THE IDEAL-GAS EQUATION

- Any equation that relates the pressure, temperature, and specific volume of a substance is referred to as an equation of state

- Property relations that involve other properties of a substance at equilibrium states are also referred to as equations of state

- The simplest and best known equation of state is the ideal-gas equation of state, which predicts the P-*v*-T behavior of a gas

or

- Any gas that obeys this relationship is referred to as an ideal gas

- In order to use this equation, ***all values ______________________________!***

THE IDEAL-GAS EQUATION OF STATE

- The gas constant R is is unique for each gas and is determined from:

- R_u is the universal gas constant and M is the molar mass

- The values for R can be found for common gases in Table A-1 and A-2 of the textbook

Substance	R, kJ/kg·K
Air	0.2870
Helium	2.0769
Argon	0.2081
Nitrogen	0.2968

$$R_u = \begin{cases} 8.31447 \text{ kJ/kmol} \cdot \text{K} \\ 8.31447 \text{ kPa} \cdot \text{m}^3/\text{kmol} \cdot \text{K} \\ 0.0831447 \text{ bar} \cdot \text{m}^3/\text{kmol} \cdot \text{K} \\ 1.98588 \text{ Btu/lbmol} \cdot \text{R} \\ 10.7316 \text{ psia} \cdot \text{ft}^3/\text{lbmol} \cdot \text{R} \\ 1545.37 \text{ ft} \cdot \text{lbf/lbmol} \cdot \text{R} \end{cases}$$

