Sharif University of Technology
School of Mechanical Engineering
Center of Excellence in Energy Conversion

Advanced Thermodynamics

Lecture 20

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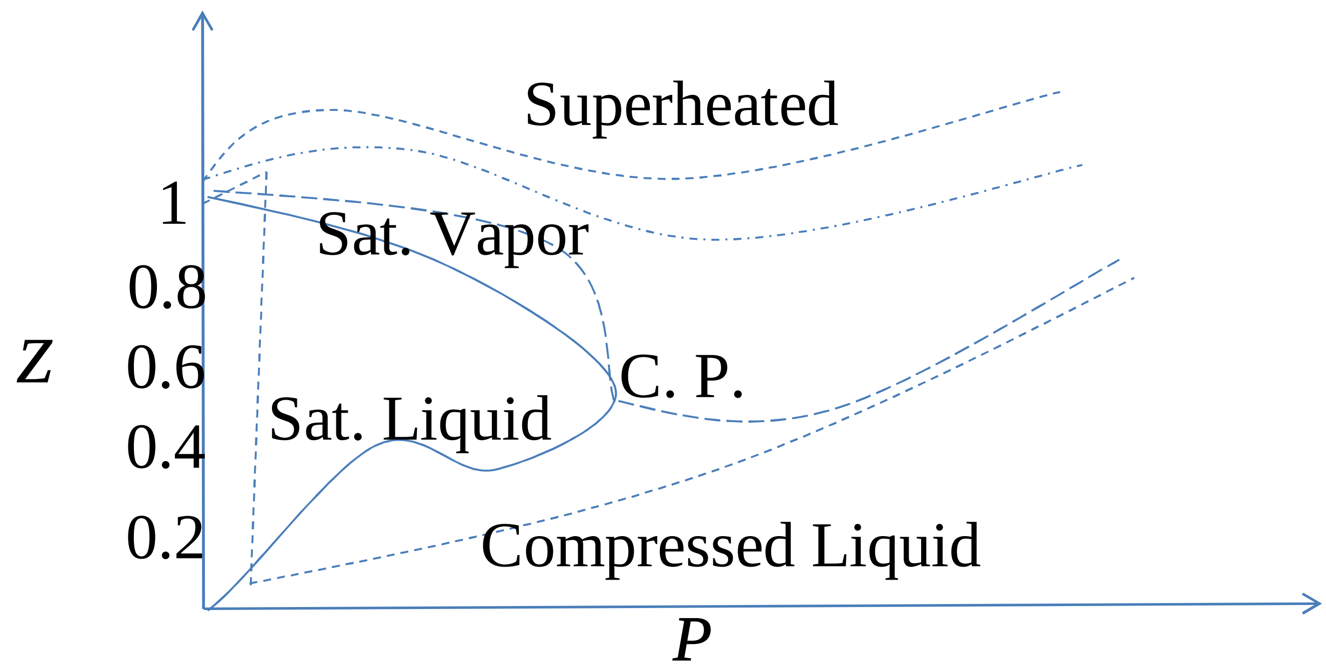
2011

- Z=compressibility factor

$$PV = ZRT = Zn\bar{R}T$$

- $Z \neq 1$ is a criterion for non-ideal gas but not sufficient



$$Z = Z(P,\ T) = Z_f + X\ Z_{fg}$$

Generalized Compressibility Chart -- "z"

