

A NEW NOMOGRAPHIC BASED CORRELATION FOR PREDICTING WATER CONTENT OF SWEET NATURAL GASES

VICTOR J. AIMIKHE*, OGBONNA F. JOEL, SUNDAY S. IKIENSIKIMAMA

Department of Petroleum and Gas Engineering,
University of Port Harcourt Choba, Port Harcourt, Nigeria

*Corresponding Author: itubulars@yahoo.com

Abstract

Water in natural gas can create serious operational problems, resulting in increased operational costs, when not properly managed. Hence, there is a growing need to develop better correlations or improve on the existing ones, for better water content prediction, within certain pressure and temperature ranges. As a result, this study focused on developing a new, simple to use, correlation, using data from the Campbell chart. On validation with published experimental results from different gas -water systems, the new model gave a percentage average absolute deviation of 2.65 for the methane-water system; 4.40 for ethane -water system and 4.62 for the natural gas mixture -water system. In comparison, the model was found to be in good agreement with the Cubic Plus Association Equation of State results, and also performed better than three widely used correlations in the natural gas industry, with a percentage average absolute deviation of 3.28, 1.74 and 2.28, respectively, for the pressure and temperature ranges considered. The results therefore, suggested that the new correlation was adequate and reliable for the prediction of the water content of sweet natural gases.

Keywords: Correlation, Cubic plus association equation of state, Sweet natural gas, Water content.

1. Introduction

The knowledge of the maximum water content in natural gas is essential in the overall operability and optimization of gas production, transportation, processing and storage facilities. For instance, it is very useful for designing efficient dehydration units, optimum hydrate inhibitor injection rate and efficient corrosion management system [1]. It is also very important in ascertaining the optimum heating requirement needed before throttling and by extension the total energy consumption requirements in the facility [2].

Numerous correlations for predicting the water content of sweet natural gas have been developed over the years. Some of these correlations emanated from experimental data, while others were developed using data from charts or thermodynamic models. Although studies have revealed that the water content of sweet natural gases is independent of composition [3, 4], these correlations, however, have a limited range of validity when it comes to gas compositions, pressure and temperature ranges. Even when some of these correlations were reported to be valid over a given range of temperature and pressure, their reliability has often been questioned, when validated with reliable experimental and thermodynamic data. Despite this, correlations are still very popular for use in the natural gas industry for estimating the amount of water present in the gas at a particular pressure and temperature. A key significance of these correlations is that they form the basis for which, computer software is developed for the water content of natural gas determination. As a result, the need to develop easy to use and more efficient correlations for determining the maximum water content in gas at any given pressure and temperature is highly imperative.

The focus of this study, therefore, is to develop a new correlation using data from the Campbell chart reported to be very reliable [5]. The reliability and accuracy of the new correlation will be ascertained with results from the Cubic Plus Association Equation of State (CPA-EoS), published experimental data, and then compared with three (3) widely used correlations in the natural gas industry.

2. Prediction of Sweet Natural Gas Water Content

Various calculation methods (correlations) exist for estimating the water content of sweet natural gas in equilibrium with the water. They were mainly developed from:

- Experimental data, e.g., Campbell et al. [5], Lin et al. [6] and Behr [7] correlations in Eqs. (1-8).
- Nomographs, e.g., Song and Kobayashi [8], Ning et al. [9], Gandhidasan [10] and Ghiasi and Bahadori [11] correlations in Eqs. (9-12).
- Equation of state models.

The validity and operating conditions of these correlations are given in Table A-1 in *Appendix A*.

$$\ln \frac{p^v}{p_c} \left[a_1 \tau + a_2 \tau^{1.5} + a_3 \tau^3 + a_4 \tau^{3.5} + a_5 \tau^4 + a_6 \tau^{7.5} \right] \left[\frac{T_c}{T} \right] \quad (1)$$

where,

$$\tau = 1 - \left(\frac{T}{T_c} \right) \quad (2)$$

$$W = 47430 \left[\frac{P^v}{P} \right] \quad (3)$$

$$W = \left(\frac{A}{P} + B \right) C \quad (4)$$

$$A = A_A + B_A T + C_A T^2 + D_A T^3 + E_A T^4 \quad (5)$$

$$B = A_B + B_B T + C_B T^2 + D_B T^3 + E_B T^4 \quad (6)$$

where C, A_A, B_A, \dots, E_A and A_B, B_B, \dots, E_B , are model constants.

