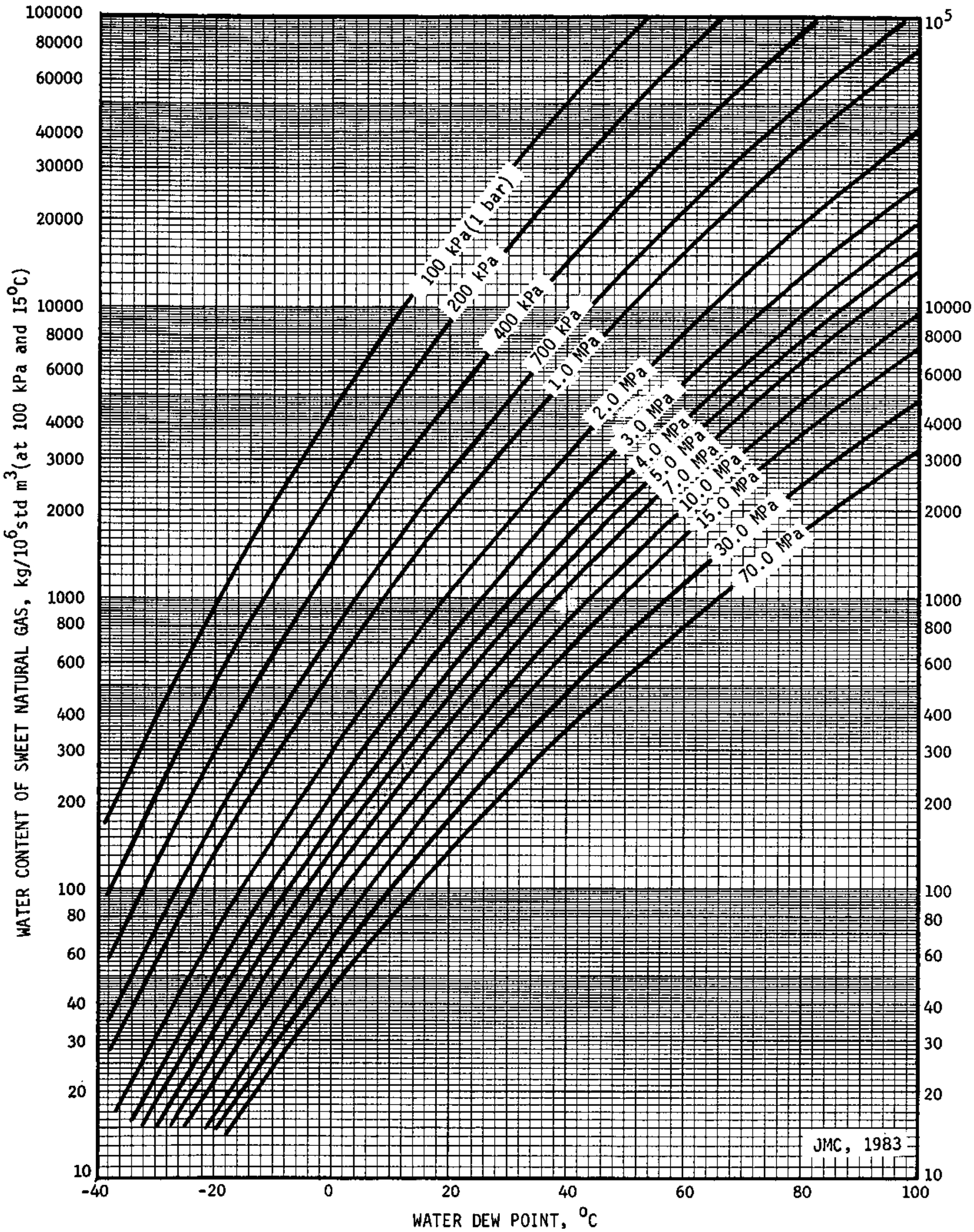

Figure 6.1 Water Content of Sweet, Lean Natural Gas

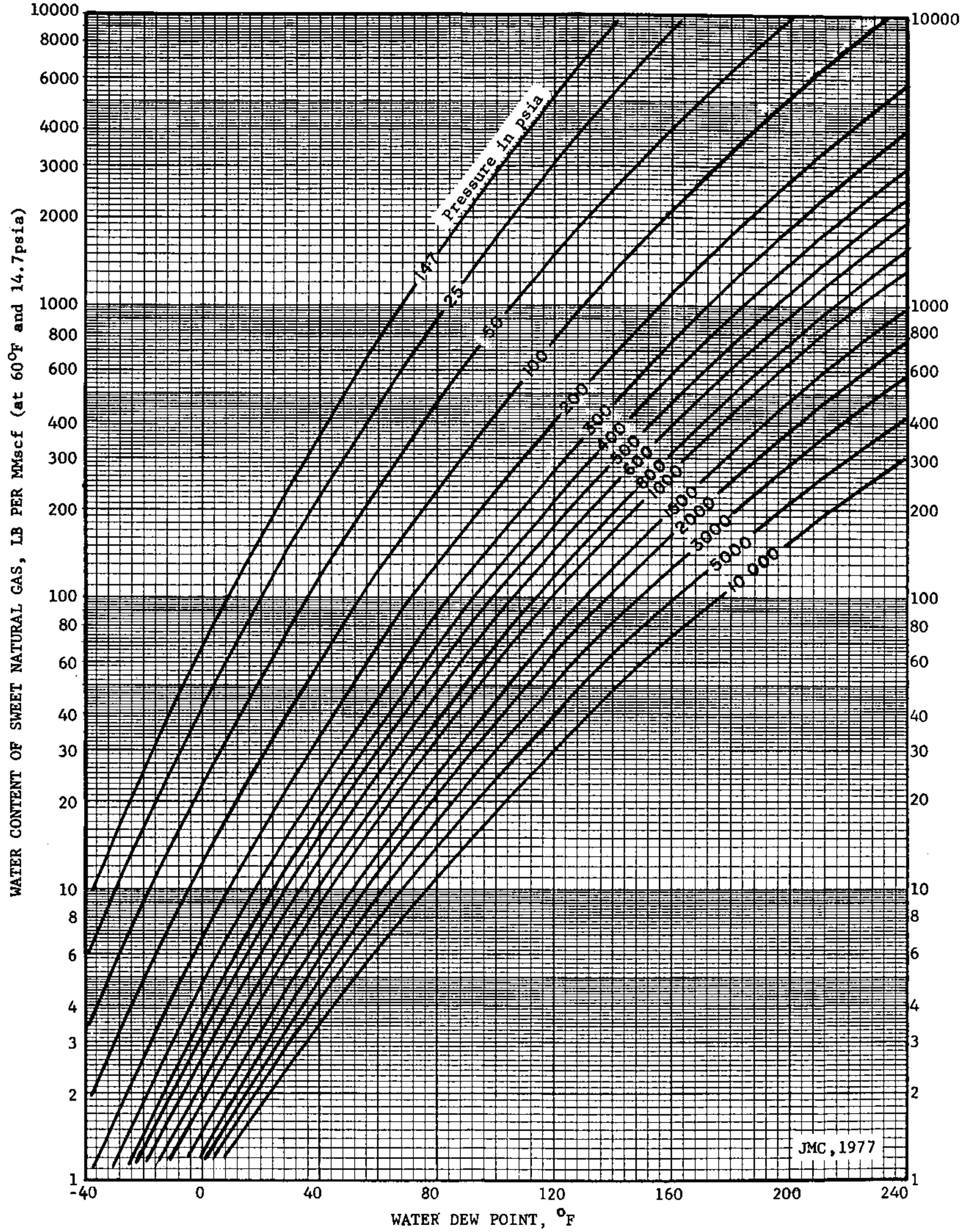

Figure 6.1(a) Water Content of Sweet, Lean Natural Gas

WATER CONTENT OF SOUR GASES

There are several available methods for determining the water content of gases containing H_2S and CO_2. Two of these use Equation 6.2 by multiplying the water content of the pure sour component by its mol fraction in the mixture. Figures 6.2 and 6.3 show what is called the "effective water content." These curves were based on the pure sour component data but were adjusted so that Equation 6.2 matched measured data on high pressure streams containing more than 20% H_2S.

As we have compared the results of this method with others we find that it is consistently high. It is the maximum possible value that can occur within a range of possible values.

$$W = y\,W_{hc} + y_1\,W_1 + y_2\,W_2 \tag{6.2}$$

Where:
- W = water content of gas
- W_{hc} = water content of hydrocarbon part of gas from Figure 6.1
- W_1 = water content of CO_2 from Figure 6.2 or 6.4
- W_2 = water content of H_2S from Figure 6.2 or 6.5
- y = $1 - y_1 - y_2$,
- y_1 = mol fraction of CO_2,
- y_2 = mol fraction of H_2S

A second correlation using Equation 6.2 is based on the data of Sharma discussed on the following pages. Figures 6.4 and 6.5 were obtained by cross-plotting and smoothing Sharma's binary data for methane, CO_2, and H_2S.[(6.5)]

SRK Sour Gas Correlation

Figure 6.6 is another correlation for estimating sour gas water content.[(6.6)] The charts shown were calculated from the SRK equation of state assuming that the hydrocarbon portion of the gas was methane. It was assumed also that CO_2 had 75% of the water content of H_2S at the same conditions. One thus multiplies the percent CO_2 by 0.75 and adds the result to the percent H_2S to use the charts. The water content shown in API bbl/MMscf can be converted as follows:

$$\text{lbm/MMscf} = (350)(\text{bbl/MMscf})$$

$$\text{kg}/10^6\ \text{std m}^3 = (5543)(\text{bbl/MMscf})$$

Figure 6.6 is a quick way to estimate sour gas water content. As shown, however, it also is limited somewhat by its reliance on binary data.

