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**IMPLEMENTATION OF IMPROVED APPLICATION
FOR DETERMINING GAS Z-FACTOR OF GAS
FROM THE MOLVE FIELD**

1. INTRODUCTION

Calculation of volumetric properties of a gas in petroleum engineering applications is performed using real gas equation of state (EOS). Volumes (i.e. molar volumes or densities) of real gases at desired pressure and temperature conditions can be calculated if gas correction of volume – Z-factor of a real gas is known.

However, EOS cannot represent phase behavior of reservoir fluids accurately, especially for gas condensates and for near critical reservoir fluids. As a result, the parameters in equations of state need to be tuned to improve the representation of PVT and physical properties of reservoir fluids.

Minimum input are pressure-volume-temperature dependent (PVT) data that were measured in a laboratory and some of well known cubic EOS, then can be fitted to the specific analyzed gas p-V isotherm(s) by using one of the PVT simulation software packages available. The process EOS fitting with a measured p-V isotherm requires fluid composition data and properties (critical pressure, P_c , critical temperature, T_c , acentric factor, ω) of each component. A true boiling point (TBP) residue or plus fraction which is too heavy to be separated by use of a TBP distillation procedure is usually defined by measured specific gravity (and molar weight) and boiling point of a plus fraction. In this work we proposed the methodology to determine required parameters for EOS that would show good matching with measured values. For that purpose, p-Z curves can show any discrepancy of analytically obtained and measured p-V isotherms.

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2. THEORETICAL OVERVIEW OF THE CORRELATIONS EXAMINED WITH DATA FROM MOLVE WELLSTREAM FLUID

From Standing (1977) correlation for “wet” gases ($\gamma_g > 0.75$):

$$T_{pc} = 187 + 330\gamma_g - 71,5\gamma_g^2 \quad (1a)$$

$$p_{pc} = 706 + 51,7\gamma_g - 11,1\gamma_g^2 \quad (1b)$$

Sutton (1985) also expressed pseudocriticals as quadratic function:

$$T_{pc} = 169,2 + 349,5\gamma_g - 74,0\gamma_g^2 \quad (2a)$$

$$p_{pc} = 756,8 + 131,0\gamma_g - 3,6\gamma_g^2 \quad (2b)$$

If there is high percent of non-hydrocarbon components like CO_2 i H_2S , it is recommended to use Wichert and Aziz (1972) correction method:

$$\varepsilon = 120 \left[\left(y_{\text{H}_2\text{S}} + y_{\text{CO}_2} \right)^{0,9} - \left(y_{\text{H}_2\text{S}} + y_{\text{CO}_2} \right)^{1,6} \right] + 15 \left(y_{\text{H}_2\text{S}}^{0,5} - y_{\text{CO}_2}^{4,0} \right) \quad (3a)$$

$$T_{pc}^{korig} = T_{pc} - \varepsilon \quad (3b)$$

$$p_{pc}^{korig} = \frac{p_{pc} T_{pc}^{korig}}{\left[T_{pc} + \varepsilon (1 - y_{\text{H}_2\text{S}}) y_{\text{H}_2\text{S}} \right]} \quad (3c)$$

Riazi and Daubert (1987) published generalized correlation (Tab. 1):

$$\theta = aM^b \gamma^c \text{EXP} [dM + e\gamma + fM\gamma] \quad (4)$$

Table 1

θ	a	b	c	d	e	f
$T_c, ^\circ\text{R}$	5,444000E+02	2,998000E-01	1,055500E+00	-1,347800E-04	-6,164100E-01	0,000000E+00
p_c, psia	4,520300E+04	-8,063000E-01	1,601500E+00	-1,807800E-03	-3,084000E-01	0,000000E+00
$V_c, \text{ft}^3/\text{lb}$	1,206000E-02	2,037800E-01	-1,303600E+00	-2,657000E-03	5,287000E-01	2,601200E-03
$T_b, ^\circ\text{R}$	6,778570E+00	4,016730E-01	-1,582620E+00	3,774090E-03	2,984036E+00	-4,252880E-03

For a plus fraction, Kessler and Lee (1976) correlation (as function of boiling temperature and specific gravity) is widely used in PVT simulators:

$$P_c = \exp \left[\begin{array}{l} 8.364 - 0.0566/\gamma - \left(0.24244 + 2.2898/\gamma + 0.11857/\gamma^2\right) \times 10^{-3} \times T_b \\ + \left(1.4685 + 3.648/\gamma + 0.47227/\gamma^2\right) \times 10^{-7} \times T_b^2 \\ - \left(0.42019 + 16977/\gamma^2\right) \times 10^{-10} \times T_b^3 \end{array} \right] \quad (5a)$$

$$T_c = 341.7 + 811\gamma + (0.4244 + 0.1774\gamma) \times T_b + (0.4669 - 3.2623\gamma) \times 10^5 / T_b \quad (5b)$$