THE IDEAL-GAS EQUATION OF STATE

- The mass of a system is equal to the product of its molar mass M and the mole number N

$$m = MN$$

- It follows that the ideal gas equation of state can be written in several different forms:

$$PV = mRT$$

$$PV = NR_u T$$

$$Pv = RT$$

- It follows that for a fixed mass:

$$\frac{PV}{T} = Constant$$

THE IDEAL-GAS EQUATION OF STATE

- An ideal gas is an imaginary substance that obeys the ideal gas relationship
- It has been experimentally observed that the ideal-gas relation closely approximates real gases at ***low densities***
- Low densities are encountered when a gas is at ______________________________

  or ____

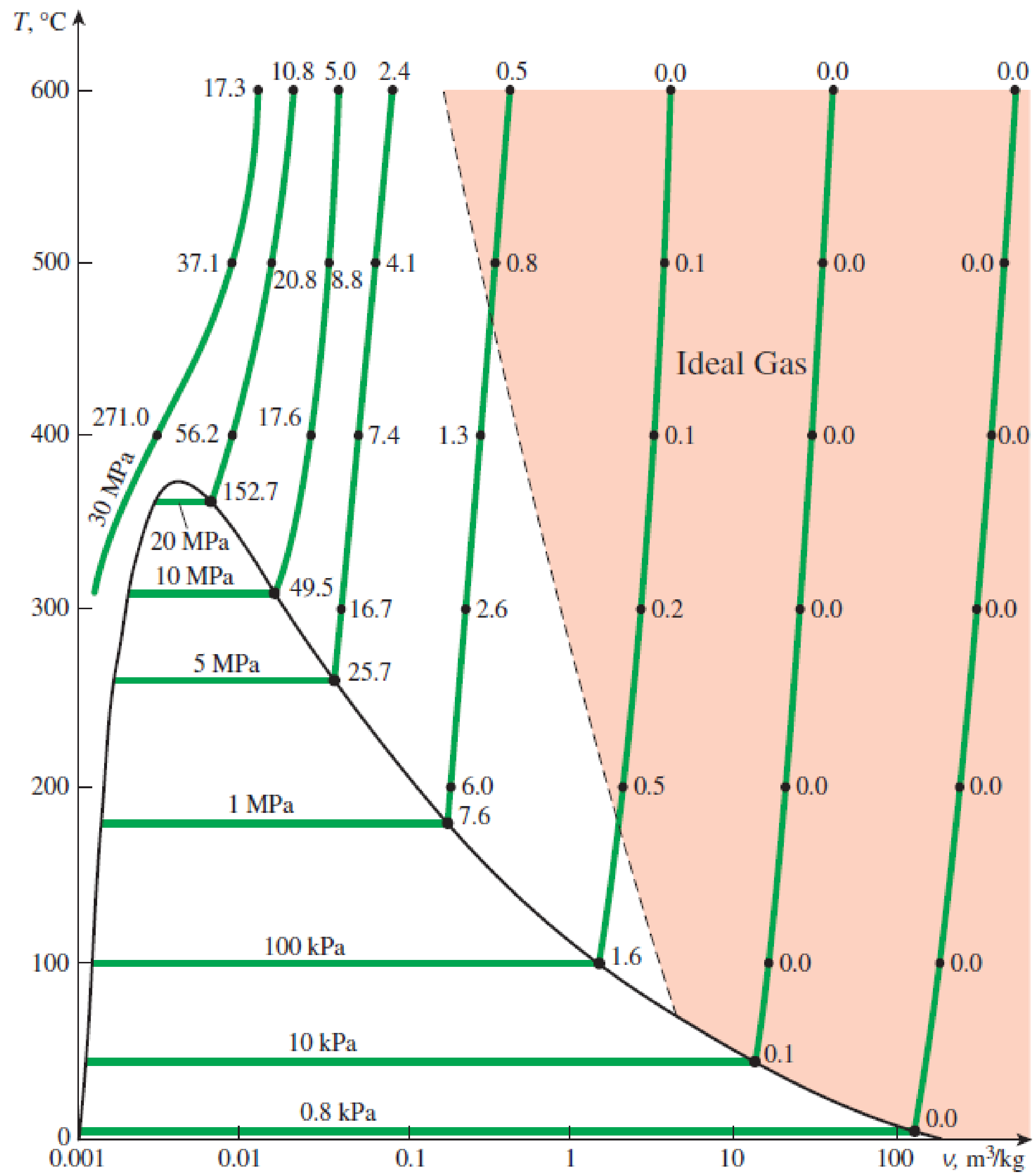
  - Familiar gases such as air, nitrogen, oxygen, hydrogen, helium, argon, krypton and carbon dioxide can ***<u>often</u>*** be treated as an ideal gas with negligible error
- However, dense gases such as ***<u>water vapor</u>*** in steam power applications and ***<u>refrigerant vapor</u>*** should not be treated as ideal gases -> _______________________

