Rapid Estimation of Water Content of Sour Natural Gases

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Water is associated with natural gas from the reservoir, through production and processing and is a concern in transmission. Also the water content of sour natural gases is an important parameter in the design of facilities for the natural gas production, transmission, and processing. The aim of this study is to develop an easy-to-use method which is simpler than current available models involving a large number of parameters and requiring more complicated and longer computations, for an appropriate estimation of water content of sour natural gas mixtures containing up to 40% acid gas components (CO2 and H2S). The new developed method works for pressures ranging from 1000 to 15,000 kPa and temperatures from 15 to 120°C. Simple-to-use approach can be of immense practical value for the engineers and scientists to have a quick check on the water content of sour natural gases at various temperatures and pressures without performing any experimental measurements. In particular, gas process engineers would find the proposed approach to be user friendly involving no complex expressions with transparent calculations. Results have been compared with the reported data and excellent agreement has been obtained between the predicted results and observed values. The average absolute deviations from the reported data were found to be 3.5%.

Keywords
Natural gas, Water content, Sour gas, Correlation, Gas processing, Acid gas

1. Introduction

Natural gas reservoirs always have water associated with them and hence the gas in the reservoir is water saturated. When the gas is produced there is a simultaneous production of water as well. Some of this water is produced water from the reservoir directly. Other water produced with the gas is a result of water condensation due to the variations in pressure and temperature during production. Accurate determination of water content of sour natural gases therefore requires a careful study of the existing literature information and available experimental data. In most cases, using additional experimental data is the best way to verify the model based predictions. Natural, associated, or tail gas usually contains water, either in liquid or vapor form, at source as well as due to sweetening with an aqueous solution. Operating experience and thorough engineering have proved that it is necessary to reduce and control the water content of gas to ensure safe processing and transmission. The first step in evaluating and/or designing a gas dehydration system is therefore to determine the water content of the gas. This data is most critical when designing sour gas dehydration facilities and estimating water production with sour gas in the plant inlet separator1).

There are numerous methods available for determining water content of natural gases. In general, for acid gas concentrations less than about 30%, existing methods are satisfactory. However, for higher acid gas concentrations (above 50%), particularly at higher pressures, existing methods can lead to serious errors in estimating water contents2). An appropriate method has been recently introduced3). It is chart based method which provides good estimates of the equilibrium water vapor content of sour natural gas for a range of conditions, including H2S contents of 3-38 mol% with CO2 contents of 3-43 mol%, pressures ranging from 2000 to 70,000 kPa, and temperatures from 10 to 175°C. The overall average error of this method is less than 1%. However, a few points showed a discrepancy of more than ±10%. In the method the water content of the sour gas is calculated by the multiplication of correction factor, and the water content of sweet gas from the McKetta-Wehe chart4). For most gas systems the McKetta-Wehe chart, generated from empirical data, provides the standard for water content determination. This chart can be used to predict the saturated water content of sweet, pipeline quality natural gas. However, this chart is so difficult to read. Kobayashi et al.5) presented a correlation for the curves plotted in the
McKetta-Wehe chart. However, their equation is quite complicated and is only applicable for temperatures up to 49°C and pressures up to 14,000 kPa. Therefore, as a first step to predict water content of natural gases, an appropriate equation representing the McKetta-Wehe (1958) chart is required.

Both H₂S and CO₂ contain more water at saturation than sweet natural gas mixtures. The relative amounts vary considerably with temperature and pressure. Saturated water contents of pure CO₂ and H₂S can be significantly higher than that of sweet natural gas, particularly at pressures above about 4800 kPa (abs) at ambient temperatures. Corrections for H₂S and CO₂ should be applied when the gas mixture contains more than 5% H₂S and/or CO₂ at pressures above 4800 kPa (abs). These corrections become increasingly significant at higher concentrations and higher pressures.

2. Methodology to Develop New Correlation

The required data to develop this correlation includes the reported data for effective water content of H₂S and CO₂ from reference 6 as well as temperature and pressure of sour natural gases. In this work, the water content of sour natural gas is predicted rapidly by proposing a new correlation, which has been developed, based on newly proposed numerical model[7,8]. The following methodology has been applied to develop this correlation.

Firstly, effective water content of CO₂ and H₂S and sweet natural gases are correlated as a function of temperature for various reported pressures. Then, the calculated coefficients for these polynomials are correlated as a function of pressure. The derived polynomials are applied to calculate new coefficients for Eq. (1) to predict the effective water content of CO₂ and H₂S. Table 1 shows the tuned coefficients for Eqs. (2) to (5).

The same procedure is repeated for sweet natural gases to derive the polynomial coefficients for Eqs. (7) to (10).

