1.Natural Gas Properties

From the previous section it is clear that the fluid finds itself at different pressures and temperatures during the whole process of natural gas production. Unlike those of oil, natural gas properties vary significantly with pressure, temperature, and gas composition. Below is an outline of the gas properties that play very important roles in gas production, prediction, and evaluation. These include the gas specific gravity (often compared to air), the gas deviation factor, density, viscosity, isothermal compressibility, and the formation volume factor.

1.1Gas Specific Gravity

Gas specific gravity, Y_g, as commonly used in the petroleum industry, is defined as the ratio of the molecular weight of a particular natural gas to that of air. The molecular weight of a gas mixture is the summation of the products of the individual mole fractions and molecular weights of each individual component. Air itself is a mixture of gases. It contains about 21% oxygen, 78% nitrogen, and the rest are carbon dioxide, water vapor, and some inactive gases. So the molecular weight of air has been calculated as 28.97. Therefore, Y_g of a natural gas can be defined as

$$Y_g = \frac{MWm}{MWg} = \frac{\sum_{i=1}^{n} yi\, MWi}{29.97} \quad \ldots\ldots\ldots\ldots\ldots 1$$

where *yi* and *MWi* are the mole fractions and molecular weights, respectively, of individual components in the gas mixture. *n* is the total gas components in the gas mixture. Table 1–1 gives the molecular weights and critical properties for most hydrocarbon and nonhydrocarbon gases likely to be found in a natural gas reservoir. A lean or light gas reservoir contains primarily methane and ethane with small traces of other gases. Pure methane would have a gravity equal to (16.04/28.97 =) 0.55. A rich or heavy gas reservoir may have a gravity equal to 0.75 or, in some rare cases, higher than 0.9.

Example 1–1 Gas gravity

A natural gas consists of the following (molar) composition:

C1 = 0.871, C2 = 0.084, C3 = 0.023, CO2 = 0.016 and H2S = 0.006. Calculate

the gas gravity to air.

Solution

With the data in Table 1–1 and the given composition, the contributions to the natural gas molecular weight can be calculated and shown in Table B.1(356).

Therefore, the gas gravity is 18.419/28.97 = 0.64.

1.2 Gas Deviation Factor

A natural gas mixture under reservoir conditions is non-ideal and its behavior can be approximated by the real gas law, a general equation of state for gases:

$$PV = ZnRT, \text{ ....(1.2)}$$

where *Z* is the gas deviation factor or "*Z*-factor" in some petroleum literature. Chemical engineers have called it the super-compressibility factor. It is defined as the ratio of the real volume (the volume actually occupied by a gas at a given *p* and *T*) to the ideal volume (volume it would occupy had it behaved as an ideal gas). It is a measure of how a real gas deviates from ideality. The gas deviation factor is an important gas property and it is involved in calculating gas properties such as the formation volume factor, density, compressibility, and viscosity. All these properties are necessary in calculating initial gas-in-place (and, thus, reserves), predicting future gas production, and designing production tubing and pipelines (Elsharkawy and Elkamel, 2001).

The *Z* can be determined in a PVT laboratory. In common practice it is calculated from published charts such as the one shown in Figure 1 by Standing and Katz (1942). To use this chart, it is necessary to calculate the pseudoreduced properties (pressure and temperature).

Pseudoreduced Properties

For gas mixtures, the gas critical pressure and temperature are called pseudocritical pressure and temperature to be distinguished from those of pure components, and can be calculated as:

$$Ppc = \sum_1^n yiPci \text{ ....3}$$

$$Tpc = \sum_1^n yiTpci \text{ ....4}$$

where *pci* and *Tci* are critical pressures and temperatures of individual components, respectively. The temperature must be absolute (R or K), which is simply °F + 460 or °C + 273. The pseudoreduced pressure and temperature of the mixture are simply:

$$\text{Pr}= \frac{P}{Ppc} \text{ ....5}$$

$$\text{Tr}=\frac{T}{Tpc}\text{...............................6}$$

As can be seen from Figure 1–8, at the standard conditions of Psc = 14.7 psi and Tsc = 60°F = 520 R, the gas deviation factor, Zsc, can be taken as equal to 1.

