attractive contribution to the compressibility factor is:

$$Z^{att} = \frac{-\rho}{6kT}\int_{\sigma}^{\infty}\frac{rdu(r)}{dr}g4\pi r^2 dr$$

Show how this expression can be rearranged into two dimensionless groups, one group which includes the effects of well-depth (ε) and size (σ) (e.g. of the Sutherland potential) and another group which is a universal constant.

1.c. Estimate the vapor pressure of ethane at 244 K.

1.d. Estimate the heat of vaporization of ethane at 244 K.

2. Ethane is continuously compressed from 280 K and 1 bar to 310 K and 75 bar. Compute the change in enthalpy per gmol of ethane. (Cp/R = 5).

3. Ethane is expanded through an adiabatic, reversible turbine from 75 bar and 310 K to 1 bar. Estimate the temperature of the stream exiting the turbine and the work per gmol of ethane. (Hint: Is the exiting ethane vapor, liquid, or a little of each?)(Cp/R = 5)

4. Evaluate $(dG/dV)_T$ in terms of p, v, T, Cp, Cv, and their derivatives. Your answer may include absolute values of S if it is not associated with a derivative.

5. Develop an expression for the departure function based on the equation of state given below such that its value may be computed given T,P, and .

$[G(T,p)-G^{ig}(T,p)]/nRT$

where $Z = 1 + b\rho/(1-b\rho) - a\rho/RT^{3/2}(1+b\rho)$

(This is the Redlich-Kwong (1958)eqn. $-\ln(1-b\rho)-a/bRT^{3/2}\ln(1+b\rho)+Z-1-\ln Z$)

6. Our space program requires a portable engine to generate electricity for a space station. It is proposed to use sodium as the working fluid in a customized form of a "Rankine" cycle. The high temperature stream is not superheated before running through the turbine. Instead, the saturated vapor is run directly through the (100% efficient, adiabatic) turbine. The rest of the Rankine cycle is the usual. That is, the outlet of the turbine is cooled to saturated liquid which is pumped (neglect the pump work) back into the boiler. The cycle is to operate between T_L =1156 K (this is the boiling temperature of sodium) and T_H =1444 K.

a) Estimate the quality coming out of the turbine.

b) Compute the work output per unit of heat input to the cycle, and compare it to the value for a Carnot cycle operating between the same T_H and T_L .

(T_c =2300 K; P_c =195 bar; ω=0 ; C_P/R = 2.5)

Answers: 1.c)11.2 bar d)2777 cal/mol 2)-1852cal/mol 3)-745cal/gmol 4)$V(dp/dV)_T$ 5)$-\ln(1-b\rho)-a/bRT^{3/2}\ln(1+b\rho)+Z-1-\ln Z$ 6.a)90% b).184

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TEST 2 SSN_______

1a. Compute the specific volume (cc/mol) of saturated liquid isopentane at 1 bar. T_c =460.4; P_c =33.84 bar; ω=.227

1b. Estimate the work (J/mol) of adiabatically and reversibly compressing saturated liquid isopentane from 0.1 MPa to 20 MPa in a continuous process.

1c. Estimate the vapor pressure (bar) of isopentane at 400K.

1d. 1 liter of air (Cp/R=3.5) at 273K is to be compressed adiabatically and reversibly in a piston+cylinder to 0.1 liter. Estimate the final temperature. (5)

2. Ammonia is to be isothermally compressed in a specially designed flow turbine from 1 bar and 100°C to 50 bar. If the compression is done reversibly, compute the heat flow needed per mole of ammonia. T_c =405.6K; P_c =112.8 bar; ω=0.250; C_P/R=4.6 (20)

3. Express in terms of in terms of only P, V, T, C_P, C_V and their derivatives. Your answer may include absolute values of S if it is not associated with a derivative. $(\partial U/\partial T)_A$.(10)

4. Suppose $u(r)$ is given by the square-well potential and $g(r)$=10-5(r/σ) for $r>\sigma$. Evaluate the internal energy departure function where $N_A\rho\sigma^3$=1 and ε/kT=1. (10) -5.7π

