

PROBLEM 11.3

KNOWN: 1000 kg of water vapor fills a 23.3-m³ tank at 360°F.

FIND: Estimate the pressure using (a) the ideal gas equation, (b) the van der Waals equation, (c) the Redlich-Kwong equation, (d) the compressibility chart, (e) the steam tables.

ANALYSIS:

(a) ideal gas equation.

$$p = \frac{RT}{V} = \frac{(8314/18.02) \left(\frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}} \right) (633 \text{ K})}{(23.31/10^3) (\text{m}^3/\text{kg})} \left| \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} \right| = 125.29 \text{ bar} \leftarrow (a)$$

(2.5% high)

(b) van der Waals equation. With a and b from Table A-24

$$p = \frac{\bar{R}T}{\bar{v}-b} - \frac{a}{\bar{v}^2} = \frac{(8314 \frac{\text{N}\cdot\text{m}}{\text{kmol}\cdot\text{K}})(633 \text{ K})}{(0.42 - 0.0305) \text{ m}^3/\text{kmol}} \left| \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} \right| - \frac{5.531 \text{ bar}(\text{m}^3/\text{kmol})^2}{(0.42 \text{ m}^3/\text{kmol})^2} = 103.76 \text{ bar} \leftarrow (b)$$

(2.4% high)

where $\bar{v} = vM = \left(\frac{23.31}{10^3} \right) \left(\frac{\text{m}^3}{\text{kg}} \right) \left(18.02 \frac{\text{kg}}{\text{kmol}} \right) = 0.42 \frac{\text{m}^3}{\text{kmol}}$

(c) Redlich-Kwong equation. with a and b from Table A-24

$$p = \frac{\bar{R}T}{\bar{v}-b} - \frac{a}{\bar{v}(\bar{v}+b)T^{1/2}} = \frac{(8314)(633)}{(0.42 - 0.0211)} \left| \frac{1}{10^5} \right| - \frac{142.59}{(0.42)(0.42 + 0.0211)(633)^{1/2}} = 101.34 \text{ bar} \leftarrow (c)$$

(2.1% high)

(d) Compressibility Chart. From Table A-1, $T_c = 647.3 \text{ K}$, $P_c = 220.9 \text{ bar}$. Thus, $T_R = 633/647.3 = 0.978$. And

$$v_R = \frac{\bar{v} P_c}{\bar{R} T_c} = \frac{(0.42 \text{ m}^3/\text{kmol})(220.9 \times 10^5 \text{ N/m}^2)}{(8314 \frac{\text{N}\cdot\text{m}}{\text{kmol}\cdot\text{K}})(647.3 \text{ K})} = 1.724$$

Then, Fig A-1 gives $Z \approx 0.81$, so

$$p = Z \frac{RT}{\bar{v}} = 0.81(125.29) = 101.48 \text{ bar} \leftarrow (d)$$

(2.1% high)

(e) Steam tables. Table A-4 gives 100 bar.

Discussion: All but the ideal gas model suggest that the pressure would be in the safe range. Using the steam table value, 100 bar, as the standard, the various methods depart by the following percentages:

- ideal gas: 2.5% high
- van der Waals: 4% high
- Redlich-Kwong: 10% high
- Compressibility chart: 1.5% high