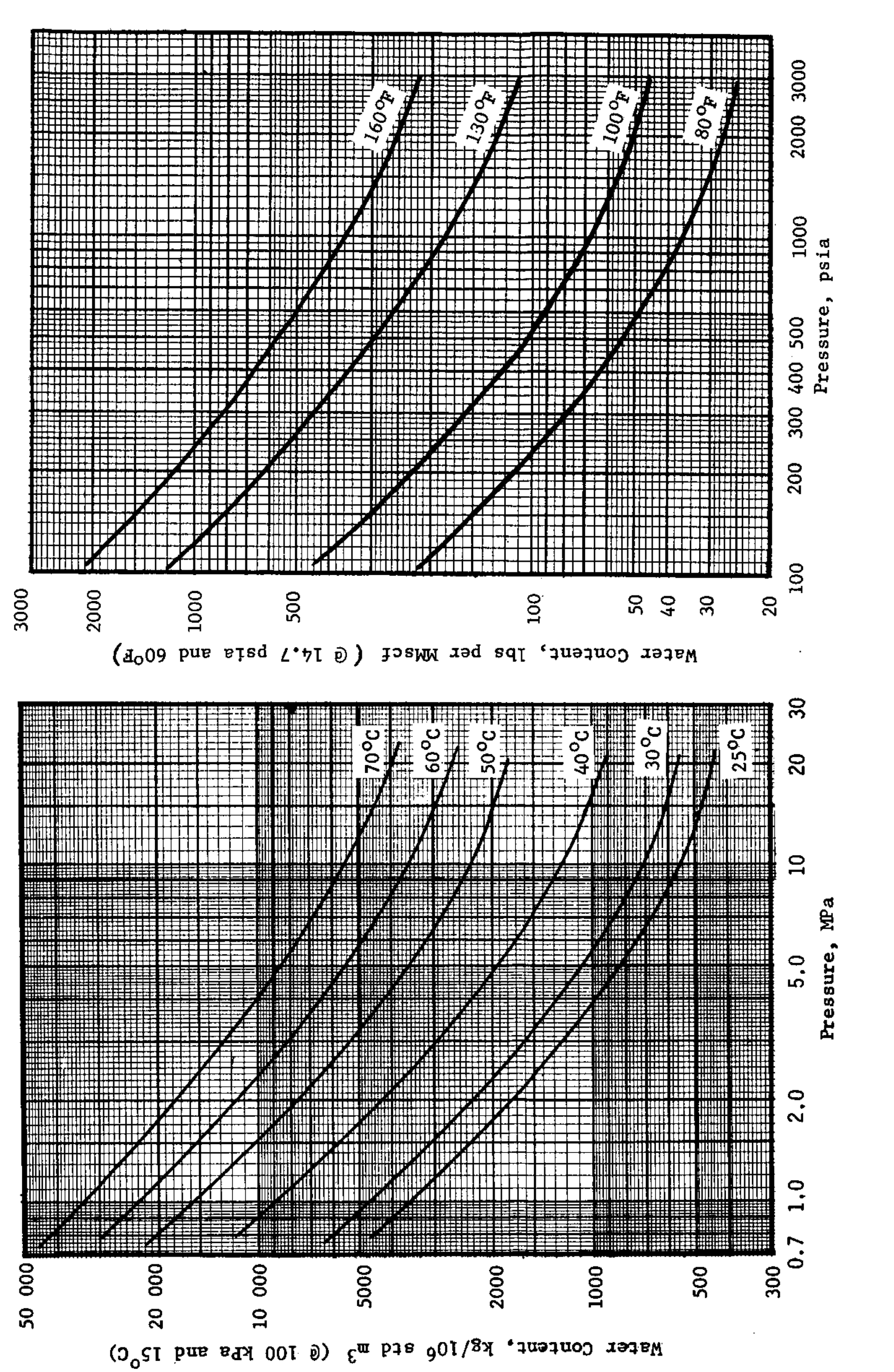

Figure 6.2 Effective Water Content of CO_2 in Saturated Natural Gas Mixtures

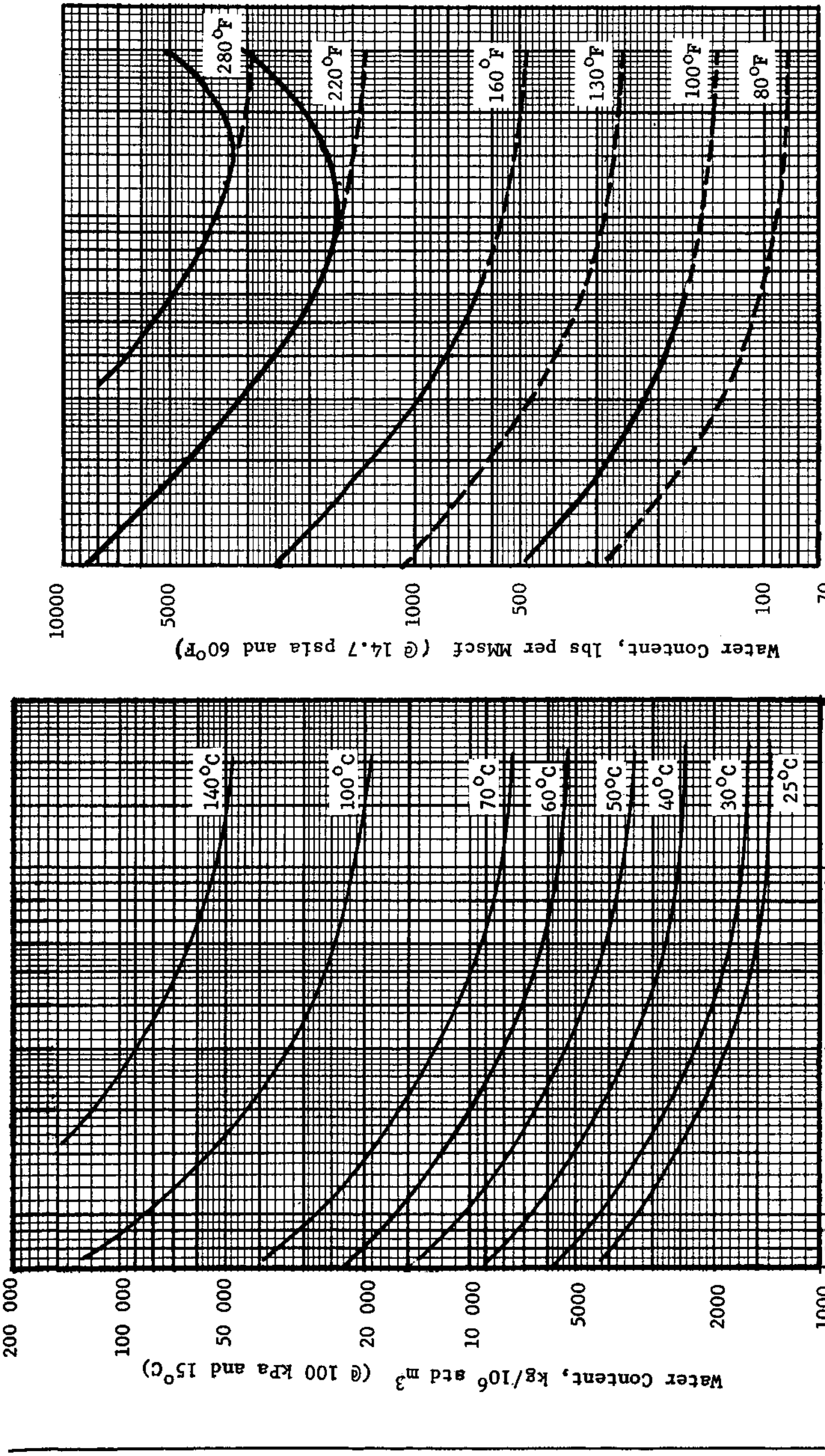

Figure 6.3 Effective Water Content of H_2S in Saturated Natural Gas Mixtures

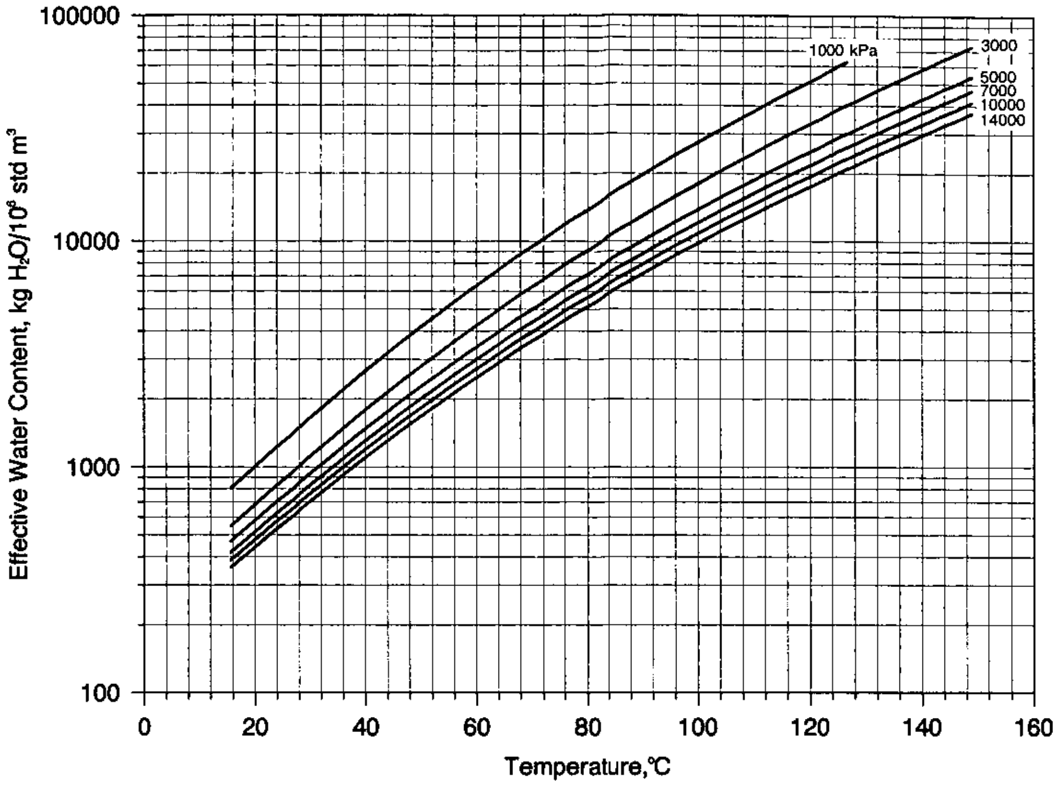

Figure 6.4 Water Content Contribution of CO_2

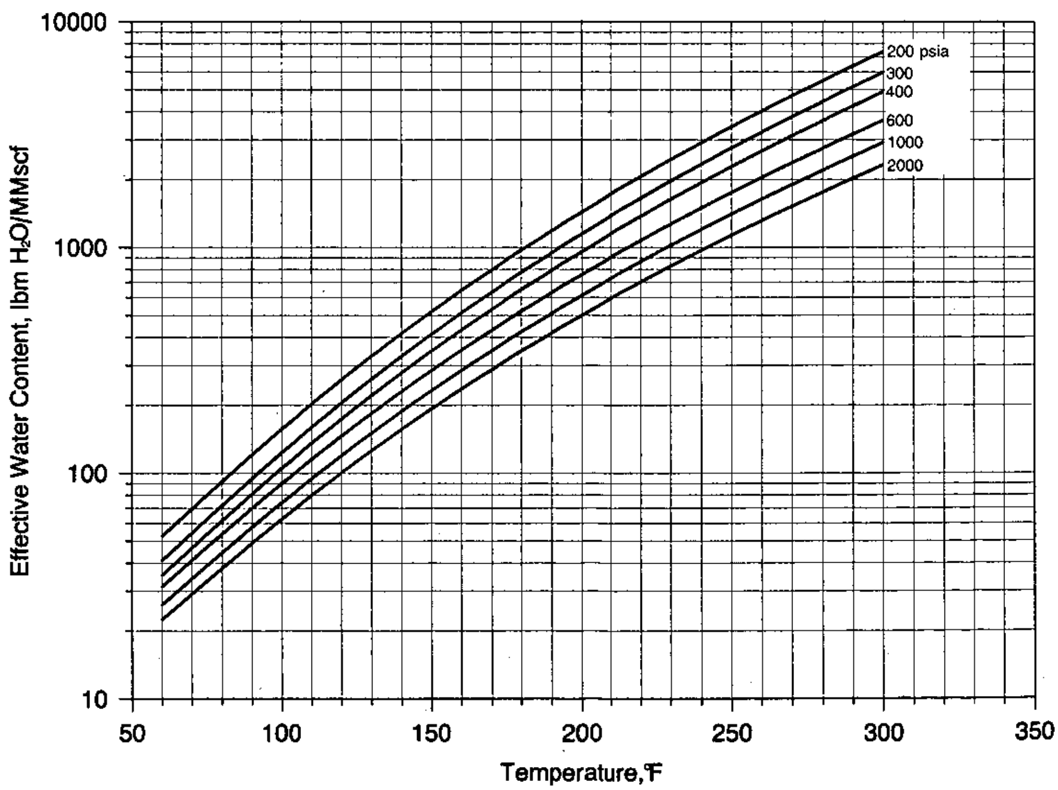

