ENGG 201 Winter 2013 – Volumetric Behaviour of Liquids Problem Set

Problem #1 – Winter 2012 Midterm 2

Use the data at the end of this exam (Table 7-1 and Table 7-2) to answer the following questions about liquid carbon tetrachloride (M=153.8 kg/kmol, T_c=556.4K, P_c=4493 kPa).

a) Calculate the volume occupied by 5 kg of carbon tetrachloride at 35°C and 1 atm using the data in Table 7-2. (/6)
b) Estimate the average isobaric coefficient of volume expansion for carbon tetrachloride between 35°C and 55°C at 1 atm. (/5)
c) Using Tait's law, calculate the volume occupied by 5 kg of carbon tetrachloride at 35°C and 200 atm. (/7) (use c and d from solution)
d) Use the Generalized Compressibility chart to estimate the molar volume of carbon tetrachloride at 35°C and 1347 kPa. (/4)

Answers: a) $3.2\times10^{-3}m^3$; b) $1.2925\times10^{-3}K^{-1}$; c) c=0.10384, d=856.6 atm, $3.125\times10^{-3}m^3$; d) 0.095 m^3/kmol

Problem #2 – Winter 2011 Quiz 4

The critical pressure of hexane is 3020 kPa and the critical temperature is 234.5°C. Use this information and the generalized compressibility chart to estimate the volume of 2 kmol of liquid hexane at 1420 kPa and 183.75°C. (/2)

Answer: 0.4815 m^3

Problem #3 – Winter 2008 Quiz 4

Calculate the specific volume of carbon tetrachloride at 25°C and 400 atm using the information in Table 7-1. The specific volume of carbon tetrachloride at 25°C and 1atm is 6.312×10^{-4} m^3/kg.*(/3)*

Answer: c=0.1066, d=985.14 atm, $6.0827\times10^{-4}m^3$/kg

Problem #4 – Winter 2005 Quiz 4

The isothermal compressibility of carbon tetrachloride (M=153.8 kg/kmol) at 35°C and 1 atm is $11.95\times10^{-10}m^2$/N, and at 35°C and 1000 atm is 5.52 $\times10^{-10}m^2$/N. Use the data to calculate the specific volume of liquid carbon tetrachloride at 700 atm and 35°C, given that the specific volume of liquid carbon tetrachloride at 1 atm and 35°C is 6.39×10^{-4} m^3/kg. (*3 Marks*).

Answer: c=0.1039, d=857.7 atm, $5.994\times10^{-4}m^3$/kg

Volumetric Behaviour of Liquids

$$\beta_T = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T \qquad \alpha_P = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \qquad \gamma_V = \frac{1}{P}\left(\frac{\partial P}{\partial T}\right)_V$$

$$V_T = V_{T_o}\left(1 + A\theta + B\theta^2 + C\theta^3\right)$$

Tait's Equation

$$\beta_T = \frac{c}{P+d} \qquad \frac{V_o - V}{V_o} = c\ln\left[\frac{P+d}{d}\right]$$

Table 7-1 Isothermal Compressibilities of Selected Liquids

Liquid	Temperature °C	$\beta \times 10^{10}$, m²/N 1 atm	1000 atm
Benzene	25	9.67	5.07
	35	10.43	5.28
	45	11.32	5.50
	55	12.29	5.73
	65	13.39	5.98
Carbon-tetrachloride	25	10.67	5.30
	35	11.95	5.52
	45	12.54	5.75
	55	13.63	5.97
	65	14.87	6.22
n Hexane	0	13.04	5.92
	25	16.06	6.51
	40	18.31	6.89
	60	21.93	8.87
Mercury	20	0.40	0.39
Water	25	4.57	3.46
	35	4.48	3.42
	45	4.44	3.40
	55	4.44	3.42
	65	4.48	3.47

Table 7-2 Coefficients of Cubical Expansion of Liquids at 1 atm, T_o = 0°C

	A x 10^3	B x 10^6	C x 10^8	V_{T_o} x 10^3 m³/kg
Acetone	1.324	3.809	−0.87983	1.230
Benzene	1.17626	1.27755	0.80648	1.1109
Carbon-tetrachloride	1.18384	0.89881	1.35135	0.6126
Mercury	0.18169	0.00295	0.01146	0.07356
Water	−0.05325	7.6153	−4.3722	1.00013
n - Pentane	1.50697	3.435	0.975	1.549

Question Number IV *(22 Marks ~ 26 minutes)*

Use the data at the end of this exam to answer the following questions about liquid carbon tetrachloride (M=153.8 kg/kmol, T_c=556.4K, P_c=4493 kPa).