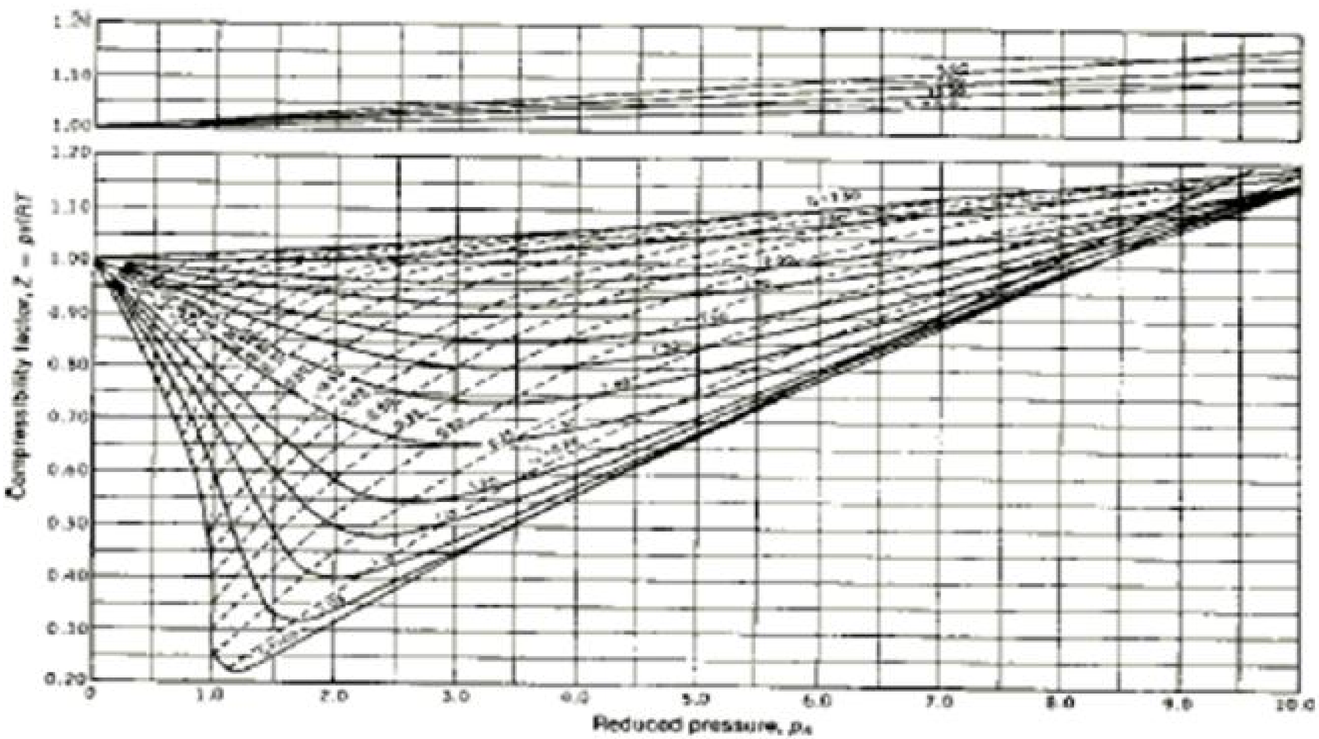