  ____

THE IDEAL-GAS EQUATION OF STATE

- At pressures below 10 kPa, water vapor can be treated as an ideal gas, regardless of its temperature, with negligible error (less than 0.1 percent).
- At higher pressures, however, the ideal gas assumption yields unacceptable errors, particularly in the vicinity of the critical point and the saturated vapor line.
- In some instances, such as air-conditioning applications, the water vapor in the air can be treated as an ideal gas since the pressure of the water vapor is very low
- However, for this class, **<u>for properties of water and R-134a</u>**

  <u>always ____________________</u>



COMPRESSIBILITY FACTOR

- The deviation of a gas from ideal-gas behavior can be easily accounted for by introducing the compressibility factor, Z:

- where

  - v_{ideal} can be calculated from the ideal-gas relationship:

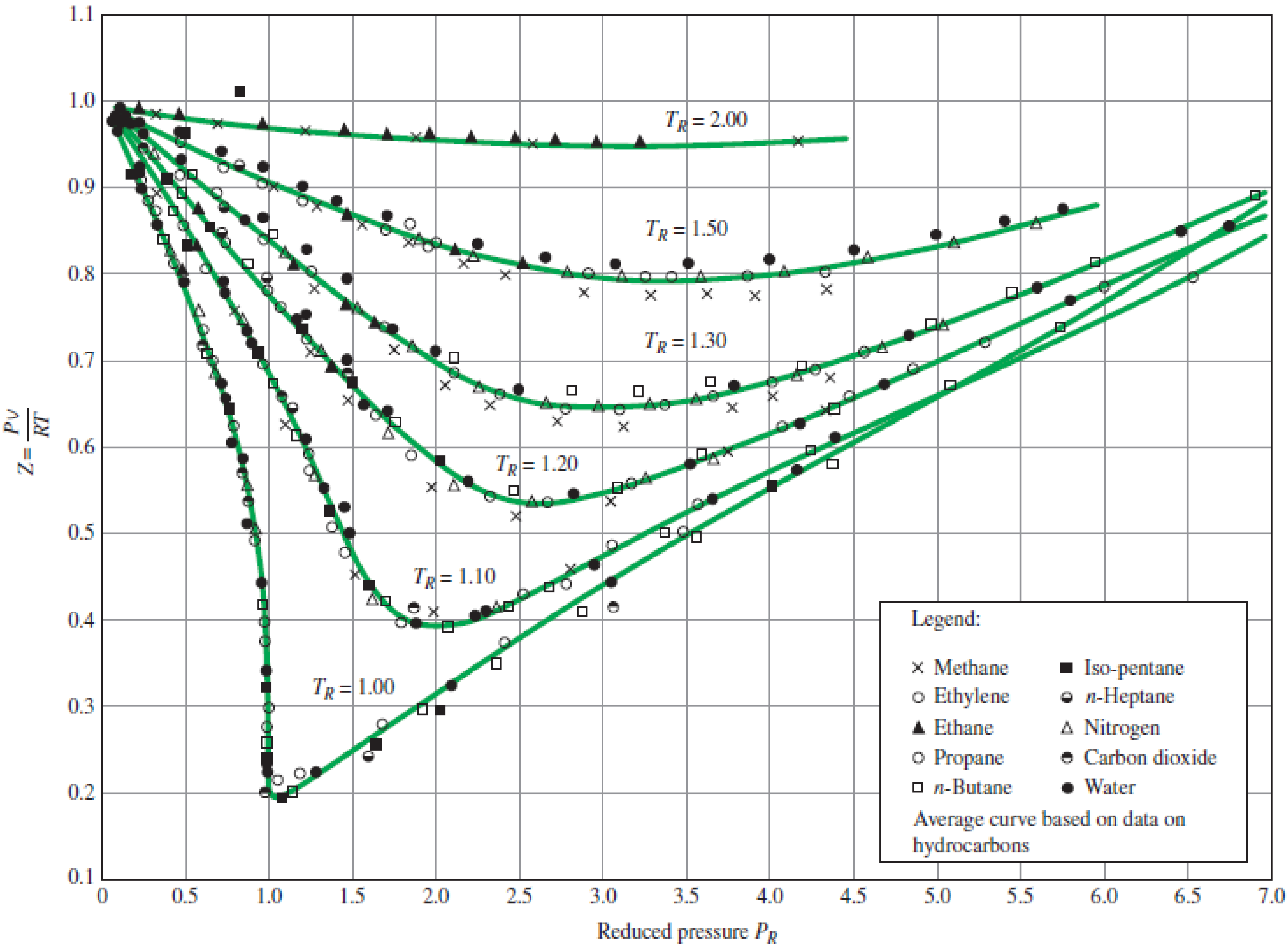
$$v_{ideal} = \frac{RT}{P}$$

- The farther Z is from a value of 1, the more the gas deviates from ideal gas behavior