Figure 6.4(a) Water Content Contribution of CO_2

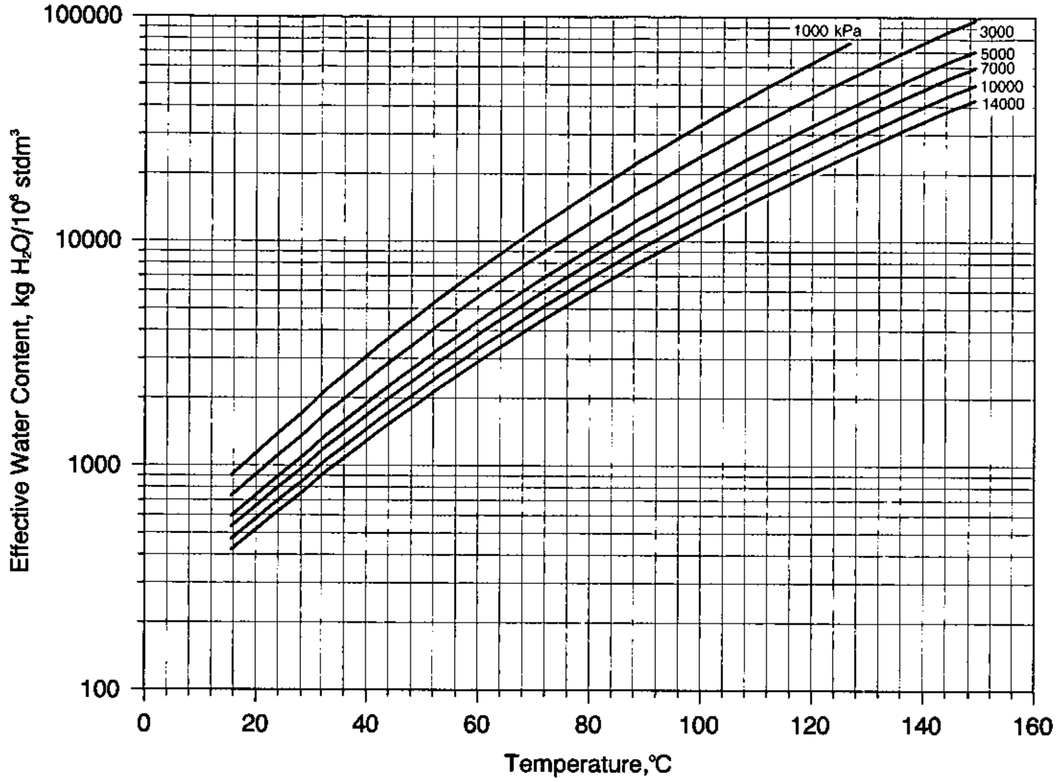

Figure 6.5 Water Content Contribution of H_2S

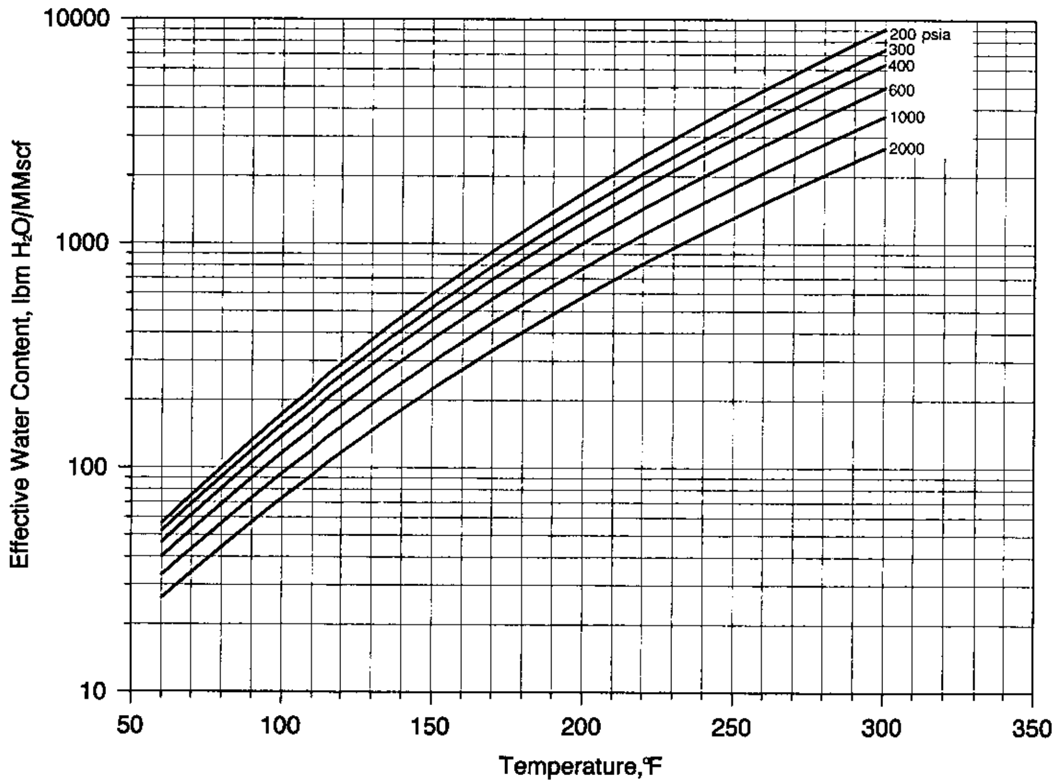

Figure 6.5(a) Water Content Contribution of H_2S

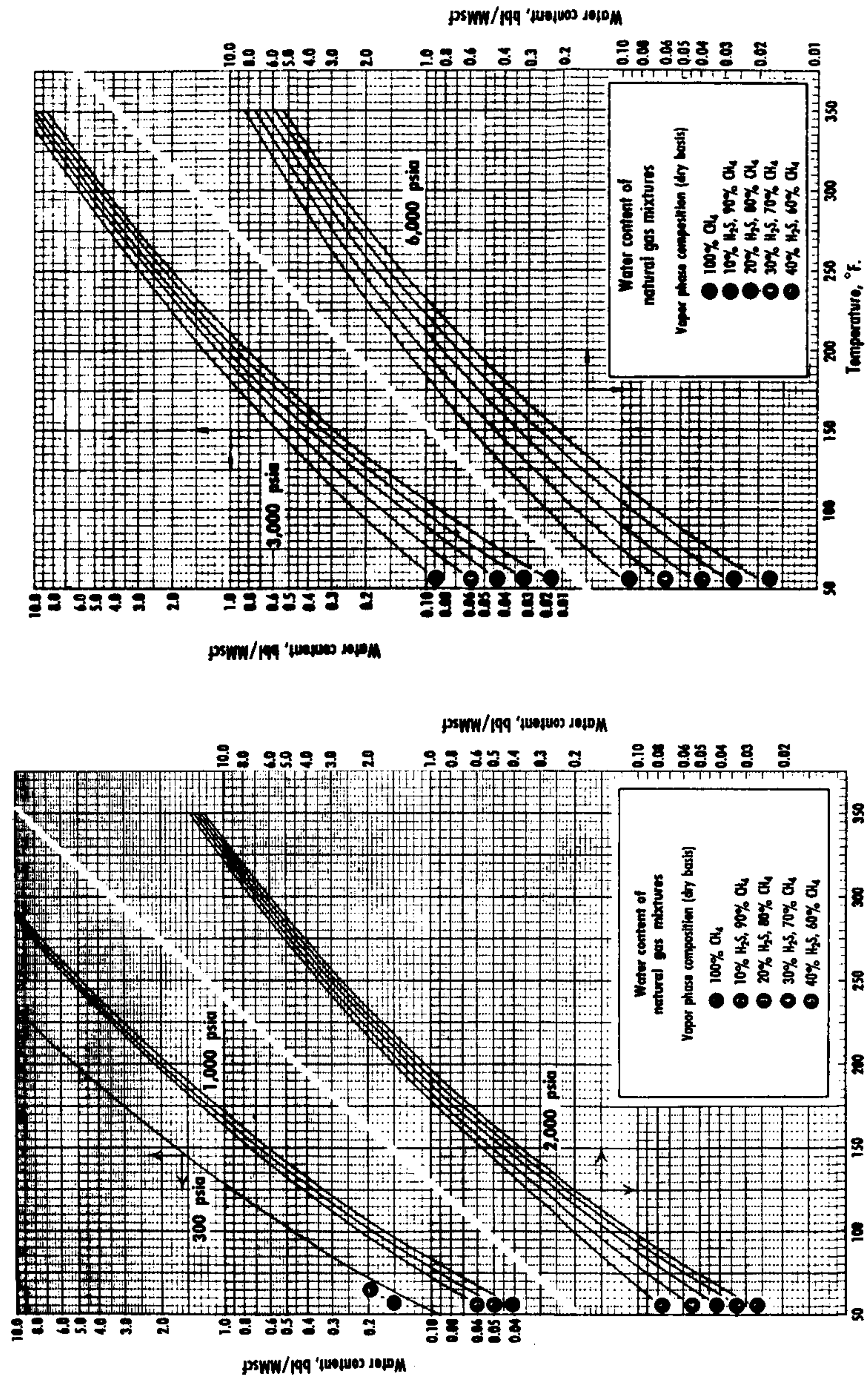

Figure 6.6 Another Correlation for Sour Natural Gases

Another Equation of State Approach

Suresh Sharma and the author have combined the Eykman Molecular Refraction concepts with standard physical chemistry equations to provide a basic correlation for sour gases. It too is empirical. It is more tedious manually than the others but represents a reliable alternative approach in the suite of methods presented. All of the figures shown herein are of course unnecessary when using the computer program for this method.