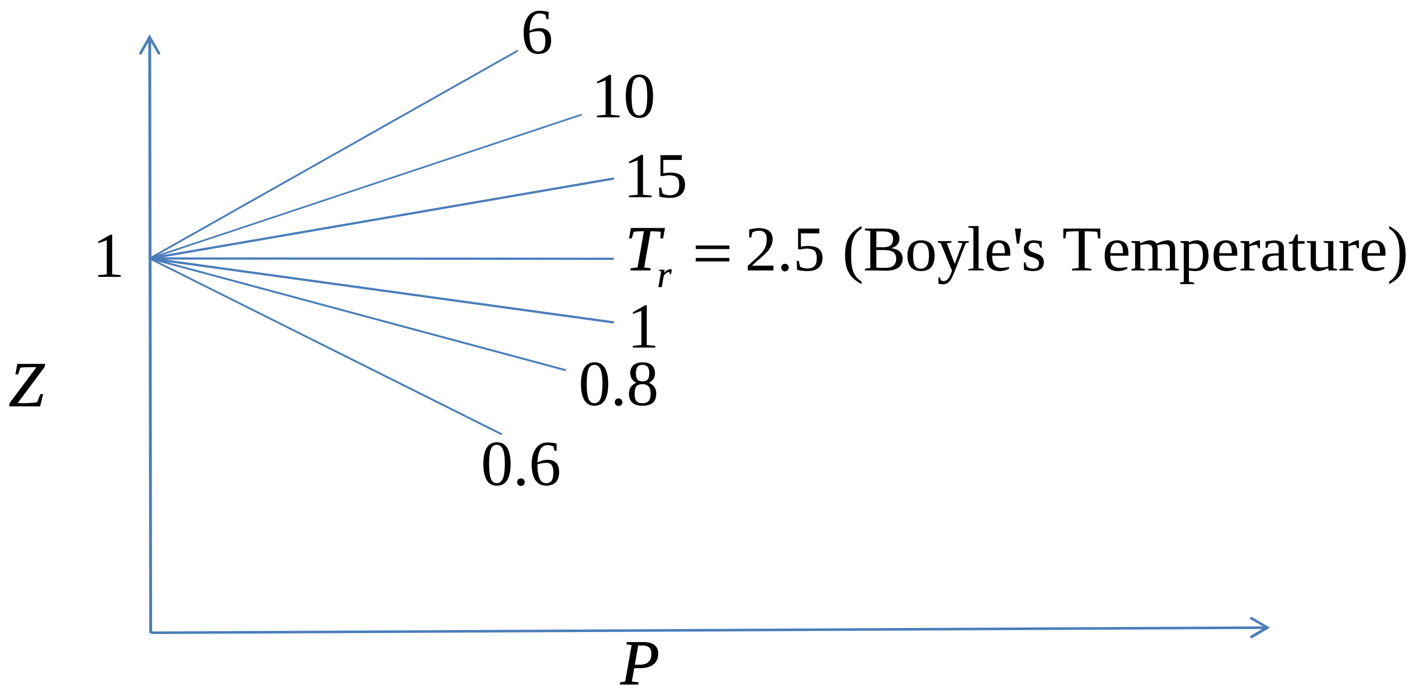