According to Campbell [5], for the correlation, Eqs. (1-3) are used when the pressure is less than 100 psi, while Eqs. (4-6), are used for pressures above 100 psi.

$$W = 101.325 \frac{\sum_{i=0}^7 a_i T_i}{P} + \sum_{i=0}^7 b_i T_i \quad (7)$$

where a_i and b_i are model constants.

$$W = a_0 + \exp \left[\begin{array}{l} a_1 + \frac{a_2 + a_3 \ln P + a_4 (\ln P)^2}{(T + 273.15)^2} + a_5 \ln P + a_6 (\ln P)^2 + \\ a_7 (\ln P)^3 + \frac{a_8 + a_9 \ln P + a_{10} (\ln P)^2 + a_{11} (\ln P)^3}{(T + 273.15)^3} \end{array} \right] \quad (8)$$

$$W = 16.02 \exp \left[a_1 + a_2 \ln p + \frac{a_3 + a_4 \ln p}{T + 273.15} + \frac{a_5}{(T + 273.15)^2} + a_6 (\ln p)^2 \right] \quad (9)$$

$$\ln W = a_0 + a_1 T + a_2 T^2 \quad (10)$$

$$W_{water} = 593.335 e^{0.05486T} \times P^{-0.81462} \quad (11)$$

$$\log W = [A_1 \log P + A_2 \log P^2 + A_3 \log P^3] + [B_1 \log T + B_2 \log T^2 + B_3 \log T^3] + [C_1 \log P \times \log T + C_2 \log P^2 \times \log T + C_3 \log P \times \log T^2] + D \quad (12)$$

where $A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2, C_3$, and D , are correlation coefficients.

3. New Model Development

Based on the studies by Campbell and Hubbard [12], the data points were obtained using the Get Data Graph Digitizer Version 2.26.0.20 and used in the development of the model. Based on that, the water content values were plotted against temperature for each selected constant pressure value. A polynomial function of the fourth-order was found to fit accurately into the data set. Trend lines that best defined the curves followed a fourth-order polynomial equation. Figure 1 gives an

illustration of water content versus temperature at constant pressures of selected trend lines, used in the development of the model in this study. The fourth-order polynomial that fitted perfectly with the trend lines as shown in Fig. 1 is given as:

$$W = aT^4 + bT^3 + cT^2 + dT + e \tag{13}$$

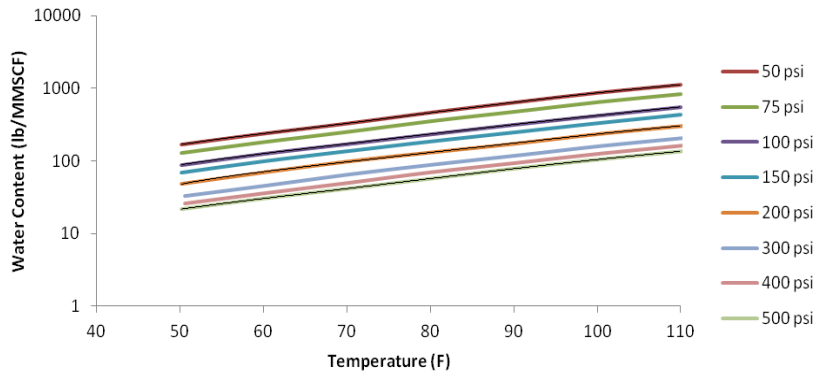


Fig. 1. Water content versus temperature at constant pressures.

The choice of a polynomial model for this study stems from the Weierstrass approximation theorem [13, 14], which states, “any continuous function can be approximated on a finite interval as closely as one wishes by a suitable polynomial”. This has made the use of polynomials popular among other existing approximating functions. The theorem has been proved by a number of authors and has been found to be accurate in approximating functions. A vivid description of the benefits of using polynomials as a tool for approximating functions has also been well outlined [15].