The first workable method for predicting water content was based on the concepts of EMR shown in Chapter 3 and standard physical chemistry principles.(6.7, 6.8) The method has been designed as a computer solution but can be performed manually using Figures 6.7-6.9

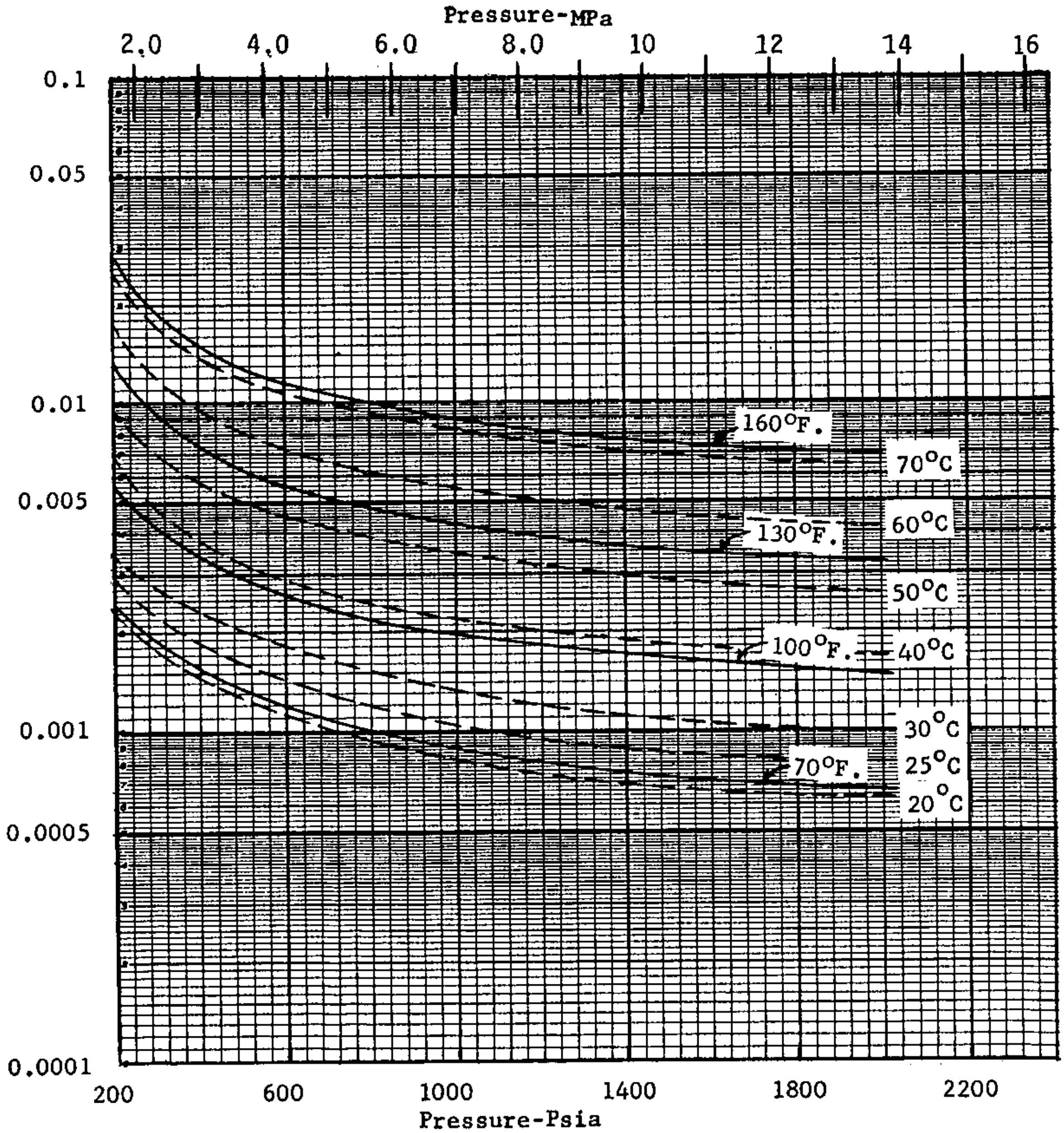

Figure 6.7 **Constant 'k" as a Function of Pressure and Temperature**

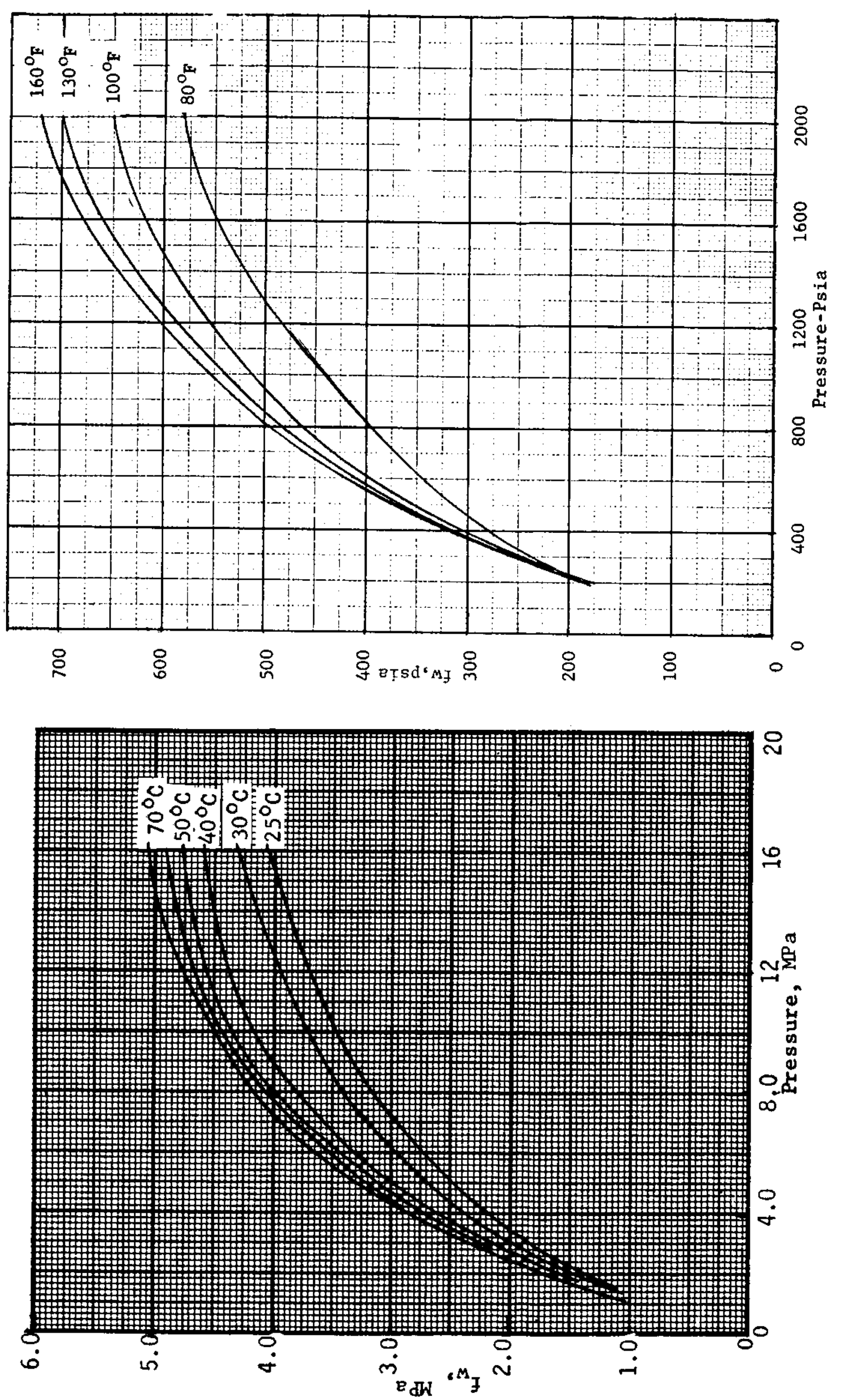

Figure 6.8 Water Fugacity as a Function of Pressure and Temperature

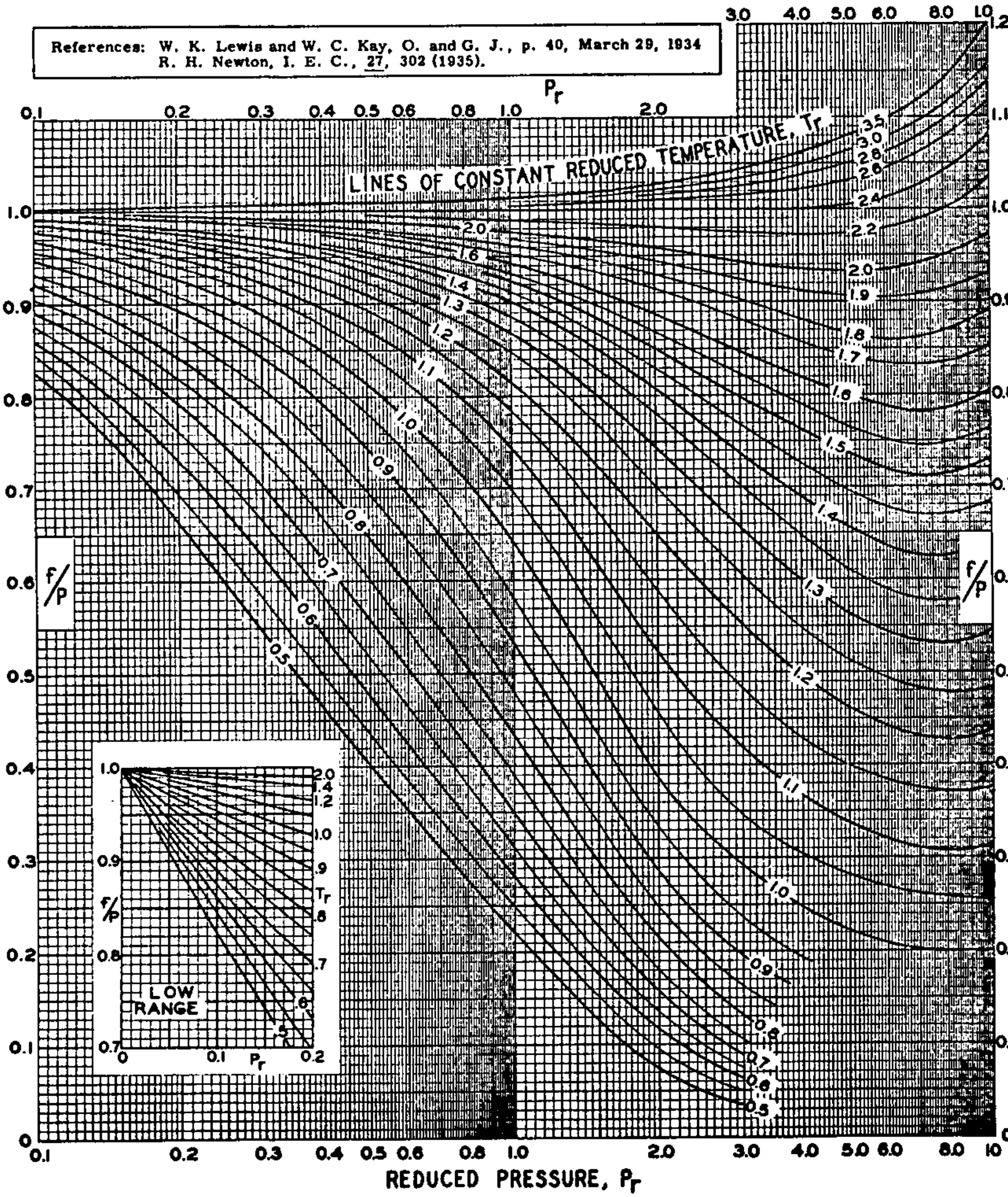

Figure 6.9 **General Fugacity Coefficient Chart**

The procedure is as follows.

1. Calculate the critical pressure and temperature of the mixture, using the technique of McLeod and Campbell summarized in Chapter 3, which utilizes molecular refraction as a third parameter.
2. Calculate reduced pressure and temperature for the gas system. Determine "Z" from EMR approach.
3. Find the value for constant "k" from Figure 6.7, or calculate by the equation.

$$k = \left(\frac{P_w^o}{P}\right)\left(\frac{f_w^o/P_w^o}{f_w/P}\right)\left(\frac{P}{P_w^o}\right)^{0.0049} \tag{6.3}$$

Where: P_w^o = vapor pressure of water at system temperature (T)
P = system pressure
f_w^o = fugacity of water at P_w^o and T
f_w = fugacity of water at P and T
0.0049 = semi-empirical constant

4. Determine the fugacity of water (f_w) from Figure 6.8, or calculate from Figure 6.9, using P_c and T_c for water.