5. A tank containing carbon dioxide (C_P/R=4.5) at 350 K and 50 bar is vented until the temperature in the tank falls to 280K. Assuming no heat transfers between the gas and tank find the pressure in the tank at the end of the venting process.
T_c =304.2K; P_c =73.76 bar; ω=.225 (20)

6. In our discussion of departure functions we derived the following expression for evaluating the internal energy departure function given any equation of state.

$$\frac{\left(U-U^{ig}\right)}{RT}=\int_o^\rho -T\left[\frac{\partial Z}{\partial T}\right]\frac{d\rho}{\rho}$$

a) Derive the analogous expression for $(C_v-C_v^{ig})/R$

b) Derive an expression for $(C_v-C_v^{ig})$/R in terms of a, b, ρ, T for the EOS:

$$Z=1+\frac{b\rho}{1+b\rho}-\rho[\exp(a/T)-1]$$

Answers: 1a) 112 (b) 2220 J/mol (c)12.5bar(d)686K (2)-13900J/mol(3)Cv-$S/p[T(dp/dT)-p]$

(4) -5.7π (5)20.8bar(6.a) ($\int_o^\rho -2T\left[\frac{\partial Z}{\partial T}\right]-T^2\left[\frac{\partial^2 Z}{\partial T^2}\right]\frac{d\rho}{\rho}$(b) $a^2\rho T^{-2}\exp(a/T)$)

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TEST 2 NAME_______

1a. Compute the density (g/cc) of liquid MethylTertiaryButylEther (MTBE) (MW=88) at 1 bar and 300K. T_c =496.4; P_c =33.7 bar; ω =.269(5)

1b. Estimate the vapor pressure (bar) of MTBE at 400K.(5)

1c. When the radial distribution function is equal to unity, how does the coordination number change with respect to the range of the neighborhood around the central atom?. Give an equation with no integral signs in it. (5)

2. Express in terms of in terms of only P, V, T, C_P, C_V and their derivatives. Your answer may include absolute values of S if it is not associated with a derivative. $(\partial A/\partial V)_P$.(10)

3. Ammonia is continuously compressed from 1 bar and 100°C to 50 bar and 150°C. Compute the enthalpy change per mole of ammonia. T_c =405.6K; P_c =112.8 bar; ω=0.250; C_P/R=4.6 (20)

4. Suppose $u(r)$ is given by the 1.5 square-well potential and $g(r)$=exp(5σ/r) for r>σ. Evaluate the internal energy departure function where ρσ^3=1 and ε/kT=1. (15)

5. Vapor Freon 152a is to be adiabatically and reversibly compressed from 1 bar and 248 K to 10 bars in a continuous process. Compute the work required in Joules per mole (20) (T_c =386.7; P_c =45bar; ω=0.256; C_P =68 J/mol-K)
6. Suppose an equation of state of the form:
Z = 1 + 10 *Ybρ**exp(2 *Ybρ*) where *Y* = exp(*a/Tr*)-1 and *a,b* are constants
Develop an expression for the Helmholtz energy departure function.(20)
Answers: 1a0.76g/cc (b) 6.5 bars (c) ρ 4π/3 R^3 2. 69J/mol ± 40 J/mol 3. $-S(\partial T/\partial V)_P - P$ 4. 5092 ±400 6.5[exp(2*Yb*ρ)-1]