However, Eq. (13) only presents water content as a function of temperature. To modify the equation to have water content as a function of temperature and pressure, the values of the coefficients *a* to *e*, generated from the trend lines were plotted against pressures respectively. This was done in order to determine their (the coefficients) relationship with pressure. This also showed the degree of dependence or significance of the coefficients on pressure. Table 1 show some of the coefficients and pressure values. From the plots of the pressures versus coefficients, appropriate relationships were adopted, from which, the model in this study was developed. Figures 2 to 6, give an illustration of how the relationships between pressure and the coefficients, *a* to *e* for instance, were obtained.

From the relationship between pressure and the various constants *a* to *e*, the following relationships were intuitively adopted from a rather rigorous procedure:

- a* = *a*/(*P*+*f*) -a linear function
- b* = *b* - no significant relationship between *b* and pressure (low *R*²)
- c* = (*c*/*P*^{*g*}) -inverse power function
- d* = (*d*/*P*^{*h*}) -inverse power function
- e* = (*e*/*P*) -inverse function

A new constant ‘*i*’ was added to the equation. This gave rise to a modified model of the form:

$$W_c = \frac{a}{(P+f)}T^4 + bT^3 + \frac{c}{P^g}T^2 + \frac{d}{P^h}T + \frac{e}{P} + i \tag{14}$$

Table 1. Selected coefficients for model development.

Pressure (psi)	$a (\times 10^6)$	b	c	d	e
25	13	0.000313	0.0363	3.092	39.430
35	10	0.000191	0.0300	2.413	32.340
50	6	0.000333	0.0334	1.839	10.487
75	5	0.000344	0.0333	1.234	7.575
100	4	0.000420	0.0329	0.805	-0.529
150	3	0.000303	0.0240	0.643	0.067
200	2	0.000273	0.0230	0.410	-2.869
250	2	0.000266	0.0220	0.334	-3.876
300	2	0.000256	0.0206	0.253	-4.901
350	2	0.000243	0.0230	0.067	-1.873
400	1	0.000171	0.0173	0.030	-0.693

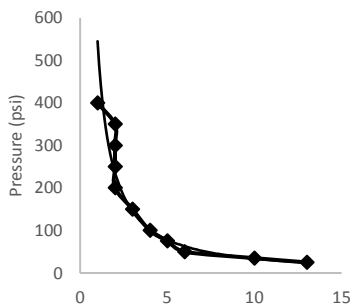


Fig. 2. Pressure versus coefficient a .

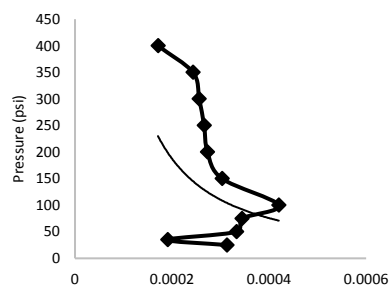


Fig. 3. Pressure versus coefficient b .

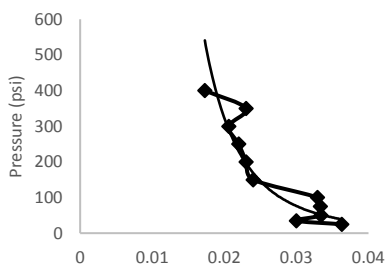


Fig. 4. Pressure versus coefficient c .

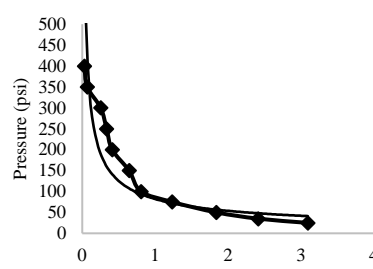


Fig. 5. Pressure versus coefficient d .

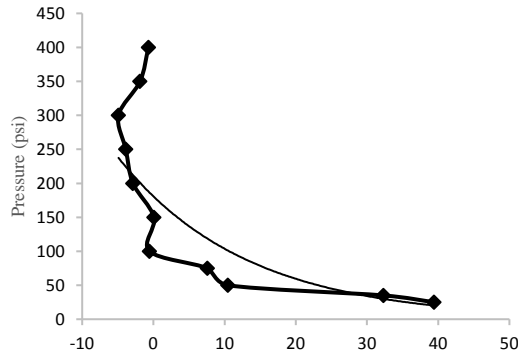


Fig. 6. Pressure versus coefficient *e*.