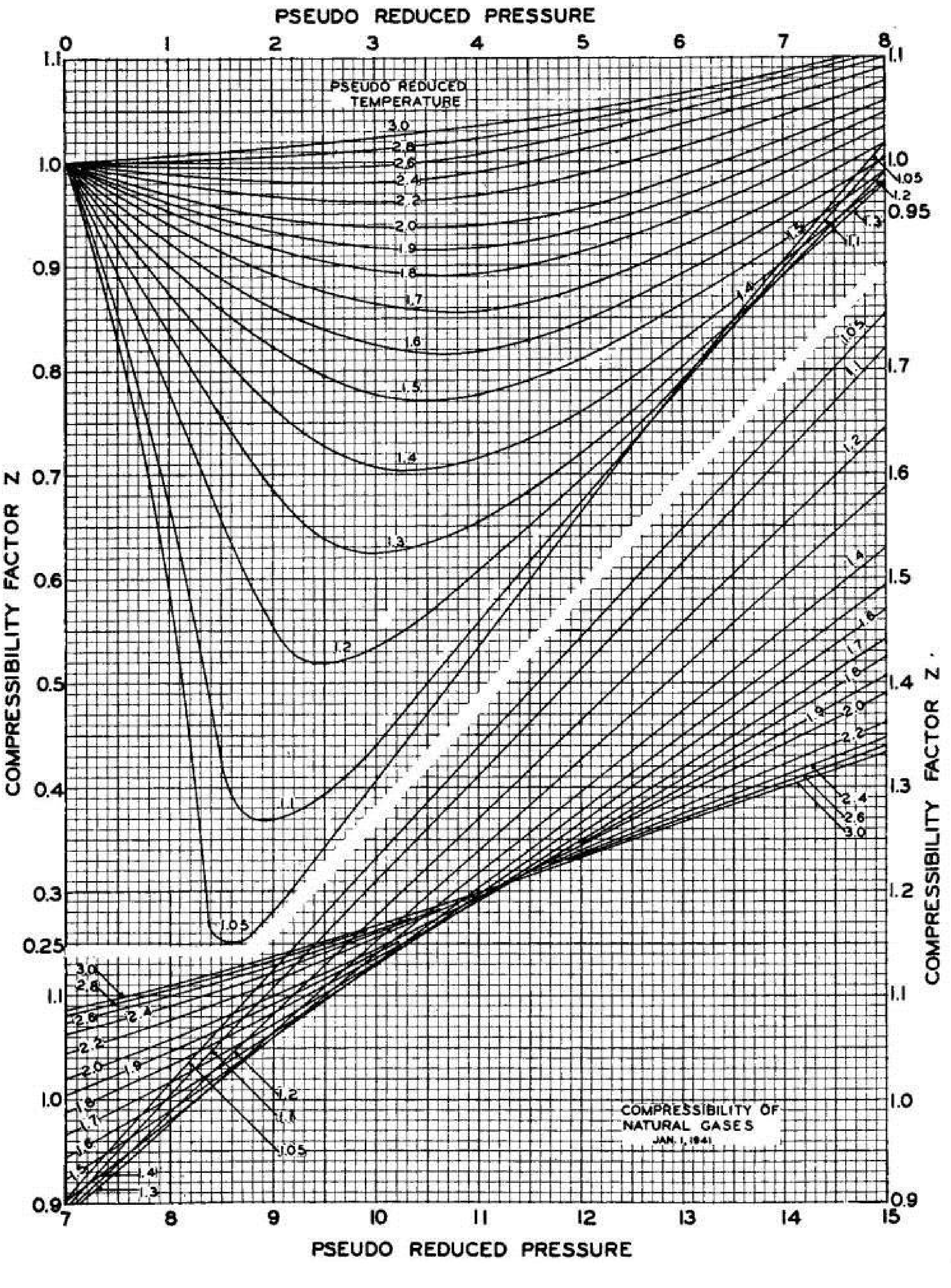

Figure 1 *The gas deviation factor for natural gases* (Standing and Katz, 1942).

Pseudocritical properties of gas mixtures can be estimated from the given gas specific gravity if gas composition is not known. Figure 2 relates the gas specific gravity (to air) with the pseudocritical properties of gas mixtures. This chart can be used as an approximation when only the gas specific gravity is known or when a quick calculation is indicated.