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TEST 2 SSN _______

1.a. Estimate the vapor pressure of propane at 325 K.
1.b. Estimate the saturated liquid density (g/cc) of propane at 325 K.
1.c. What is it about molecules that causes the compressibility factor to be less than unity most of the time?
1.d. Estimate the heat of vaporization (J/mole) of propane at 325 K.
2. Express in terms of *P, V, T, Cp, Cv,* and their derivatives. Your answer may include absolute values of *S* if it is not associated with a derivative. $(\partial S/\partial T)_H$.(10)
3. Estimate the change in en**tropy** (J/mole-K) for raising propane from a saturated **liquid** at 230K to a saturated vapor at 298K.(20) (C_P/R = 8.85)
4. Suppose the radial distribution function at intermediate densities can be reasonably represented by: g ~ $(1+2(\sigma/r)^2)$ at all temperatures. Derive an expression for the attractive contribution to the compressibility factor for fluids that can be accurately represented by the Sutherland potential.(15)
5. Suppose we wanted to design a fix-a-flat system based on propane. Let the can be 500 cc and the tire be 40,000 cc. Assume the tire remains isothermal and at low enough pressure for the ideal gas approximation to be applicable. The can is ~ filled with 250 g of saturated liquid propane at 298K. If the pressure in the can drops to 0.85 MPa, what is the pressure in the tire and the amount of propane remaining in the can? Assuming 20 psig is enough to drive the car for a while, is the pressure in the tire sufficient? Could you fill another tire?(20)
6. Even in the days of van der Waals, the second virial coefficient for square-well fluids was known to be: $B2/b = 4 + 9.5\,[\exp(N_A\varepsilon/RT)-1]$. Noting that $e^x \sim 1 + x + x^2/2$, this observation suggests the following equation of state:

$$Z = 1 + \frac{4b\rho}{1-b\rho} - \frac{9.5N_A\varepsilon}{RT}b\rho$$

Derive an expression for the Helmholtz energy departure function for this equation of state. (15)
1)18bar,.44,molecular attraction,12300(2)ugly(3)79(4)$3\pi\rho\sigma^3\varepsilon/kT$(5)-4ln(1-bρ)-9.5εbρ/*kT*

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TEST 2 SSN _______
1.a. Estimate the fugacity of saturated liquid n-butane at 390 K.
1.b. Which would you expect to be higher: the density of butane at 426K and 38 bars or the density of butane at 450K and 60 bars? Why?
1.c. Why does the radial distribution function go to zero for $r < \sigma$?
1.d. Estimate the heat of vaporization (J/mole) of n-butane at 390 K.
2. n-butane is isothermally compressed from 425K and 1 bar to 100 bars. Estimate the change in enthalpy (J/mole).
3. Estimate the work output (J/mole) for n-butane when it is continuously, adiabatically, and reversibly expanded from a saturated **liquid** at 390K to 1.5 bars.(20)
4. Suppose the radial distribution function can be reasonably represented by:

$$g = 1 + \left[1 + \frac{2b\rho\cos[\pi(x-1)]}{(1-2b\rho)x^5}\right]\left[1 + \frac{\varepsilon}{kT(1+2b\rho x^5)}\right]$$ where $x \equiv r/\sigma$ and *cos* is evaluated in radians

Derive an expression for the compressibility factor for fluids that can be accurately represented by the Square-Well potential.(20)

5. Based on the work of Lee and Sandler (1986), one might propose the following equation of state:

$$Z = 1 + \frac{8b\rho}{2-4b\rho} - \frac{9.5\varepsilon b\rho}{kT}\frac{1+b\rho}{1+5b\rho\varepsilon/kT}$$

Derive an expression for the Gibbs energy departure function of this equation of state (20).

Hint: $\int \frac{xdx}{ax+b} = \frac{x}{a} - \frac{b}{a^2}\ln(ax+b)$

Answers: 1)15.6bars, 12544, (450,60), 2 in same place (2) -15235 (3) -2804

(4) $Z = 1 + 4b\rho\left\{\left[1+\frac{2b\rho}{(1-2b\rho)}\right]\left[1+\frac{\varepsilon/kT}{(1+2b\rho)}\right] - 1.5^3\left[\exp(\varepsilon/kT)-1\right]\left[1+\frac{\varepsilon/kT}{(1+15b\rho)}\right]\right\}$

(5) $\frac{G-G^{ig}}{RT} = -2\ln(1-2b\rho) - \frac{9.5}{5}\left[b\rho + (1-kT/5\varepsilon)\ln(1+5b\rho\varepsilon/kT)\right] + Z - 1 - \ln Z$

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TEST 2 SSN _______

1.a. Estimate the density (g/cm^3) of saturated liquid carbon dioxide at 290 K. (*MW*=44)

1.b. An absorption experiment requires a flow rate of 7.5 kg/hr of CO2. A standard cylinder of CO2 contains 48139 cm^{3}of saturated liquid at 290K. A typical run of the experiment takes 2 hours. How many runs can we make on one cylinder?