Re-arranging the model coefficients alphabetically gave the proposed model, which is of the form:

$$W_c = \frac{a}{(P + b)}T^4 + cT^3 + \frac{d}{P^e}T^2 + \frac{f}{P^g}T + \frac{h}{P} + i \quad (15)$$

With a temperature and pressure validity range of 68 °F - 239 °F and 25 to 10,000 psi, respectively. Table 2 shows the new model coefficients developed for the various pressure ranges.

Table 2. New model coefficients.

Coefficients	Pressure range				
	25-100 psi	100-300 psi	300-500 psi	500-1,000 psi	1000-10,000 psi
<i>a</i>	0.000233282	0.000343783	0.000335384	0.000367921	0.00038021
<i>b</i>	-5.0557635	11.64765879	1.000721385	120.3605141	120.3605141
<i>c</i>	0.000127411	6.61677E-07	0	1.86287E-05	0.00001568
<i>d</i>	0.000938568	0.106665937	1	-0.02305892	-0.02048728
<i>e</i>	0.344700368	0.769304521	6.234248732	0.319132831	0.31963295
<i>f</i>	33.92841037	20.72463476	26.62518046	32.91028892	32.9102902
<i>g</i>	0.712045082	0.831237513	0.959855786	0.69477713	0.69443522
<i>h</i>	1348.591682	1456.895566	9992.831452	1348.820194	1348.820194
<i>i</i>	-3.641579597	0.289699262	0.368259675	0.290578393	0.29058232

Error analysis

The percentage absolute and average absolute deviation statistical models were adopted in this study for determining the degree of accuracy of the correlations under consideration. These models are of the form:

$$\% AD = \left| \frac{W_{exp} - W_{cal}}{W_{exp}} \right| 100 \quad (16)$$

$$\% AAD = \frac{1}{n} \left| \frac{W_{exp} - W_{cal}}{W_{exp}} \right| 100 \quad (17)$$

4. New Model: Validation and Verification

In order to ascertain its reliability and accuracy, the model developed in this study was validated with different published gas-water systems [16-18]. These systems include:

- Natural gas mixture (94% CH_4 + 4% C_2H_6 + 2% C_3H_8)-water system.
- Methane-water system.
- Ethane-water system.

To further ascertain the performance of the new model, results were compared with values obtained from the Cubic Plus Association Equation of State (CPA-EoS). The form of the CPA-EoS, used in this study is shown in *Appendix B*. The CPA-EoS [19] has been reported to be specifically designed for handling predictions of the water content of natural gases with a high degree of accuracy.

Unlike some published experimental water content data, which are unable to clearly indicate the most stable equilibrium phase, the CPA-EoS, handles this problem effectively. In addition, the CPA-EoS was designed to handle a wider range of gas compositions, temperatures and pressures, than most; if not all; of the existing models [20].

Results from three (3) existing widely used water content correlations [5, 6, 11], were also compared with the results from the new model, using the CPA-EoS results as the basis for determining their relative accuracy.

Comparisons were done for pressures of 735, 1102.5 and 1470.15 psi and temperatures of between 68 and 176 °F, which are quite consistent with the pressure and temperature ranges of natural gas distribution and transmission lines in sub-Saharan Africa.

The choice of these three correlations was because they were reported to have a wide range of temperature and pressure applicability as well as performed equally or better than most of the other existing correlations. As a result, they would provide a good basis for comparison as well as a reliable means of ascertaining the accuracy and reliability of the model developed in this study.

5. Results and Discussion

A new correlation for determining the maximum amount of water in sweet natural gas in Eq. (15) has been developed with the method described above. This makes it one of the very limited water content models developed using data from the Campbell chart. In addition, the new correlation is quite easy to use as against the polynomial model [5] described by Eqs. 4 to 6, which has very numerous temperature-dependent coefficients, thereby making it more rigorous.

The coefficients of the developed correlation are pressure dependent without pressure discontinuities, unlike the Ning et al. [9] model (which is also a

polynomial with pressure dependent coefficients) that has a series of pressure discontinuities, requiring interpolations in such cases.

The reliability and accuracy of the newly developed correlation have been affirmed by comparing and validating the results of the correlation with that of existing correlations [5, 6, 11] as well as published experimental data [16-18]. The results from the comparative analysis in Tables 3, 4 and 5 showed a percentage absolute deviation (% AAD) of 2.65 for a methane-water system, 4.40 for ethane-water system and 4.62 for natural gas mixture-water system.