Example 1–2 Calculations with real gas law Given the natural gas gravity to air *gg* = 0.75, the pseudocritical pressure, *ppc* and temperature, *Tpc* are 667 psi and 405 R, respectively. If the pressure and temperature are 1,500 psi and 20°F, respectively, calculate how many lb of gas can fit in 1,000 ft3 of space? At what pressure increase would the mass increase by 50%, if the temperature remains constant?

Solution

For T = 20°F = 480 R, Tpr = 480/405 = 1.19 (which will remain constant). For P = 1,500 psi, Ppr = 1,500/667 = 2.25. From Figure 1, Z is obtained as 0.51. By using the real gas law and gas gravity definition, the mass of gas that can fit in 1,000 ft^3 of space is:

m= 12 408 lb.

Example1- 3 Calculation of gas reservoir volume Use the real gas law to calculate the volume of 5 lb-mol of a gas mixture at reservoir conditions of T = 180°F and p = 4,000 psi. Assume that this natural gas has the following molar composition: C1 = 0.874, C2 = 0.083, C3 = 0.022, i-C4 = 0.006, n-C4 = 0.002, i- C5 = 0.008, n-C5 = 0.003, n-C6 = 0.001 and C7+ = 0.001.

Solution

OPTION 1—Calculate the pseudocritical properties of the mixture. These properties are simply the summation of the individual contributions of the component gases, weighted by their molar fractions. This is based on the classical thermodynamics law for ideal mixtures and Dalton's law of partial pressures. the results of this calculation.

Mwt=18.94, *Ppc*=671 psi ,*Tpc*=378 R,

The pseudoreduced properties are, *Ppr* = 4,000/671 = ( )and *Tpr* = (180 + 460)/378 =( ). From Figure 1, *Z* =( ). Then, from Eq. (1.2) and rearrangement,

V=ZnRT/P=

Presence of Nonhydrocarbon Gases

It is worth noting that the well known graph in Figure 1 was constructed for only hydrocarbon gas mixtures. In the presence of large amounts of nonhydrocarbon gases, the gas deviation factor must be adjusted. In the absence of complete natural gas composition but knowing the gas gravity and the composition of nonhydrocarbon gases. the inserts in Figure 2 can be used to adjust the pseudocritical properties of a gas mixture to account for the presence of nonhydrocarbon gases. Wichert and Aziz (1972) have presented a correlation that allows the use of the Standing-Katz graph (Figure 1) in the presence of nonhydrocarbon gases. The pseudocritical properties, *Tpc* and *ppc*, can be corrected by

$$T'_{PC} = Tpc - \varepsilon_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

$$P'_{PC} = (T'_{PC}\, Ppc)/\, Tpc + y_{H2S}(1 - y_{H2S})\, \varepsilon_3 \quad \ldots\ldots\ldots 8$$

where is the mole fraction of hydrogen sulfide (natural gas with a high content of H2S is often referred to as a "sour" gas) and the term *e3* is a function of the H2S and CO2 concentrations, which can be obtained from Figure 3.