Cavett (1962) also published correlation for critical pressure and temperature of C^{7+} as function of boiling temperature and specific gravity in $^\circ\text{API}$:

$$T_c = a_0 + a_1 T_b + a_2 T_b^2 + a_3 (\text{API})(T_b) + a_4 T_b^3 \quad (6a)$$

$$+ a_5 (\text{API})(T_b)^2 + a_6 (\text{API})^2 (T_b)^2$$

$$\text{Log}(p_c) = b_0 + b_1 T_b + b_2 T_b^2 + b_3 (\text{API})(T_b) + b_4 T_b^3 \quad (6b)$$

$$+ b_5 (\text{API})(T_b)^2 + b_6 (\text{API})^2 (T_b)^2 + b_7 (\text{API})^2 (T_b)^2$$

For T_b , we used Soreide correlation:

$$T_b = 1071.3 - \left(0.942 \times 10^5\right) M^{-0.03522} \gamma^{3.266} \quad (7)$$

$$\times \exp\left(-M \times 4.922 \times 10^{-3} - 4.7685\gamma + M\gamma \times 3.462 \times 10^{-3}\right)$$

Dranchuk and Abou-Kassem (1975, DAK) gave EOS with 11 constant parameters for Z-factor calculation:

$$Z = \left[A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} + \frac{A_4}{T_{pr}^4} + \frac{A_5}{T_{pr}^5} \right] \rho_r + \left[A_6 + \frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right] \rho_r^2 - \quad (8a)$$

$$A_9 \left[\frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right] \rho_r^5 + A_{10} (1 + A_{11} \rho_r^2) \frac{\rho_r^2}{T_{pr}^3} \text{EXP} \left[-A_{11} \rho_r^2 \right] + 1$$

ρ_r – reduced gas gravity:

$$\rho_r = \frac{0.27 p_{pr}}{Z T_{pr}} \quad (8b)$$

Where constants A_1 to A_{11} are respectively:

$$A_1 = 0.3265, A_2 = -1.0700, A_3 = 0.5339, A_4 = 0.01569, A_5 = -0.05165, A_6 = 0.5475, \\ A_7 = -0.7361, A_8 = 0.1844, A_9 = 0.1056, A_{10} = 0.6134, A_{11} = 0.7210.$$

Newton-Raphson iteration for p_r to obtain Z-factor was used in this work. Average error of 0,5% for pseudoreduced values

$$0.2 \leq p_{pr} < 30 \quad \text{and} \quad 1.0 < T_{pr} \leq 3.0$$

was smaller than error showed by using Hall-Yarborough iteration or Standing-Katz diagram.

3. ANALYSIS AND DATA PREPARATION OF GAS FROM MOLVE FIELD

Molve gas field is located in Drava depression and is producing more than 25 years more than $2.5E6 \text{ m}^3$ of gas and about 170 m^3 of condensate per day. Density of condensate is 780 kg/m^3 , and specific gas gravity is 0.83 (air=1). There are 21 producing wells, 6 testing, 7 injection (water disposal wells) 9 abandoned and one water-producing well.

16 separator PVT measurements and 16 wellstream PVT and composition measurements have been taken into consider by plotting p-Z diagrams. Then, p-Z diagrams using critical temperatures and pressures calculated by Standing and by Sutton correlation, using gas specific gravity and neglecting the fluid composition were plotted. Finally, for each measurement we took composition and critical properties of C^{7+} fraction from several abovementioned correlations

Standing and Sutton correlations show similar T_{pc} values but when $\gamma_g > 0.75 P_{pc}$ values slightly differ.

Table 2 presents the overall composition of Molve field gas.

Because each single analysis contains some data inconsistency, molar mass of the plus component was reduced by grouping C^7 , C^8 , C^9 and C^{10+} fraction to a calculated C^{7+} fraction by equations:

$$M_w = \sum_{i=1}^n y_i \times M_i \quad (9a)$$

$$M_{C^{7+}} = \frac{M_w - \sum_{i=1}^{C_6} y_i \times M_i}{\sum_{i=7}^{C_{10}} y_i} \quad (9b)$$

resulting in new definition of overall composition with average C^{7+} fraction molecular weight $M_{wC^{7+}} = 136.3$.

After some correlations were discarded, we compared the correlations that show the smallest error in calculated Z factors (Tab. 3). We let Lin Chao correlation, as one of discarded, because of interesting coincidence – it is very close to the measured data both for + fraction and for the compound.

Table 2
Overall composition of Molve field gas

<i>i</i>	<i>y_i</i> %	<i>z_i</i> %
N ₂	1.767	1.760
CO ₂	24.245	24.165
C ₁	68.450	68.168
C ₂	2.682	2.678
C ₃	0.850	0.854
i-C ₄	0.227	0.229
n-C ₄	0.236	0.239
i-C ₅	0.138	0.142
n-C ₅	0.098	0.104
C ₆	0.400	0.411
C ₇	0.907	0.933
C ₈		0.049
C ₉		0.049
C ₁₀₊		0.227

Table 3
Comparison of critical temperatures and pressures calculated with selected correlations