This is an indication that the model in this study is adequate and reliable. Furthermore, the results from this study by Campbell [5], Lin et al. [6] and Ghiasi and Bahadori [11] were plotted alongside the CPA-EoS results at 735, 1102.5 and 1470.15 psi.

It showed that the correlations were in good agreement with the results obtained from CPA-EoS. This indicates the reliability of the models. Figure 7 shows the trend analysis of the correlations and CPA- EoS model at a pressure of 1470.15 psi.

The % AAD analysis in Fig. 8 for a temperature range of 68-176 °F showed that the correlation by Lin et al. [6] performed better at 735 psi with a % AAD of 2.59 closely followed by the model in this study with a % AAD of 3.28. At 1102.5 and 1470.15 psi, the model in this study performed better than the other correlations with a % AAD of 1.74 and 2.28 respectively.

Tables C-1, C-2 and C-3 in *Appendix C* show the performance of the correlations. The correlation by Campbell [5] gave the highest overall % AAD among the correlations considered with minimum and maximum values of 6.08 and 7.33 respectively. It also showed that the new correlation performed better than the correlations by Campbell [5] and Ghiasi and Bahadori [11] for all cases of pressure and temperature conditions considered in this study.

More so, the correlation in this study performed better than the correlation by Lin et al. [6] at 1102.5 and 1470.15 psi. The results, therefore, suggest that the new correlation is adequate and reliable for the prediction of the water content of sweet natural gases within the pressure and temperature range of 730-1500 psi and 68-176 °F.

The accuracy of the model developed in this study highlights its significance in its application for determining the maximum amount of water natural gas can hold at given temperatures and pressures. The range of pressures and temperatures used in this study, for instance, are consistent with conditions in gas dehydration columns as well as natural gas transmission and distribution lines in sub-Saharan Africa.

The ability to adequately predict the maximum water content underscores the reliability of the newly developed model in accurately estimating the Gross Heating Value (GHV) of sweet natural gases and the amount of water necessary for corrosion and hydrate formation.

This, in turn, will enhance proper GHV, corrosion and hydrate monitoring and management programs (thereby reducing operating costs significantly). In addition, the simplicity of the developed model makes it a good candidate for developing simple to use spreadsheets.

Table 3. Absolute deviation for natural gas mixture-water system.

Temperature (°F)	Pressure (psi)	Water content (mol fraction)		
		Experiment [16]	This study	% AD
85.91	75.117	0.00847	0.00869	2.59
87.35	156.996	0.00430	0.00363	15.56
85.91	355.005	0.00198	0.00185	6.56
119.93	77.322	0.02260	0.02292	1.42
119.93	282.828	0.00644	0.00613	4.81
119.57	613.578	0.00305	0.00294	3.61
139.01	74.970	0.03970	0.03840	3.27
139.19	223.881	0.01340	0.01310	2.23
139.73	428.505	0.00722	0.00700	3.05
139.53	720.594	0.00453	0.00445	1.77
165.47	83.349	0.06890	0.06470	6.09
190.49	255.780	0.04010	0.0378	5.74
190.13	676.053	0.01520	0.01469	3.36

Table 4. Absolute deviation for methane-water system.

Temperature (°F)	Pressure (psi)	Water content (mol fraction)		
		Experiment [16, 17]	This study	% AD
77.00	345.450	0.001483	0.001492	0.60
77.00	596.820	0.000915	0.000867	5.20
119.57	613.578	0.003050	0.002940	3.60
119.93	77.322	0.002260	0.002292	1.42
122.00	711.480	0.002921	0.002815	3.60
122.00	1002.540	0.002185	0.002205	0.92
139.19	223.881	0.013400	0.013100	2.20
139.55	720.594	0.004530	0.004450	1.77
167.00	458.640	0.013350	0.012680	5.00
167.00	804.090	0.008030	0.007900	1.60
212.00	843.780	0.019920	0.018830	5.50
212.00	1056.783	0.016430	0.015992	2.70
212.00	1374.009	0.013090	0.013040	0.38

Table 5. Absolute deviation for ethane-water system.