a) Calculate the volume (v) occupied by 5 kg of carbon tetrachloride at 35°C and 1 atm using the data in Table 7-2. (/6)

$$V_T = V_{T0}(1 + A\theta + B\theta^2 + C\theta^3)$$

$$\theta = 35 - 0$$

$$V_{T0} = 0.6126\times10^{-3}\ m^3/kg$$

$$V_T = 0.6126\times10^{-3}(1 + 1.18384\times10^{-3}(35) + 0.89881\times10^{-6}(35)^2 + 1.35135\times10^{-8}(35)^3)$$

$$V_T = 6.39\times10^{-4}\ m^3/kg$$

$$v = mV_T = 5\,kg \times 6.39\times10^{-4}\ m^3/kg = \boxed{3.20\times10^{-3}\ m^3}$$

b) Estimate the average isobaric coefficient of volume expansion for carbon tetrachloride between 35°C and 55°C at 1 atm. (/5)

$$V_{35} = 6.39\times10^{-4}\ m^3/kg$$

$$V_{55} = 0.6126\times10^{-3}(1 + 1.18384\times10^{-3}(55) + 0.89881\times10^{-6}(55)^2 + 1.35135\times10^{-8}(55)^3)$$

$$V_{55} = 6.56\times10^{-4}\ m^3/kg$$

$$\alpha_P = \left(\frac{\Delta V/V}{\Delta T}\right)_P = \frac{(V_{55} - V_{35})/V_{35}}{\Delta T}$$

$$\alpha_P = \frac{(6.56 - 6.39)\times10^{-4}\ m^3/kg \,/\, 6.39\times10^{-4}\ m^3/kg}{20}$$

$$\boxed{\alpha_P = 1.2925\times10^{-3}\ K^{-1}}$$

c) Using Tait's law, calculate the volume occupied by 5 kg of carbon tetrachloride at 35°C and 200 atm. (/7)

$$\frac{V_0 - V}{V_0} = c \ln\left[\frac{P+d}{d}\right] \quad @ \ 35°C$$

$P_1 = 1$ atm $\quad \beta_1 = 11.95 \times 10^{-10}\ m^2/N \times 101325\ Pa/atm = 1.21 \times 10^{-4}\ atm^{-1}$

$P_2 = 1000$ atm $\quad \beta_2 = 5.52 \times 10^{-10} m^2/N \times 101325 = 5.593 \times 10^{-5}\ atm^{-1}$

$$\beta_1 = \frac{c}{P_1 + d} \qquad \beta_2 = \frac{c}{P_2 + d} \longrightarrow c = \beta_1 (P_1 + d) - \beta_2 (P_2 + d)$$

$$d = \frac{\beta_1 P_1 - \beta_2 P_2}{\beta_2 - \beta_1} = \frac{(1.21 \times 10^{-4})(1) - (5.593 \times 10^{-5})(1000)}{5.593 \times 10^{-5} - 1.21 \times 10^{-4}} = 856.617\ atm$$

$$c = \beta_1 (P_1 + d) = 1.21 \times 10^{-4}(1 + 856.617) = 0.10384$$

$$\frac{V_0 - V}{V_0} = c \ln\left[\frac{P+d}{d}\right] \longrightarrow V = V_0\left(1 - c \ln \frac{P+d}{d}\right)$$

$V_0 = 6.39 \times 10^{-4}\ m^3/kg \quad @ \ 1\ atm, 35°C$

$$V = 6.39 \times 10^{-4}\left(1 - 0.10384 \ln\left(\frac{200 + 856.617}{856.617}\right)\right)$$

$$V = 6.25 \times 10^{-4}\ m^3/kg$$

$$V = \frac{v}{m} \rightarrow v = Vm = 5\ kg \times 6.25 \times 10^{-4}\ m^3/kg$$

$$\boxed{v = 3.125 \times 10^{-3}\ m^3}$$

d) Use the Generalized Compressibility chart to estimate the molar volume of carbon tetrachloride at 35°C and 1347 kPa. (/4)

$T_r = T/T_c = 308.15/556.4 = 0.55$

$P_r = P/P_c = 1347/4493 = 0.30$

$> Z = 0.05$ (chart)

$$V_m = \frac{ZRT}{P} = \frac{(0.05)(8.314)(308.15)}{1347} = \boxed{0.095\ m^3/kmol}$$

$$\left(\text{EXTRA} \rightarrow V = \frac{0.095}{153.8} = 6.18 \times 10^{-4}\ m^3/kg\right)$$

Name____Date__March 22, 2011____ Tutorial _03_

2. The critical pressure of hexane is 3020 kPa and the critical temperature is 234.5°C. Use this information and the generalized compressibility chart to estimate the volume of 2 kmol of liquid hexane at 1420 kPa and 183.75°C. (/2)