COMPRESSIBILITY FACTOR

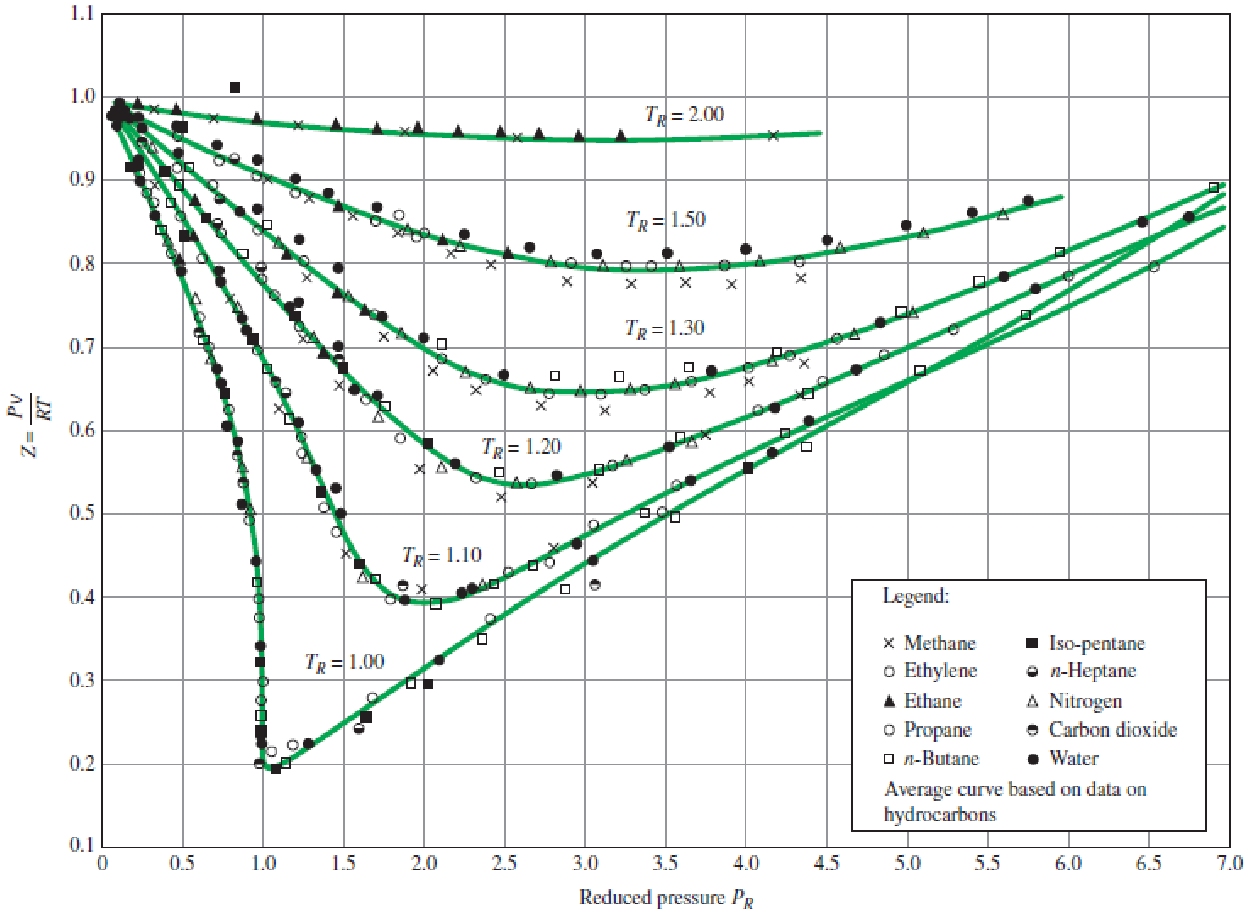
- It has been mentioned previously that the ideal-gas equation is followed by gases at low pressure and high temperatures
    - For example, at -100°C and atmospheric pressure, air can be treated as an ideal gas with under 1% error
- We define what counts as a "high" or "low" temperature / pressure by introducing a normalization
    - The reduced pressure is defined as:
    - The reduced temperature is defined as:
- For the reduced pressure and temperature, ***absolute units must be used!***
- The Z factor for all gases is approximately the same at the same reduced pressure and temperature