1.c. Write the energy and entropy balances for the above CO2 cylinder as the experiment proceeds.

1.d. Estimate the heat of vaporization of CO2 at 290K. If 1 kg of CO2 were vaporized, how much heat (kJ) would be required?

2. Express in terms of *P, V, T, Cp, Cv,* and their derivatives. Your answer may include absolute values of *S* if it is not associated with a derivative. $(\partial S/\partial U)_P$.(15)

3. A physicist studying superconductivity needs to cool his experiment by continuously passing a stream of nitrogen through a throttle impinging on his apparatus. In your calculations, please take the saturated liquid at 0.003 MPa to be the Reference State.

a. If he can maintain the outlet from the throttle at 0.003 MPa, what temperature will he maintain at the throttle outlet? (5)

b. Write the energy balance for the throttle. (5)

c. If his nitrogen inlet is saturated liquid at 0.1 MPa, what quality is obtained from the throttle at 0.003 MPa? In your calculations, please take the saturated liquid at 0.003 MPa to be the reference state. (15)

4. Suppose the radial distribution function can be reasonably represented by:

$$g = \left[1 + \frac{Y}{(1+2b\rho)x^2}\right]$$

where $x \equiv r/\sigma$, $Y = [\exp(N_A\varepsilon/RT)-1]$, and $b = \pi N_A \sigma^3/6$

a. Derive an expression for the internal energy departure function for fluids that can be accurately represented by the Square-Well potential.(15)

b. Evaluate the expression at $b\rho = 0.3$ and $\varepsilon/kT = 0.5$ (5)

5. Based on the work of Kihara (1976), the third virial coefficient for the square-well fluid can be written as:

$B3^* = B3/b^2 = 10 - 19.5\,Y + 30.5\,Y^2 - 8.5\,Y^3$

Where: $Z = 1 + B2^*\,\eta + B3^*\,\eta^2$

$Y = [\exp(N_A\varepsilon/RT)-1]$, and $b = \pi N_A \sigma^3/6$, $\eta = b\rho$, $B2^* = 4 - 9.5\,Y$

Derive an expression for the Internal energy departure function of this equation of state(20).

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TEST 2 SSN _______

1.a. Estimate the density (g/cm^3) of saturated liquid propylene at its normal boiling temperature. (MW=42) (5)

T_c = 364.8, P_c = 4.613 MPa, ω = 0.142, A = 3.710, B = 0.2345, C = -1.16E-4, D=2.205E-8

1.b. Compute the heat of vaporization (kJ/kg) of propylene at its normal boiling temperature.(5)
1.c. Write the energy and entropy balances for reversible, **isothermal** compression of propylene from 1 bar and 298K to 22 bars. (5)

2. Express in terms of *P, V, T, Cp, Cv,* and their derivatives. Your answer may include absolute values of *S* if it is not associated with a derivative. $(\partial V/\partial T)_U$.(10)

3. Propylene (NOT propane) is to be used in a vapor compression cycle with turbine expansion operating between 297K at the exit from the condenser and 187K in the evaporator. The heat removal rate from the evaporator is to be 215,000 kJ/hr. The compressor and turbine can be assumed adiabatic and reversible. Compute the Coefficient of Performance of this cycle using propylene.(20)
$T_c = 364.8$, $P_c = 4.613$ MPa, $\omega = 0.142$, $A = 3.710$, $B = 0.2345$, $C = -1.16\text{E-}4$, D=2.205E-8