$P_c = 3020 \text{ kPa}$

$T_c = 234.5\ °C = 507.65$

$P = 1420 \text{ kPa}$

$T = 183.75°C = 456.9 K$

$$T_r = \frac{T}{T_c} = \frac{456.9}{507.65} = \underline{0.90}$$

$$P_r = \frac{P}{P_c} = \frac{1420}{3020} = \underline{0.47}$$

$$Z_c = 0.09$$

$$PV_m = ZRT$$

$$V_m = \frac{ZRT}{P} = \frac{0.09\left(8.314 \frac{\text{kPa m}^3}{\text{kmol K}}\right)(456.9 K)}{1420 \text{ kPa}}$$

$$V_m = 0.24076 \text{ m}^3/\text{kmol}$$

$$V_m = \frac{V}{n} \rightarrow V = V_m n$$

$$= 0.24076 \times 2 \text{ kmol}$$

$$\boxed{V = 0.4815 \text{ m}^3}$$

Name______________________________ Date__ March 20, 2008 ____ Tutorial _01_

4. Calculate the specific volume of carbon tetrachloride at 25°C and 400 atm using the information in the Table below. The specific volume of carbon tetrachloride at 25°C and 1atm is 6.312×10^{-4} m^3/kg. (/3)

Table 7-1 Isothermal Compressibilities of Selected Liquids

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	35	11.95	5.52
	45	12.54	5.75
	55	13.63	5.97
	65	14.87	6.22

$V = ?$ @ 25°C, 400 atm

$$\frac{V_0 - V}{V_0} = c \ln\left[\frac{P+d}{d}\right]$$

need c, d @ 25°C

$$\beta_1 = \frac{c}{P_1 + d} \qquad \beta_2 = \frac{c}{P_2 + d}$$

$$c = \beta_1 (P_1 + d) \qquad c = \beta_2 (P_2 + d)$$

$$\beta_1 P_1 + d\beta_1 = \beta_2 P_2 + d\beta_2$$

$$d = \frac{\beta_2 P_2 - \beta_1 P_1}{\beta_1 - \beta_2}$$

$P_1 = 1$ atm

$\beta_1 = 10.67 \times 10^{-10} \frac{m^2}{N}$ ← $\frac{1}{Pa}$

$\beta_1 = 1.081 \times 10^{-4}$ atm^{-1} @ $P_1 = 1$ atm

$\beta_2 = 5.3 \times 10^{-10} \frac{m^2}{N}$

$\beta_2 = 5.37 \times 10^{-5}$ atm^{-1} @ $P_2 = 1000$ atm

$$d = \frac{(5.37 \times 10^{-5})(1000) - (1.081 \times 10^{-4})(1)}{1.081 \times 10^{-4} - 5.37 \times 10^{-5}}$$

▷ $d = 985.14$ atm

$c = \beta_1 (P_1 + d) = 1.081 \times 10^{-4} (1 + 985.14)$

▷ $c = 0.1066$

$$1 - \frac{V}{V_0} = c \ln\left[\frac{P+d}{d}\right] \rightarrow V_0\left[1 - c \ln\left[\frac{P+d}{d}\right]\right] = V$$

$$V = 6.312 \times 10^{-4} \frac{m^3}{kg}\left[1 - 0.1066 \ln\left[\frac{400 + 985.14}{985.14}\right]\right]$$

$$\boxed{V = 6.0827 \times 10^{-4} \frac{m^3}{kg}}$$

Name____________________________________Date__________________ Tutorial _03_

2. The isothermal compressibility of carbon tetrachloride (M=153.8 kg/kmol) at 35°C and 1 atm is $11.95\times10^{-10} m^2/N$, and at 35°C and 1000 atm is $5.52 \times10^{-10} m^2/N$. Use the data to calculate the specific volume of liquid carbon tetrachloride at 700 atm and 35°C, given that the specific volume of liquid carbon tetrachloride at 1 atm and 35°C is 6.39×10^{-4} m^3/kg. (*3 Marks*).

$V = ?$ @ 35 °C, 700 atm

$$\frac{V_0 - V}{V_0} = c \ln\left[\frac{P+d}{d}\right]$$

need c, d @ 35 °C

$$\beta_1 = \frac{c}{P_1 + d} \qquad \beta_2 = \frac{c}{P_2 + d}$$

$$c = \beta_1 (P_1 + d) \qquad c = \beta_2 (P_2 + d)$$

$$\beta_1 P_1 + d\beta_1 = \beta_2 P_2 + d\beta_2$$

$$d = \frac{\beta_2 P_2 - \beta_1 P_1}{\beta_1 - \beta_2}$$

Solve for c=0.1039, d=857.7 atm given data in problem

$$1 - \frac{V}{V_0} = c \ln\left[\frac{P+d}{d}\right] \rightarrow V_0\left[1 - c\ln\left[\frac{P+d}{d}\right]\right] = V$$

$$V = 6.39 \times 10^{-4} \frac{m^3}{kg}\left[1 - 0.1039 \ln\left[\frac{700 + 857.7}{857.7}\right]\right]$$

$$\boxed{V = 5.994 \times 10^{-4} \frac{m^3}{kg}}$$