In brief, the following steps are repeated to tune the correlation’s coefficients.
1. Correlate the reported effective water content of H₂S and CO₂ or sweet natural gases as a function of pressure for the selected pressure.
2. Repeat steps 2 and 3 for other data and other pressures.
3. Correlate corresponding polynomial coefficients, which were obtained for different pressures versus temperatures, a = f(T), b = f(T), c = f(T), d = f(M) [see Eqs. (2)-(5) and Eqs. (7)-(10)].
4. Calculate the effective water content of H₂S and CO₂ and sweet natural gases water content as a function of temperature from Eqs. (1) and (6), respectively.

3. Novel Proposed Correlation

The proposed approach consists of two main sets of equations and a table containing tuned coefficients based on the data reported in the Gas Processor and Suppliers Association (GPSA) Engineering Data Book[9]. Equation (1) presents the new correlation for predicting water content of sweet gases, in which four coefficients are used to correlate water content and pressure of a gas.

\[
W_{HC} = 10^{\left(\alpha + \beta \cdot \log(P) + \gamma \cdot \log(P)^2 + \delta \cdot \log(P)^3\right)}
\]  \hspace{1cm} (1)

Where:
\[
a = A_1 + B_1T + C_1T^2 + D_1T^3
\]  \hspace{1cm} (2)
\[
b = A_2 + B_2T + C_2T^2 + D_2T^3
\]  \hspace{1cm} (3)
\[
c = A_3 + B_3T + C_3T^2 + D_3T^3
\]  \hspace{1cm} (4)

Table 1 Tuned Coefficients Used in Proposed Correlations of Determining the Water Contents of HC and Effective Water Contents of H₂S and CO₂ in Natural Gas Mixture

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Sweet gas water content</th>
<th>Effective water content of H₂S</th>
<th>Effective water content of CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>-19.476736072</td>
<td>-2.2847355055 × 10^6</td>
<td>-5.15705929706 × 10^6</td>
</tr>
<tr>
<td>B₁</td>
<td>0.06274213412</td>
<td>410.13435673</td>
<td>253.953558137</td>
</tr>
<tr>
<td>C₁</td>
<td>2.384743561 × 10^-4</td>
<td>-0.023387094972</td>
<td>-0.0218797871207</td>
</tr>
<tr>
<td>D₁</td>
<td>-5.673899072 × 10^-7</td>
<td>1.55604987964 × 10^-7</td>
<td>7.00196727253 × 10^-7</td>
</tr>
<tr>
<td>A₂</td>
<td>30.0071017143</td>
<td>2.2856962175 × 10^4</td>
<td>1.54692319504 × 10^4</td>
</tr>
<tr>
<td>B₂</td>
<td>-0.1701087797</td>
<td>-4.28913302821</td>
<td>-2.7543190822</td>
</tr>
<tr>
<td>A₃</td>
<td>2.26883134 × 10^-4</td>
<td>2.84221095695 × 10^-4</td>
<td>2.51540980528 × 10^-4</td>
</tr>
<tr>
<td>B₃</td>
<td>3.123350518 × 10^-8</td>
<td>-4.35332471889 × 10^-9</td>
<td>-8.37305127559 × 10^-9</td>
</tr>
<tr>
<td>A₄</td>
<td>-15.133474</td>
<td>-76.4984711141</td>
<td>-52.448485734</td>
</tr>
<tr>
<td>B₄</td>
<td>0.0120144827</td>
<td>0.0149336555228</td>
<td>9.97118369879 × 10^-3</td>
</tr>
<tr>
<td>C₃</td>
<td>-2.165793851 × 10^-4</td>
<td>-1.11025629876 × 10^-6</td>
<td>-9.594033224 × 10^-7</td>
</tr>
<tr>
<td>D₃</td>
<td>1.348432385 × 10^-7</td>
<td>2.3467115643 × 10^-11</td>
<td>3.3075581263 × 10^-11</td>
</tr>
<tr>
<td>A₄</td>
<td>1.955487254</td>
<td>0.085733579771</td>
<td>0.0605410197916</td>
</tr>
<tr>
<td>B₄</td>
<td>1.3039699162</td>
<td>1.73248222725 × 10^-3</td>
<td>1.20630929063 × 10^-3</td>
</tr>
<tr>
<td>C₄</td>
<td>3.268468205 × 10^-10</td>
<td>1.41055829053 × 10^-9</td>
<td>1.21662951101 × 10^-9</td>
</tr>
<tr>
<td>D₄</td>
<td>-2.420198973 × 10^-8</td>
<td>-3.5666823871 × 10^-14</td>
<td>-4.31605047324 × 10^-14</td>
</tr>
</tbody>
</table>

\[ d = A_4 + B_4 T + C_4 T^2 + D_4 T^3 \]  
(5)

In the above equations, \( W_{HC} \) is the water content of sweet hydrocarbons (mg/m³), and parameters \( T \) and \( P \) are temperature and the pressure of natural gas in K and kPa, respectively. The tuned coefficients are also given in Table 1.