Temperature (°F)	Pressure (psi)	Water content (mol fraction)		
		Experiment [18]	This study	% AD
100.004	405.72	0.002641	0.002439	7.65
100.004	809.97	0.001474	0.001354	8.14
100.004	1012.83	0.001244	0.001166	6.27
100.004	1519.98	0.000949	0.000856	9.80
100.004	2027.13	0.000812	0.000695	14.41
129.992	405.72	0.006000	0.005720	4.67
129.992	809.97	0.003250	0.003170	2.46
129.992	1012.83	0.002740	0.002720	0.73
129.992	1519.98	0.002020	0.002000	0.99
129.992	2027.13	0.001680	0.001630	2.98
159.998	405.72	0.012690	0.012190	3.94
159.998	809.97	0.006833	0.006697	1.99
159.998	1012.83	0.005675	0.005715	0.71
159.998	1519.98	0.004147	0.004199	1.25
159.998	2027.13	0.003409	0.003408	0.03

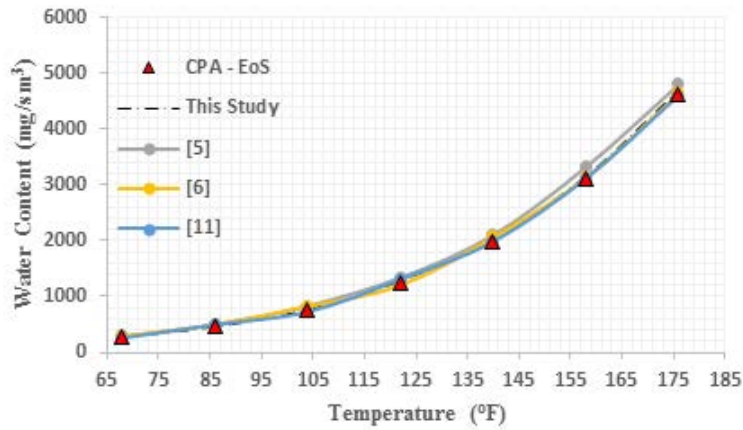


Fig. 7. Correlations comparison at 1470.15 psi.

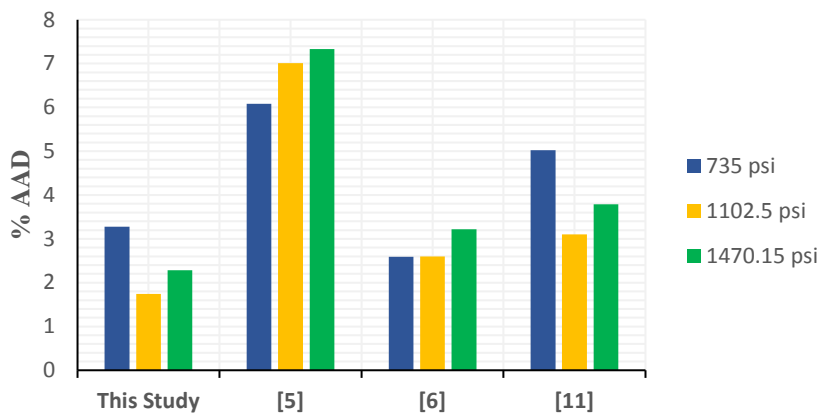


Fig. 8. Error analysis of correlations at different pressures.

6. Conclusions

A new model for predicting the water content of sweet natural gases has been developed and presented. This was achieved by using data obtained from the Campbell chart. The validity, accuracy and reliability of the new model were ascertained by comparing the results with those of published experimental data (methane-water, ethane-water and natural gas mixture-water systems) and results from the CPA EoS. A comparison between the new correlation and three (3) widely used correlations was also performed. The conclusions from the study are highlighted below.

- The new model developed in this study is adequate and reliable for handling; methane-water, ethane-water and natural gas mixture-water systems.
- It is in good agreement with results obtained from the CPA-EoS.
- On comparison, the new model performed better than the widely used correlations within the pressure and temperature range of 730-1500 psi and 68-176 °F considered in this study.