5. Determine value of (f/P), the fugacity coefficient from Figure 6.9, using the reduced parameters from Step 2. Calculate "f."
6. Determine the water content by the equation

$$y = k\,(f_w/f)^Z \tag{6.4}$$

Where: y = mol fraction of water in vapor

In solving Equation 6.4 note that the Z must be from the EMR combination rule and no other source.

I use all of the above methods when calculating a sour gas water content. The reason – the random behavior of such systems. The repeatability of data is very poor, even in the laboratory. One should recognize this in applying such information.

You likely will get four different answers with the four correlations above. If dehydrator design or operation is involved, I suggest you use the highest of the results to be on the safe side.

Effect of Nitrogen and Heavy Ends

Nitrogen will hold less water than methane. At pressures to about 7.0 MPa [1000 psia] the water content of nitrogen is about 6-9% less than for methane. This deviation increases with pressure. Thus, including nitrogen as a hydrocarbon is practical and offers a small safety factor.

The presence of heavy ends tends to increase the water capacity of the gas. Once again the deviation is relatively small at normal system pressures. The nitrogen and heavy end effects tend to cancel out each other in many production systems.

Example 6.1: Calculate the saturated water content of a gas with the analysis shown below at 1100 psia and 120°F. EMR Z = 0.79, P_c = 867 psia, T_c = 436°R.