Figure A-2 Generalized compressibility chart, $p_R \le 10.0$. *Source:* E. F. Obert, *Concepts of Thermodynamics*, McGraw-Hill, New York, 1960.

Non-Ideal Gas Criteria

1. $Z = \dfrac{Pv}{RT} \neq 1$ (essential but not sufficient)



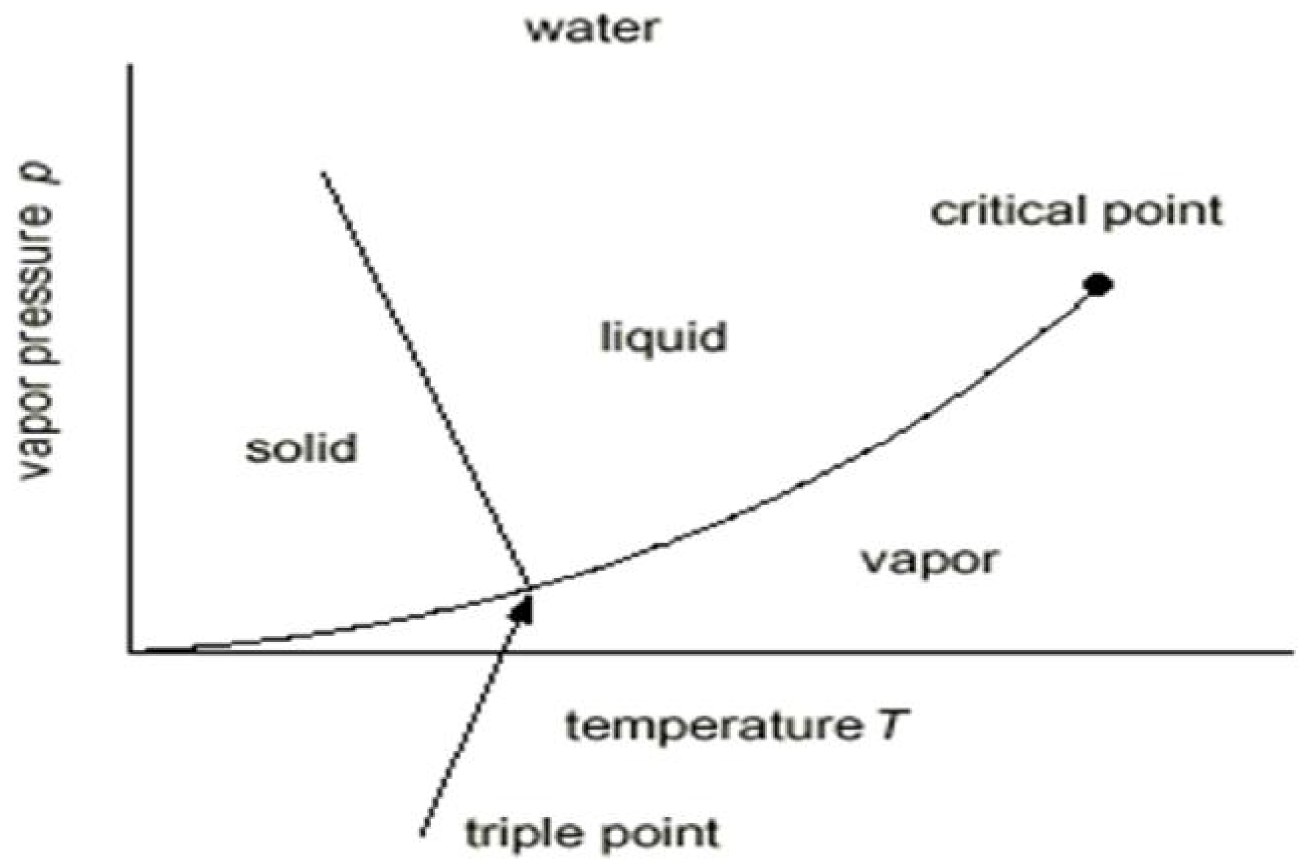
2. Remaining volume $a = \dfrac{RT}{P} - v$ Ideal Gas $\rightarrow a = 0$ (at T_r=2.5)

$$\lim\left(\frac{Z-1}{P-0}\right) = f\left(T_r\right) = -\frac{1}{RT}\lim a$$

3. Joule-Thomson coefficient (essential but not sufficient)

$$m_j = \left(\frac{\partial T}{\partial P} \right)_h$$

$$\text{Ideal Gas} \rightarrow m_j = 0$$



4. Fugacity, *f*, (essential but not sufficient)

$$\text{Ideal Gas} \rightarrow \lim_{P \to 0} f/P = 1$$

- Generalized or Reduced Properties:

1. Generalized Equations of State

    - Generalized compressibility factor chart
    - Generalized enthalpy chart
    - Generalized entropy chart
    - Generalized fugacity chart

- These are derived from the general gas behavior; without corresponding to a certain gas.

$$\left(\frac{\partial P}{\partial V}\right)_{T_C} = 0 \text{ and } \left(\frac{\partial^2 P}{\partial V^2}\right)_{T_C} = 0$$

- Ideal gas equation of state and Van der Waals equation of state

2. Empirical or Experimental Equations of State

- Obtained through experimentation and modeling.
- Example: Benedict-Webb-Raubin Equation of state

3. Analytical or Theoretical Equations of State

- Presented in Virial Form

$$Z = \frac{Pv}{RT} = 1 + \frac{B(T)}{v} + \frac{C(T)}{v^2} + \frac{D(T)}{v^3} + \ldots$$

- *B(T)*: Second virial coefficient (consideration of two molecules collision).
- *C(T)*, *D(T)*, ….
- We are looking for potential functions which calculate these forces.