Second set of equations provides a correlation for estimating “effective” water content of natural gas mixtures containing up to 40% acid gas components. Equation (6) calculates \( \text{H}_2\text{S} \) and \( \text{CO}_2 \) effective water contents in natural gas mixtures:

\[ W_{NHC} = \alpha + \beta P + \gamma P^2 + \theta P^3 \]  
(6)

Where:

\[ \alpha = A_1 + B_1 T + C_1 T^2 + D_1 T^3 \]  
(7)

\[ \beta = A_2 + B_2 T + C_2 T^2 + D_2 T^3 \]  
(8)

\[ \gamma = A_3 + B_3 T + C_3 T^2 + D_3 T^3 \]  
(9)

\[ \theta = A_4 + B_4 T + C_4 T^2 + D_4 T^3 \]  
(10)

In Eq. (6), \( W_{NHC} \) is the “effective” water content of \( \text{CO}_2 \) and \( \text{H}_2\text{S} \) components in natural gas mixtures (mg/m³). The tuned coefficients for Eqs. (7) to (10) are given in Table 1, which can be also retuned if more accurate data are available.

Finally, Eq. (11) is applied to calculate the saturated water content of sour natural gases “\( W \)” in mg/(m³ (Std.)).

\[ W = y_{\text{HC}} W_{HC} + y_{\text{CO}_2} W_{\text{CO}_2} + y_{\text{H}_2\text{S}} W_{\text{H}_2\text{S}} \]  
(11)

Note that Eq. (6) provides values for what is termed the “effective” water content of \( \text{CO}_2 \) and \( \text{H}_2\text{S} \) in natural gas mixtures to be used only in Eq. (11). These are not for pure \( \text{CO}_2 \) and \( \text{H}_2\text{S} \) water contents.

4. Results

Figure 1 illustrates the obtained results for the prediction of water content of sweet natural gases. Figures 2 and 3 show the obtained results of new proposed correlations for predicting the effective water contents of \( \text{CO}_2 \) and \( \text{H}_2\text{S} \) components in natural gas mixtures, respectively. As can be seen, the obtained results show good agreement with the reported data. Table 2 shows that the proposed correlation has good agreement with the reported data (reference 6) and the average absolute deviation being around 3.5%.

4.1. Example of Sour Gas Containing and \( \text{CO}_2 \)

Determine the saturated water content of a mixture containing 80% \( \text{CH}_4 \) and 20% \( \text{CO}_2 \) at 70°C and 13,800 kPa (abs). The reported water content is 2560 mg/(m³ (Std.)).

**Solution:**

\[ W_{HC} = 2603 \text{ mg/} \text{m}^3 \text{ (Std.)} \] (from Eq. (1))

\[ W_{\text{CO}_2} = 1921 \text{ mg/} \text{m}^3 \text{ (Std.)} \] (from Eq. (6))

And finally from Eq. (11), we have:

\[ W = (0.80)(2603) + (0.20)(1921) = 2464 \text{ mg/} \text{m}^3 \text{ (Std.)} \]

In this example the average absolute deviation percent is 3.9%.

4.2. Example of Sour Gas Containing \( \text{CH}_4 \) and \( \text{H}_2\text{S} \)

Determine the saturated water content of a mixture

Table 2  Comparison of Obtained Results of New Proposed Method for Predicting Water Content of Sour Gases with the Reported Data

<table>
<thead>
<tr>
<th>Temperature [℃]</th>
<th>Pressure [kPa]</th>
<th>Equivalent H2S mole fraction</th>
<th>Equivalent H2S water content [mg/m³]</th>
<th>Hydrocarbon water content [mg/m³]</th>
<th>Predicted water content of sour gases using new method [mg/m³]</th>
<th>Reported dataδ</th>
<th>Absolute deviation percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>9621</td>
<td>0.16</td>
<td>1086</td>
<td>637</td>
<td>753</td>
<td>794</td>
<td>5.4</td>
</tr>
<tr>
<td>39.11</td>
<td>6965.5</td>
<td>0.17</td>
<td>1552</td>
<td>1036</td>
<td>1124</td>
<td>1150</td>
<td>2.3</td>
</tr>
<tr>
<td>39.11</td>
<td>4213.8</td>
<td>0.19</td>
<td>2077</td>
<td>1518</td>
<td>1624</td>
<td>1580</td>
<td>2.8</td>
</tr>
<tr>
<td>39.11</td>
<td>2469</td>
<td>0.21</td>
<td>2673</td>
<td>2363</td>
<td>2428</td>
<td>2460</td>
<td>1.3</td>
</tr>
<tr>
<td>39.11</td>
<td>9600</td>
<td>0.275</td>
<td>1370</td>
<td>828</td>
<td>977</td>
<td>940</td>
<td>3.9</td>
</tr>
<tr>
<td>39.11</td>
<td>6379.3</td>
<td>0.29</td>
<td>1629</td>
<td>1104</td>
<td>1256</td>
<td>1200</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Average Absolute Deviation Percentage (AADP) 3.5%