GENERALIZED COMPRESSIBILITY CHART – EXPERIMENTAL DATA

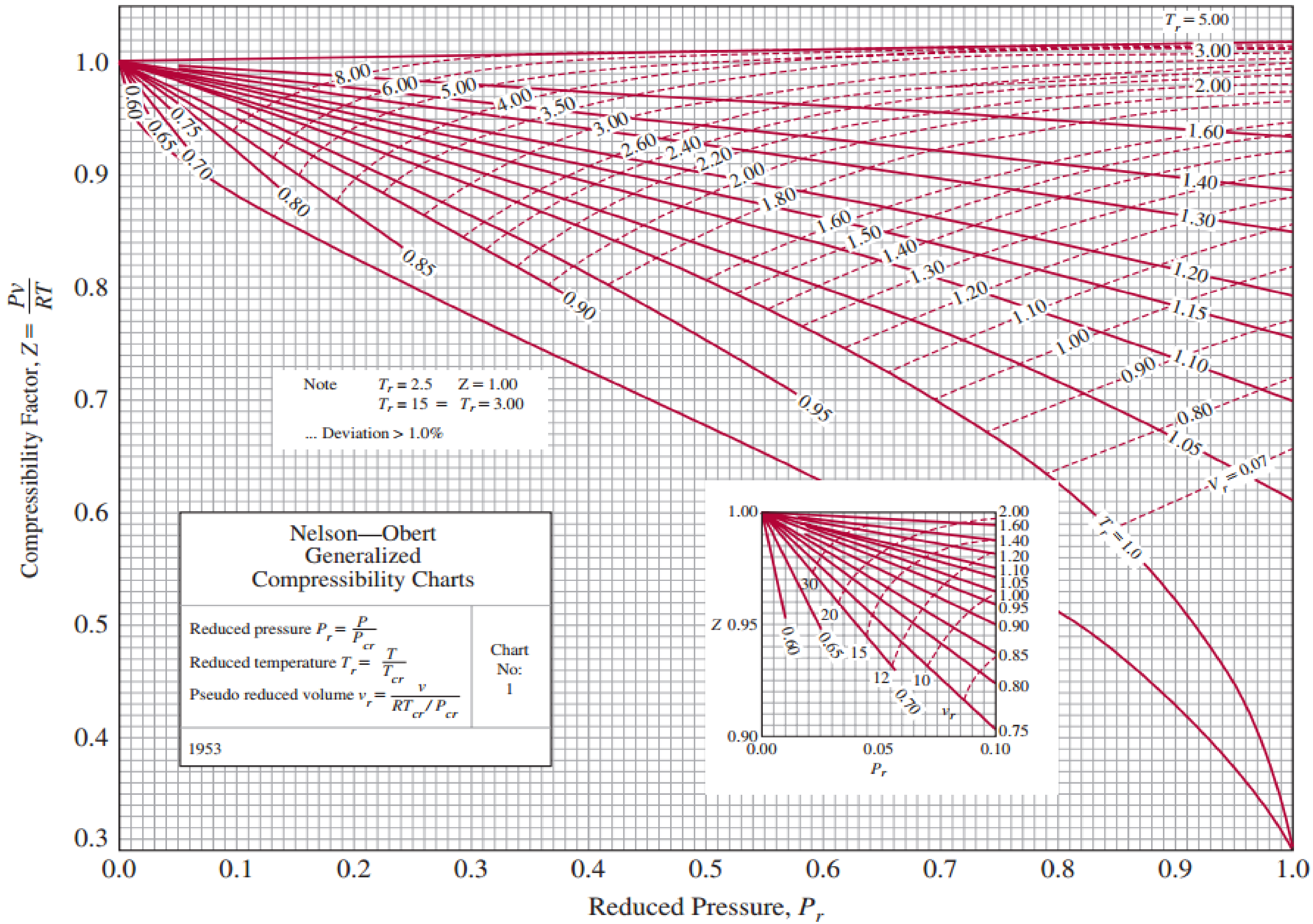


COMPRESSIBILITY FACTOR

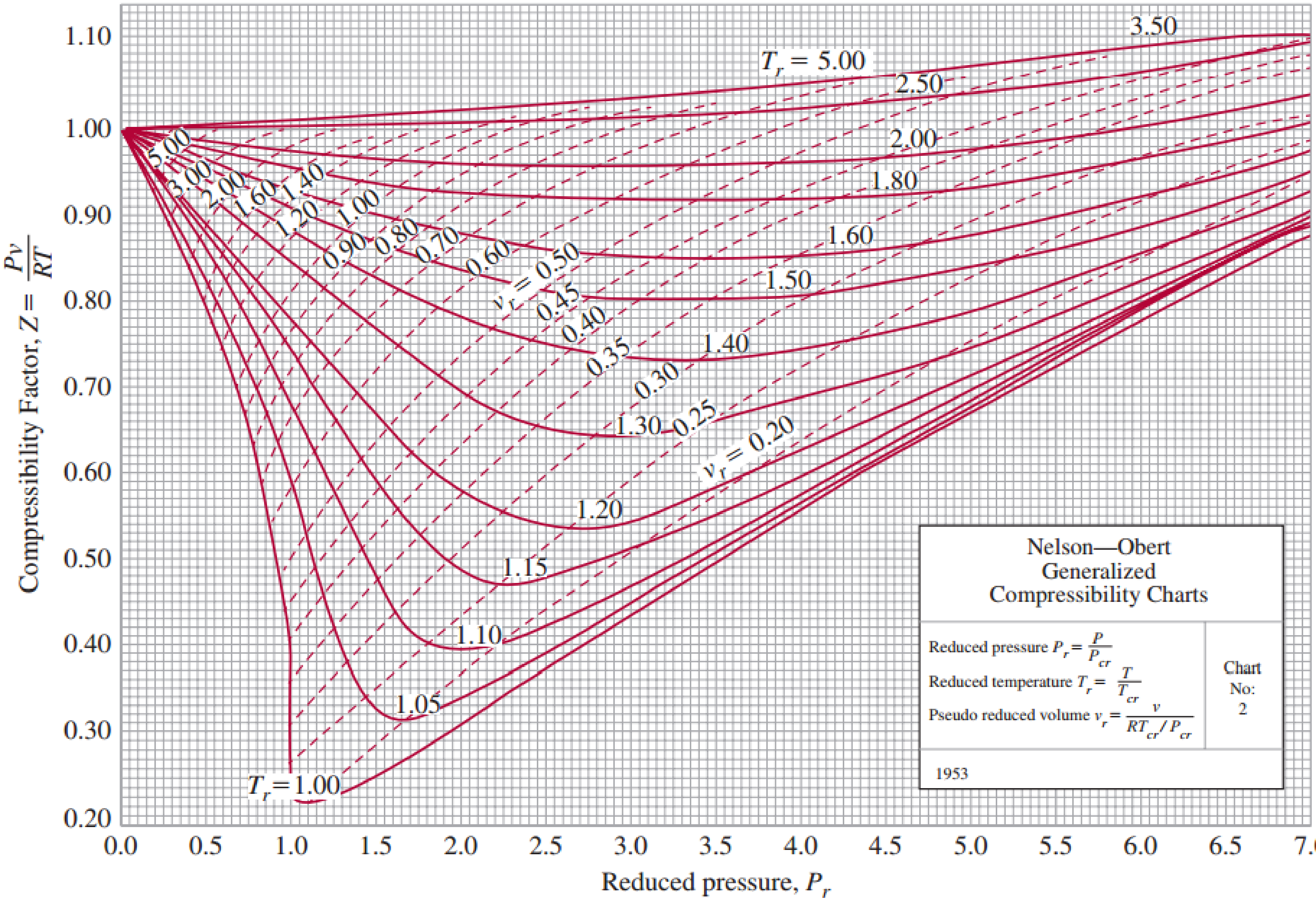
- The following observations can be made from the generalized compressibility chart
  - At very low pressures (P_R ___________), gases behave as an ideal gas regardless of temperatures (***in general – not always***)
  - At high temperatures (T_R ___________), ideal gas behavior can be assumed with good accuracy regardless of pressure (i***n general – not always***)