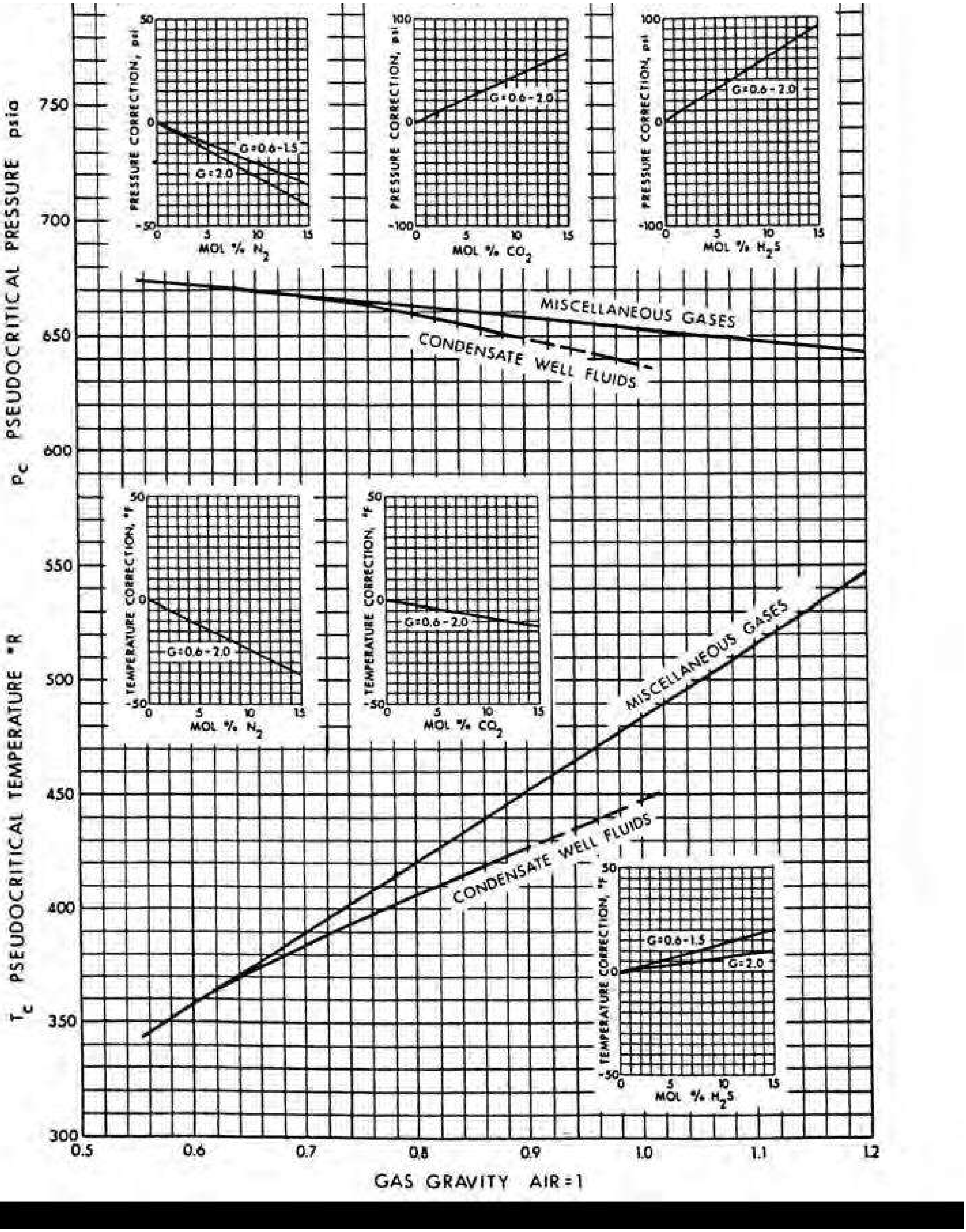

Figure 2 *Pseudocritical properties of natural gases* (Brown et al., 1948; inserts from Carr et al., 1954)