Nomenclatures

A_i	Association sites on a molecule
a	Attractive parameter
a, b, \dots, i	Constants
a_0, a_1, a_{11}	Constants
b	Repulsive parameter
g	Radial distribution function
n	Total number of data points
p	Pressure, psi/atm/MPa
p_c	Critical pressure, MPa
p_v	Vapour pressure, MPa
R	Gas constant, psi-ft ³ /lb-mol °R
R^2	Coefficient of determination
T	Temperature, Celsius/Fahrenheit/Rankine
T_c	Critical temperature, Kelvin
V	Molar volume, ft ³ /mol
W, W_c	Water content, mole fraction/lbMMSCF/mgsm ⁻³
W_{water}	
W_{cal}	Calculated water content, mole fraction/lbMMSCF/mgsm ⁻³
W_{exp}	Experimental water content, mole fraction/lbMMSCF/mgsm ⁻³
X^{Ai}	Hydrogen bond component
x_i	Mole fraction of component
Z	Compressibility factor

Greek Symbols

ρ	Molecular density, lb/ft ³
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Abbreviations

% AD	Percentage Absolute Deviation
% AAD	Percentage Average Absolute Deviation
CPA-EoS	Cubic Plus Association, Equation of State
SRK-EoS	Soave Redlich Kwong, Equation of State

References

1. Bahadori, A. (2011). Prediction of moisture content of natural gases using simple Arrhenius-type function. *Central European Journal of Engineering*, 1(1), 81-88.
2. Rajzinger, J.; and Zálezáková, L. (2012). Calculation of maximum water in gas phase for selected natural gases. Retrieved November 21, 2015, from http://www.energetickeforum.cz/file/343_1_1/.
3. Sharma, S.C.; and Campbell, J.M. (1969). Predict natural-gas water content with total gas usage. *Oil & Gas Journal*, 67(31), 136-137.
4. Aimikhe, V.J.; Joel, O.F.; Ikiensikimama, S.S.; and Iyuke, S. (2017). Experimental determination of water content of sweet natural gas with methane component below 70%. *International Journal of Scientific and Engineering Research*, 8(7), 2324-2329.

5. Campbell, J.M. (2014). Lean sweet natural gas water content correlation. Retrieved March 14, 2016, from [http:// jmcampbell.com/tip-of-the-month/2014/09/lean-sweet-natural-gas-water-content correlation/](http://jmcampbell.com/tip-of-the-month/2014/09/lean-sweet-natural-gas-water-content-correlation/).
6. Lin, Z.; Junming, F.; Jia, Z.; Li, Q.; and Luling, L. (2014). Formula calculation methods of water content in sweet natural gas and their adaptability analysis. *Natural Gas Industry B*, 1(2), 144-149.
7. Behr, W.R. (1983). Correlation eases absorber-equilibrium-line calculations for TEG-natural gas dehydration. *Oil & Gas Journal*, 81(45), 96-98.
8. Song, K.Y.; and Kobayashi, R. (1982). Measurement and interpretation of the water content of a methane-propane mixture in the gaseous state in equilibrium with hydrate. *Industrial and Engineering Chemistry Fundamentals*, 21(4), 391-395.
9. Ning, Y.; Zhang, H.; and Zhou, G. (2000). Mathematical simulation and program for water content chart of natural gas. *Chemical Engineering Oil and Gas*, 29, 75-77. (in Chinese)
10. Gandhidasan, P. (2003). Parametric analysis of natural gas dehydration by a triethylene glycol solution. *Energy Sources*, 25(3), 189-201.
11. Ghiasi, M.M.; and Bahadori, A. (2014). A new correlation for accurate estimation of natural gases water content. *Petroleum and Coal*, 56(5), 582-594.
12. Campbell, J.M.; and Hubbard, R.A. (2004.). *Gas conditioning and processing* (8th ed.). Volume 1: The basic principles. Normal, Oklahoma, United States of America: John M. Campbell and Company.
13. Burkill, J.G. (1959). Lectures on approximation by polynomials. Retrieved October 14, 2017, from <http://www.math.tifr.res.in/~publ/ln/tifr16.pdf/>
14. Hoffman, J.D. (2001). *Numerical methods for engineers and scientists* (2nd ed.). New York, United States of America: Marcel Dekker, Inc.
15. Quarteroni, A.; Sacco, R.; and Saleri, F. (2007). *Numerical mathematics* (2nd ed.). New York, United States of America: Springer-Verlag.
16. Chapoy, A.; and Mohammadi, A.H. (2005). Estimation of water content for methane + water and methane + ethane + n-butane + water systems using a new sampling device. *Journal of Chemical and Engineering Data*, 50(4), 1157-1161.
17. Rigby, M.; and Prausnitz, J.M. (1968). Solubility of water in compressed nitrogen, argon, and methane. *The Journal of Physical Chemistry*, 72(1), 330-334.
18. Wichert, G.C.; and Wichert, E. (2003). New charts provide accurate estimations for water content of sour natural gas. *Oil and Gas Journal*, 101(41), 64-66.
19. Kontogeorgis, G.M.; Voutsas, E.C.; Yakoumis, I.V.; and Tassios, D.P. (1999). An equation of state for associating fluids. *Industrial and Engineering Chemistry. Research*, 35(11), 4310-4318.
20. Torbjørn, V.L.; Anita, B.; Kjersti, O.C.; Cecilie, F.N.; and Even, S. (2008). Water content of high-pressure natural gas: Data, prediction and experience from field. *Proceedings of the International Gas Union Research Conference*. Paris, France, 1979-2021.