containing 84% CH₄ and 16% H₂S at 34℃ and 9621 kPa (abs). The reported water content is 794 mg/(m³ (Std.)).

Solution:

\[ W_{HC} = 637 \text{ mg/(m}^3 \text{ (Std.))} \] (from Eq. (1))

\[ W_{H₂S} = 1086 \text{ mg/(m}^3 \text{ (Std.))} \] (from Eq. (6))

And finally from Eq. (11), we have:

\[ W = (0.84)(637) + (0.20)(1086) = 753 \text{ mg/(m}^3 \text{ (Std.))} \]

In this example the average absolute deviation percent is 5.1%.

4.3. Example of Sour Gas Containing, CH₄, CO₂, and H₂S

Calculate the saturated water content of a mixture containing 70% CH₄, 15% H₂S and 15% CO₂ at 40℃ and 7000 kPa (abs). The reported water content is 1262 mg/(m³ (Std.)).

Solution:

\[ W_{HC} = 1079 \text{ mg/(m}^3 \text{ (Std.))} \] (from Eq. (1))

\[ W_{H₂S} = 1590 \text{ mg/(m}^3 \text{ (Std.))} \] (from Eq. (6))

\[ W_{CO₂} = 1609 \text{ mg/(m}^3 \text{ (Std.))} \] (from Eq. (6))

And finally from Eq. (11), we have:

\[ W = (0.70)(1079) + (0.15)(1609) + (0.15)(1590) = 1235 \text{ mg/(m}^3 \text{ (Std.))} \]

In this example the average absolute deviation percent is 2.1%.

5. Conclusions

In the present work, a simple-to-use method for accurate estimation of water content of sour natural gas mixtures containing up to 40% acid gas components has been developed. The obtained results show good agreement with the reported data, where the new developed method works for pressures ranging from 1000 to 15,000 kPa and temperatures from 15 to 120℃. The proposed correlation has good agreement with the reported data. Simple-to-use approach can be of immense practical value for the engineers and scientists to have a quick check on the water content of sour natural gases at various temperatures and pressures without performing any experimental measurements. In particular, gas process engineers would find the proposed approach to be user friendly involving no complex expressions with transparent calculations.

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Nomenclatures

- A : tuned coefficient
- B : tuned coefficient
- C : tuned coefficient
- D : tuned coefficient
- P : pressure [kPa]
- Std. : standard
- T : temperature [K]
- W : sour gas water content [mg/(m³ (Std.))]
- W_{HC} : sweet gas water content [mg/(m³ (Std.))]
- W_{WSH} : effective water content of CO₂ and H₂S [mg/(m³ (Std.))]
- \( y_{CO₂} \) : carbon dioxide mole fraction
- \( y_{H₂S} \) : hydrogen sulfide mole fraction
- \( y_{HC} \) : hydrocarbons fraction

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サワーガスの水分量の迅速評価

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生産および処理を通じて貯留層から天然ガスに水は密接に結びついており、輸送時における重大な関心事である。高硫黄分を含む天然ガス（サワーガス）の水分含有量も、天然ガスの生産、輸送、処理のための設備設計において重要なパラメーターである。本研究の目的は、40％程度の酸性ガス（CO₂とH₂S）を含むサワーガスの水分量の評価に対し、多数のパラメーターやより複雑で長い計算を含む現状のモデルより簡単で使い勝手の良い方法を開発することにある。新規に開発した方法は、1000 〜 15,000 kPa の圧力範囲や 15 〜 120℃ の温度に対して使用できる。あらゆる温度や圧力においても実験による測定することなく、サワーガス中の水含有量を迅速に調べるのに取扱いが容易な手法は、技術者や科学者にとっては計りしれない実用的な価値がある。特にガス処理技術者は、明確な計算で複雑な数式を全く含まない提案された手法がユーザーにとって親切であることに気付くであろう。計算結果を報告値と比較したところ、予想値と測定値では優れた一致を得ることができた。報告値からの標準偏差は3.5%であることが分かった。