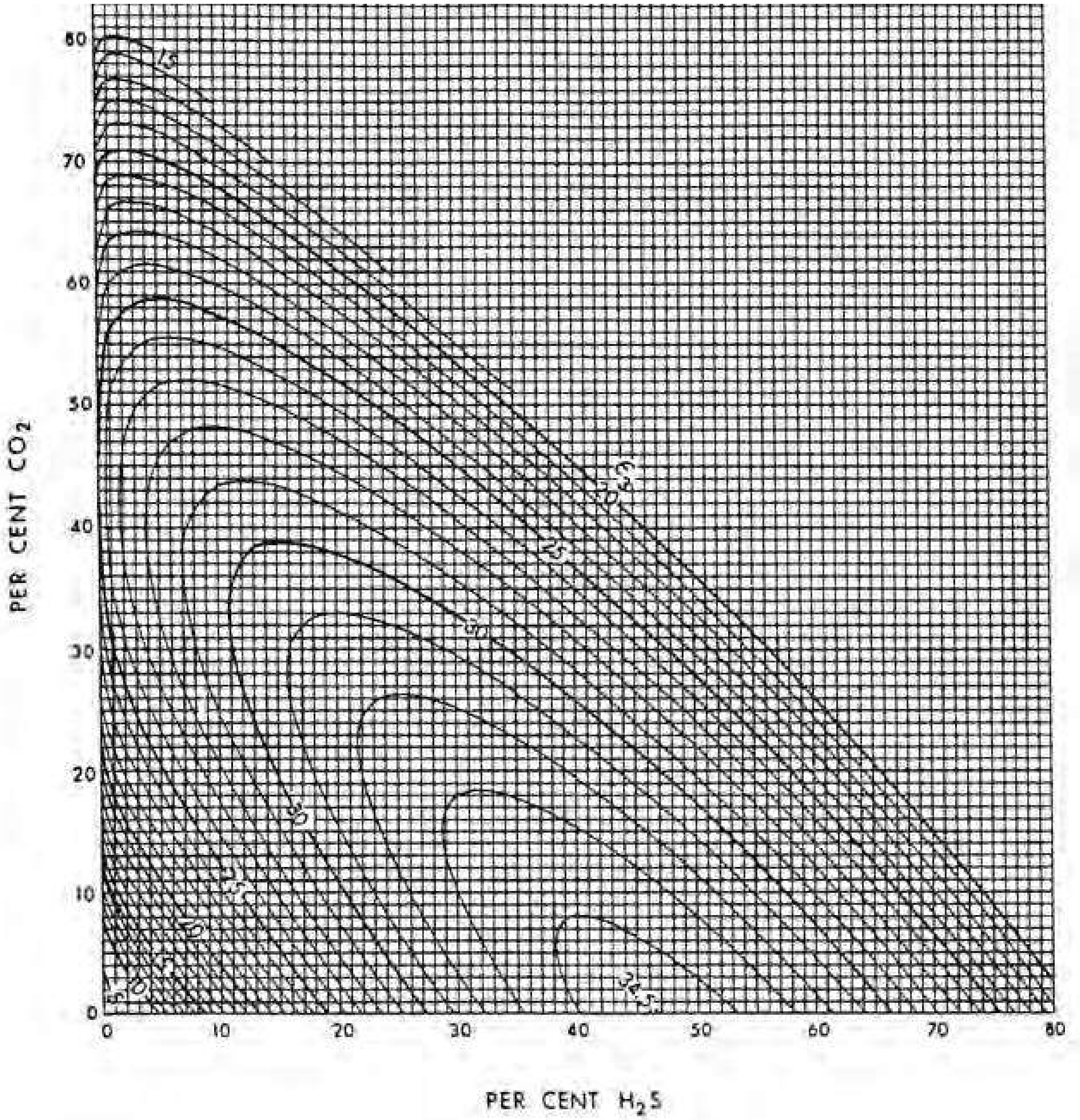

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Figure 3 *Pseudocritical temperature adjustment factor, e3* (Wichert and Aziz, 1972)

Example 1–4 Calculation of the *Z*-factor for a sour gas Calculate the gas deviation factor, *Z*, of a sour gas at 190°F and 4,000 psi. Gas composition is given below:

C1	C2	C3	i-C4	n-C4	i-C5	n-C5	C6+	N2	CO2	H2S
0.784	0.028	0.007	0.0008	0.0005	0.0008	0.0003	0.0006	0.005	0.021	0.152

Solution

OPTION 1—From Figure 1–10 and using the compositions of CO2 and H2S, the adjustment factor ε_3 = 23.5 R. The pseudocritical properties are calculated as shown. Therefore,: MW*t*= 20.19, *Ppc*= 777 psi, *Tpc*= 407R from Eq. (1.7):

T'_{PC}= 407-23.5=383.5

and from Eq. (1.8):

P'_{PC}= 777 X 383 5/ 407+(0.152(1-0.152)X23.5) = 726.7 psi

The pseudoreduced properties are then, *Tpr* = (190 + 460)/383.5 = 1.70 and *Ppr* = 4,000/726.7=5.5, respectively. From Figure 1, *Z* = 0.9.

OPTION 2—Calculate the pseudocritical properties from Figure 2. The molecular weight is 20.19, so *Yg* = 20.19/28.97 = 0.697.

Therefore, from Figure 2, *Tpc* = 390 R and *Ppc* = 668 psi. These must be corrected by the inserts in Figure 2. Thus,

Tpc = 390 – 2 – 2 + 20 = 406 R

Ppc = 668 – 2 + 9 + 92 = 767 psi