Appendix A

Validity of Correlations

The validity of the correlations described in this study is presented in the Table A-1, below. This is based mostly on the temperature and pressure ranges for which, the correlations are applicable.

Table A-1. Temperature and pressure ranges for correlations validity.

Correlations	Temperature range (°F)	Pressure range (psi)
[5]	-40 to 212	14.7 -9,993
[6]	-58 to 104	14.5 to 14,504
[7]	-nil-	203 -3,043
[8]	-40 - 120	203 -2,029
[9]	-nil-	14.7 -17,700
[10]	-nil-	-nil-
[11]	77 - 284	453 -11,603

Appendix B

CPA-EoS Form used in this Study

The CPA-EoS, used in this study is similar to the one used by Torbjørn et al. [20], and is of the form:

$$Z^{CPA} = Z^{SRK-EoS} + Z^{association}$$

$$Z^{SRK-EoS} = \frac{V}{V-b} + \frac{a}{RT(V+b)}$$

$$Z^{association} = -\frac{1}{2} \left[1 + \rho \frac{\partial \ln g}{\partial \rho} \right] \sum_i \sum_{A_i} x_i (1 - x^{A_i})$$

Appendix C

Analysis of Model Validation and Reliability

The validity and reliability of the correlation developed in this study are tested by comparing the results with those of the CPA -EoS. A comparison is also made with three (3) very accurate and widely used correlations [5, 6, 11] in order to rate the performance of the new model. The results are presented below.

Table C-1. Comparison at 735 psia.

Temperature (°F)	Water content (mg/sm ³)				
	CPA-EoS	This study	[5]	[6]	[11]
68	422.53	433.82	474.37	421.67	435.75
86	757.00	732.13	827.90	799.63	762.08
104	1301.67	1251.21	1407.17	1400.21	1282.14
122	2185.56	2093.33	2292.13	2235.47	1895.60
140	3497.37	3378.13	3641.97	3502.43	3281.69
158	5446.67	5242.66	5647.32	5332.76	5025.99
176	7710.00	7841.36	8498.80	7693.15	7505.06
% AAD		3.28	6.08	2.59	5.02

Table C-2. Comparison at 1102.50 psia.

Temperature (° F)	Water content (mg/sm ³)				
	CPA-EoS	This study	[5]	[6]	[11]
68	321.00	325.19	353.66	338.16	337.98
86	562.47	548.62	610.20	522.48	587.63
104	955.71	935.97	1026.36	950.95	983.35
122	1568.89	1562.40	1658.59	1622.86	1448.11
140	2490.00	2515.64	2615.50	2480.65	2493.43
158	3833.33	3895.99	4029.41	3866.64	3803.16
176	5632.63	5816.35	6032.62	5600.10	5657.95
% AAD		1.74	7.01	2.60	3.10

Table C-3. Comparison at 1470.15 psia.

Temperature (° F)	Water content (mg/sm ³)				
	CPA-EoS	This study	[5]	[6]	[11]
68	267.65	259.66	293.28	250.68	283.70
86	467.72	439.91	501.30	490.26	491.07
104	764.17	752.66	835.87	721.12	818.43
122	1239.41	1257.73	1341.69	1302.11	1201.62
140	1982.22	2024.62	2102.06	1980.95	2060.44
158	3106.67	3132.47	3323.57	3112.54	3132.87
176	4619.47	4670.11	4799.03	4600.74	4647.35
% AAD		2.28	7.33	3.22	3.79