4. 300 lbs of saturated liquid propylene at 297K initially fill a tank to supply an absorption test apparatus. 15 lbs per hour are used in the experiment. Assuming the supply tank is adiabatic and that only saturated liquid enters the valve and that vapor at 255K and 1 bar exits the valve, what heat rate (kW) is required for the valve? The heat rate required during the first few minutes will be sufficient. (20)

5. Suppose the radial distribution function can be reasonably approximated by:

$$g = \left[\frac{1-b\rho/2}{(1-b\rho)^2}\right]\exp\left\{\frac{N_A\varepsilon}{RT}\left[1-\frac{b\rho(3-1/x)}{(1-b\rho)}\right]\right\}$$

where $x \equiv r/\sigma$, ρ is the molar density, and $b = \pi N_A \sigma^3/6$
a. Referring to the pressure equation, derive an expression for the compressibility factor for fluids that can be accurately represented by the Square-Well potential.(15)
b. Evaluate the expression at $b\rho = 0.333$ and $\varepsilon/kT = 0.5$ (5)
6. As part of a new equation of state, one might propose the following equation of state:

$$Z = 1 + \frac{4b\rho}{(1-b\rho)^2} - \frac{9.5b\rho N_A\varepsilon}{RT}\exp\left\{\frac{N_A\varepsilon}{RT}[1-3b\rho]\right\}$$

Derive an expression for the Internal energy departure function of this equation of state (15).

Hint: $\int y\exp(ay)dy = \frac{\exp(ay)}{a}\left(y-\frac{1}{a}\right)$

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TEST 2 SSN________

1. Short Answer
a) Estimate the density of mercury (g/cc) at 0.1 MPa and 300 K. (T_c =1735 K, P_c =161 MPa, ω=-0.1644, MW = 201 g/mole)

b) Estimate the saturation temperature of mercury at 0.1MPa. (T_c =1735 K, P_c =161 MPa, ω= -0.1644)
(Hint: Are there any other questions on this test for which knowing the vapor pressure might be helpful?)

c) Estimate the change in entropy (J/mole-K) in going from carbon monoxide at 32 MPa and 197 K to 3.2 MPa and 130 K.

2. Express in terms of *P, V, T, Cp, Cv,* and their derivatives. Your answer may include absolute values of *S* if it is not associated with a derivative. $(\partial V/\partial T)_G$. (10)

3. Saturated vapor mercury is to be adiabatically and reversibly compressed from 0.1 MPa to 10 MPa in a continuous process. Compute the work required in Joules per mole. (20) (T_c =1735 K, P_c =161 MPa, ω=-0.1644, C_P/R =2.5)

4. As part of a new equation of state, the following contribution has been proposed:

$$Z = 1 + \frac{4b\rho}{[1 - 2.5b\rho + 1.5(b\rho)^2]}$$

Derive an expression for the Helmholtz energy departure function of this equation of state (20).

5. A single-stage Rankine cycle for power generation is to operate on mercury as the working fluid. The condenser is to operate at 383°C and the boiler is to operate at 10 MPa. The exit from the adiabatic, reversible turbine is saturated vapor. Estimate the thermodynamic efficiency of this cycle and compare it to the value for the Carnot cycle operating between the same highest and lowest temperatures. (T_c =1735 K, P_c =161 MPa, ω= -0.1644, C_P/R =2.5) (15)

6. Suppose the radial distribution function can be reasonably approximated by:

$$g = 1 + \frac{2b\rho\varepsilon}{kT(1 - 2b\rho)} \frac{\cos(x-1)}{x^2}$$

where $x \equiv r/\sigma$, cosine function is in radians, ρ is the molar density, and $b = \pi N_A \sigma^3/6$

a. Referring to the pressure equation, derive an expression for the compressibility factor for fluids that can be accurately represented by the Square-Well potential.(15)

b. Evaluate the expression at $b\rho$ = 0.34 and ε/kT = 0.5 (5)