Comp.	y_i
N_2	0.0046
CO_2	0.0030
H_2S	0.1438
C_1	0.8414
C_2	0.0059
C_3	0.0008
iC_4	0.0003
nC_4	0.0002
	1.0000

1. From Figure 6.1(a), W = 97 lbm/MMscf
2. $y_1 = 0.0030$, $y_2 = 0.1438$
   From Figure 6.1(a), W_{hc} = 97 lbm/MMscf
   From Figure 6.2, $W_1 = 130$
   From Figure 6.3, $W_2 = 230$
   W = (0.8532)(97) + (0.003)(130) + (0.1438)(230) = 116 lbm/MMscf
3. From Figure 6.4(a), $W_1 = 120$
   From Figure 6.5(a), $W_2 = 150$
   W = (0.8532)(97) + (0.003)(120) + (0.1438)(150) = 105 lbm/MMscf
4. Effective % H_2S = (0.3)(0.75) + (14.38) = 14.6%
   From Figure 6.6, W = (350)(0.31) = 109 lbm/MMscf
5. From Figure 6.7, k = 0.0031
   From Figure 6.8, $f_w = 555$
   $P_r' = 1100/867 = 1.27$, $T_r' = 580/436 = 1.33$
   f/P = 0.85, f = (0.85)(1100) = 935
   $y = (0.0031)(555/935)^{0.79} = 0.00205$
   W = (0.00205)(47 448) = 97.3 lbm/MMscf

In Example 6.1 the water content from Equation 6.2 is greater than from Figure 6.1. This is expected for the sour gas in question. From my experience, a value as high as 116 is not likely but it does happen. The value of 97 represents a practical minimum.

Using probability principles, the numbers would be regarded as a distribution. The mode is the most likely value but any value within the range shown has some probability of occurring. This fact must be accepted in making any decision resulting from this calculation. Merely averaging the numbers or arbitrarily picking one as "sacred" is not consistent with the true facts of the matter.

One can estimate the water content, or relative saturation of the gas entering a dehydrator, from the water content correlations.

Example 6.2: Water is separated in an inlet scrubber to a compressor plant at 7.0 MPa and 35°C. The gas is then compressed and aftercooled to 14.0 MPa and 50°C before entering a dehydrator. Is the gas saturated?

From Figure 6.1, water content at 7.0 MPa and 35°C = 810 kg/10^6 std m^3

From Figure 6.1, water content at 14.0 MPa and 50°C = 1050 kg/10^6 std m^3

The gas is capable of holding 1050 kg but has only 810 kg. Therefore, it is not saturated. There is less than the maximum amount of water to be removed. Also, there is less driving force available to aid water removal. One must consider both factors.

In other cases the maximum water capacity of the gas downstream may be less than that upstream. In this case water must condense in the section involved. The water content correlation may be used to estimate the amount of liquid water present.

If no separation occurs between the wellhead and the dehydration plant, it is reasonable to assume that the gas was saturated at the formation pressure and temperature.

Saturated Water Content in Equilibrium with Hydrates

Figure 6.1 is based on the assumption that the condensed water phase is a liquid. However, at temperatures below the hydrate temperature of the gas, the "condensed" phase will be a solid (hydrate). The water content of a gas in equilibrium with a hydrate will be lower than equilibrium with a metastable liquid.

Hydrate formation is a time dependent process. The rate at which hydrate crystals form depends upon several factors including gas composition, presence of crystal nucleation sites in the liquid phase, degree of agitation, etc. During this transient "hydrate formation period" the liquid water present is termed "metastable liquid." Metastable water is liquid water which, at equilibrium, will exist as a hydrate.

References 6.9-6.11 present experimental data showing equilibrium water contents of gases above hydrates. Data from Reference 6.10 is presented in Figure 6.10. For comparative purposes, the "metastable" water content of a sweet gas from Figure 6.1 is also shown. The water content of gases in the hydrate region is a strong function of composition. Figure 6.10 should not be extrapolated to other compositions.

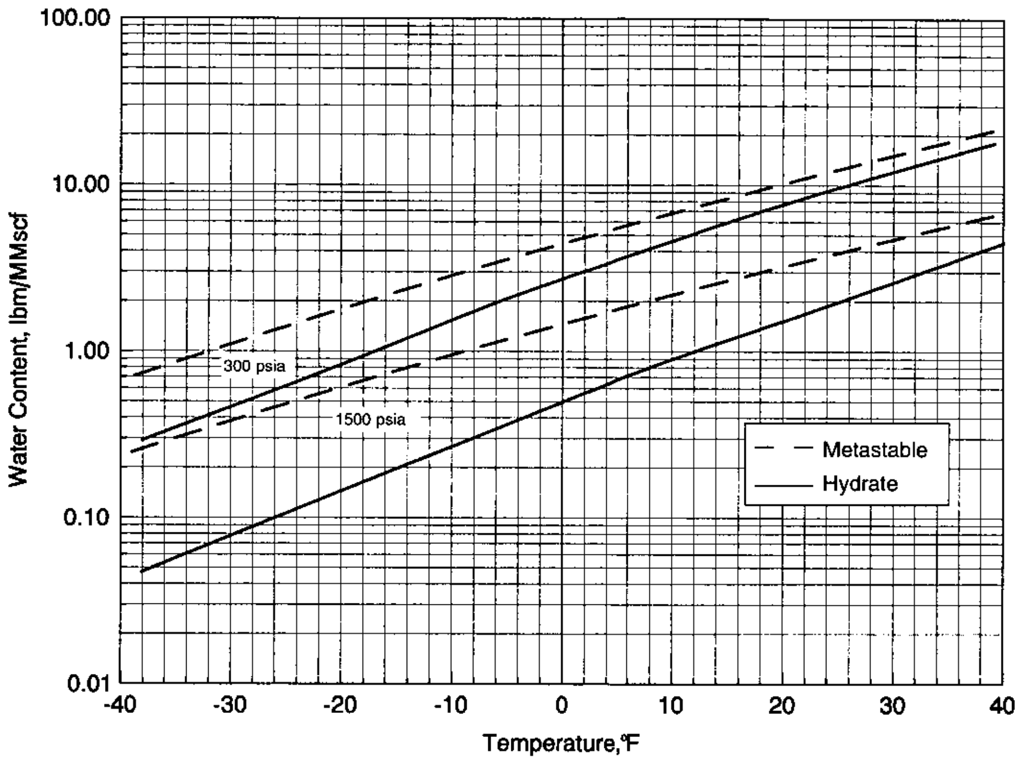

Figure 6.10 Water Content of 5.31% C_3 - 94.69% C_1 Gas in Equilibrium with Hydrate

When designing dehydration systems, particularly TEG systems to meet extremely low water dewpoint specifications, it is necessary to determine the water content of the gas in equilibrium with a hydrate using a correlation like that presented in Figure 6.10. If a metastable correlation is used, one will overestimate the saturated water content of the gas at the dewpoint specification. This, in turn, may result in a dehydration design which is unable to meet the required water removal. Where experimental data is unavailable, utilization of a sound thermodynamic-based correlation can provide an estimate of water content in equilibrium with hydrates.