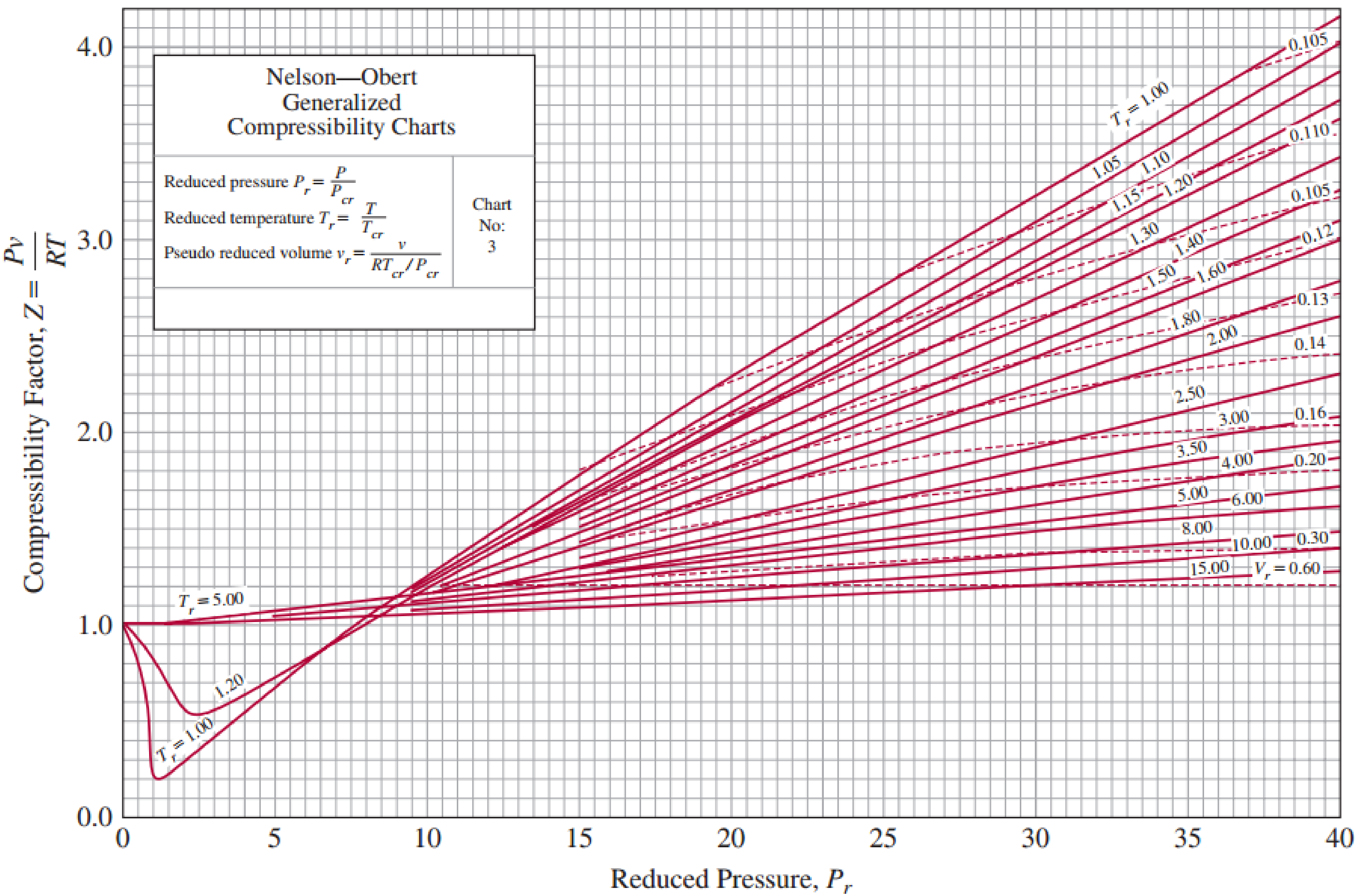
COMPRESSIBILITY FACTOR FOR P_R = 0 to 1



COMPRESSIBILITY FACTOR FOR P_R = 0 to 7



COMPRESSIBILITY FACTOR FOR P_R = 0 to 40



COMPRESSIBILITY FACTOR

- In order to use the compressibility chart when P and *v* or T and *v* are given instead of P and T, a ***pseudo-reduced specific volume*** is defined as:

- Unlike the definitions of P_R and T_R, v_R is related to both P_{CR} and T_{CR}

- Lines of constant v_R are added to the compressibility chart to enable use of v_R

COMPRESSIBILITY FACTOR

- Example 5-1:

  Determine the specific volume of nitrogen gas at 10 MPa and –123°C using (a) the ideal-gas equation (b) the compressibility chart. Determine the error involved with (a) and (b) by comparing to the experimentally measured value of 0.002388 m^3/kg.

COMPRESSIBILITY FACTOR

- Example 5-2:

  Methane at 1450 psia and 80°F is heated at constant pressure until its volume has increased by 80%. Determine the final temperature using (a) the ideal gas equation and (b) the compressibility factor.

COMPRESSIBILITY FACTOR

- Example 5-3:

  5 kg of Ethylene undergoes a constant pressure process from an initial pressure and temperature of 4.1 MPa and 310 K, respectively, to a final temperature of 775 K. Determine the change in the total internal energy of the system if 2000 kJ of heat is transferred into the system.

OTHER EQUATIONS OF STATE

- Other equations of state have also been formulated, although they are generally more complex:
  - Van der Waals Equation of State

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT \qquad a = \frac{27R^2T_{\mathrm{cr}}^2}{64P_{\mathrm{cr}}} \qquad b = \frac{RT_{\mathrm{cr}}}{8P_{\mathrm{cr}}}$$