Correlation	<i>T_{pc}</i>	<i>p_{pc}</i>	<i>T_{pc}</i> C ₇₊	<i>p_{pc}</i> C ₇₊
From composition (Kay mixing rule)	226.75	51.81	562.14	25.55
Sutton	217.98	40.14		
Standing	218.58	51.85		
Lin Chao	272.60	53.50	539.54	27.34
Cavett			574.48	26.59
Riazi-Daubert			578.50	25.36
Kessler Lee			575.20	25.91

4. RESULTS

From 16 samples of wet gas from Molve field, assuming that quadratic function can show better results for this single reservoir fluid we modified Standings correlation for pseudocritical parameters (Fig. 1a, b):

$$P_{pc} = -31.455\gamma^2 + 64.422\gamma + 19.919 \quad (10a)$$

$$T_{pc} = 651.8\gamma^2 - 1018.3\gamma + 621.81 \quad (10b)$$

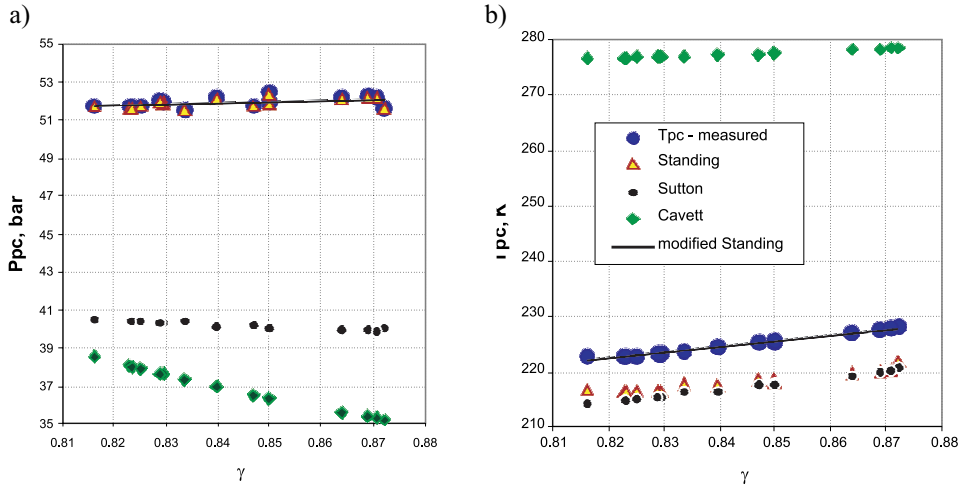


Fig. 1. Specific gravity vs. pseudocriticals (see text)

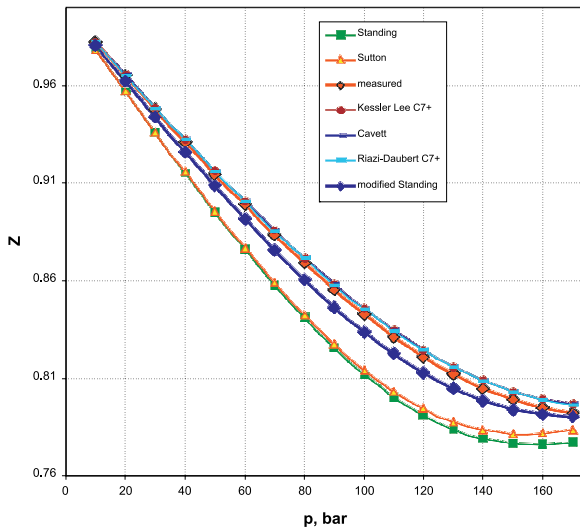


Fig. 2. Diagram p - Z plotted by using selected correlations and modified Standing correlation

To select the adequate correlations for this particular set of analyses results were compared as function of molecular weight of the plus fraction and there were observed p_c vs. T_c relations both for wellstream and separator gas (which is beyond scope of this work).

Figure 2 shows that correlations (Standing, Sutton) dependent only on specific gravity show larger error when we use them to plot p - Z diagram. Modified equation shows better results, and if we keep in mind inconsistencies of M_w for a plus fraction, which causes error when calculating T_b for plus fraction, for a quick use modified correlation is recommended.

5. CONCLUSIONS

In this work, several characterization methods have been tried and the results have been compared with the experimental data. The characterization method of Kessler-Lee, Cavett and Riazi Daubert for pseudocritical temperature and pressure of the plus fraction gave nearly the same values, even when observed through p-Z diagram because we compared results on wet-gas with low percent of plus fractions. That leads to validity of minimization of number of parameters needed to obtain pseudocriticals for the compound. Modified Standing or similar correlations then can be easily expressed as function of specific gravity or molecular weight of the whole compound.

NOMENCLATURE

- p_c – critical pressure, bar (in referenced correlations psia)
- T_c – critical pressure, K (in referenced correlations °F)
- p_{pc} – pseudo critical pressure, bar (in referenced correlations psia)
- T_{pc} – pseudo critical pressure, K (in referenced correlations °F)
- Z – compressibility factor
- T_b – boiling temperature, K
- γ – specific gravity (for gas, air=1)
- y – molar fraction
- M – molecular weight, g/mol^{-1}
- ρ_r – reduced gas gravity, g/cm^3

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