  - Beattie-Bridgeman Equation of State

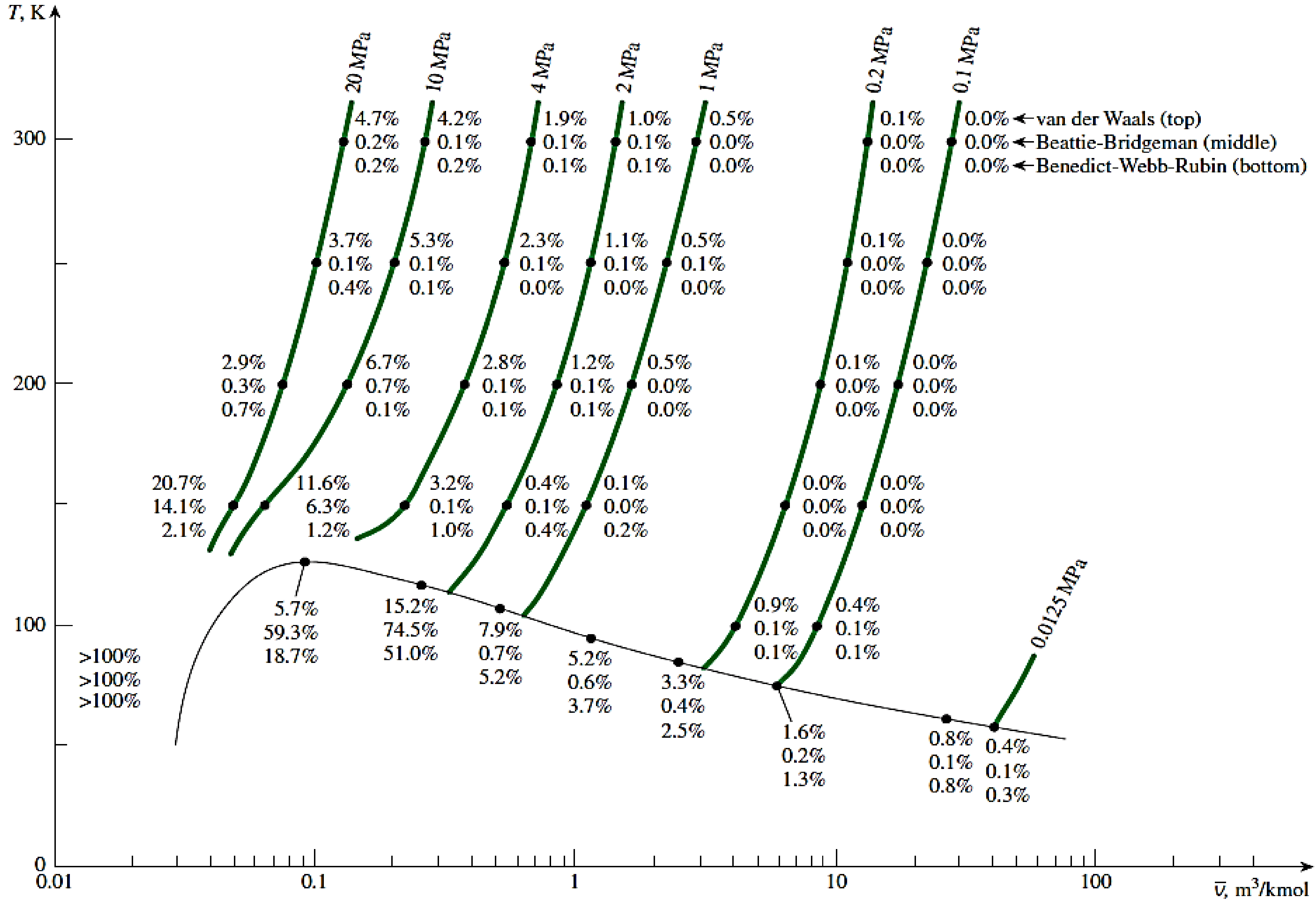
$$P = \frac{R_uT}{\overline{v}^2}\left(1 - \frac{c}{\overline{v}T^3}\right)(\overline{v} + B) - \frac{A}{\overline{v}^2}$$

$$A = A_0\left(1 - \frac{a}{\overline{v}}\right) \quad B = B_0\left(1 - \frac{b}{\overline{v}}\right)$$

  - Benedict-Webb-Rubin Equation of State

$$P = \frac{R_uT}{\overline{v}} + \left(B_0R_uT - A_0 - \frac{C_0}{T^2}\right)\frac{1}{\overline{v}^2} + \frac{bR_uT - a}{\overline{v}^3} + \frac{a\alpha}{\overline{v}^6} + \frac{c}{\overline{v}^3T^2}\left(1 + \frac{\gamma}{\overline{v}^2}\right)e^{-\gamma/\overline{v}^2}$$

OTHER EQUATIONS OF STATE – COMPARISON FOR NITROGEN



COMPRESSIBILITY – CORRECTION FOR H AND U