Predictions on the water content in natural gas and water distribution in the China-Russia eastern gas pipeline

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Abstract. In the process of natural gas transportation, the existence of free water is a disturbing problem. This paper studies the calculation model of the natural gas water content of the China-Russia eastern gas pipeline and the amount and distribution of fluid accumulation in the China-Russia eastern gas pipeline commissioning stage. By comparing the calculation, Li correlation with the Keenan-Keyes model is a suitable model for calculating the natural gas water content of the China-Russia eastern gas pipeline. According to the model and software calculation, under the winter conditions in the first year of production of the China-Russia eastern gas pipeline, the total water accumulation in the pipeline increases with the increase of water content. The water produced in the pipeline can reach $255 \times 10^3$ m$^3$ in the case of saturated water content in the first year of production. The water accumulation in the pipeline is mainly distributed in the ascending part of the low-lying pipe section. Where the height difference of the pipeline is greater, the water accumulation is more serious. In the pipeline section with a mileage of 53km - 134km, the water accumulation was the most serious, and the liquid holdup was as high as 0.66.

1. Introduction
Throughout the natural gas transportation process, the presence of water components is a disturbing problem. At the initial stage of natural gas pipeline production and operation, the water existing in the low-lying areas of the pipeline will combine with natural gas to produce hydrates, which will affect the normal transportation of the pipeline. In severe cases, it will cause ice blockage at the pipeline or corresponding equipment in the station [1-3]. Therefore, it is particularly important to study and calculate the water content of natural gas during the commission process of the China-Russia eastern gas pipeline, which can predict the amount and distribution of fluid accumulation in the China-Russia eastern gas pipeline commissioning stage, and provide technical support for the smooth commissioning of the China-Russia eastern gas pipeline.

2. Calculation model
According to the composition of natural gas on the China-Russia eastern gas pipeline and the operating conditions in the initial stage of production, the adaptability of different water content
calculation models was calculated and analyzed [4-8]. Finally, the Li correlation is chosen to be the basic model:

\[
W_{1,0} = y_{HC} \left( \frac{804 \times P_{rw}}{P - P_{sw}} + \frac{B}{1000} \right) + y_{CO_2} W_{CO_2} + y_{H_2S} W_{H_2S}
\]

Where, \(W_{1,0}\) is the water content of natural gas, g/m³; \(y_{HC}\) is the mole fraction of hydrocarbon; \(y_{H_2S}\) is the mole fraction of H₂S in natural gas; \(y_{CO_2}\) is the mole fraction of CO₂ in natural gas; \(W_{HC}\) is the water content in hydrocarbon, g/m³; \(W_{CO_2}\) is the effective water content of CO₂, g/m³; \(W_{H_2S}\) is the effective water content of H₂S, g/m³; \(t\) is the temperature, °C; \(A_1, A_2, A_3, A_4, A_5, B, C_1, C_2, C_3, C_4\) are constants given in Table 1. \(P_{rw}\) is the water saturation vapor pressure, kPa; \(P\) is the pressure of the natural gas, kPa; \(t\) is the temperature, °C.

**Table 1. Constants in correlation (1).**

| P (MPa) | \(A_1\) | \(A_2\) | \(A_3\) | \(A_5\) | \(C_1\) | \(C_2\) | \(C_3\) | \(C_4\) |
|--------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1.38   | 0.00006 | -0.0045 | 0.1999  | -1.2666 | 0.00006 | 0.0034  | 0.1487  | -0.6714 |
| 2.06   | 0.00005 | -0.0032 | 0.1385  | -0.7694 | 0.00006 | 0.0046  | 0.2015  | -1.3042 |
| 2.75   | 0.00003 | -0.0014 | 0.0715  | -0.2265 | 0.00006 | 0.0046  | 0.2125  | -1.2473 |
| 4.13   | 0.00002 | -0.0004 | 0.0271  | 0.1778  | 0.00003 | 0.0021  | 0.1111  | -0.6242 |
| 6.89   | 0.00001 | -0.0002 | 0.0201  | 0.1739  | 0.00002 | 0.0010  | 0.0536  | -0.0557 |

The water saturation vapor pressure in the \(f\) correlation is calculated by the Keenan-Keyes model:

\[
P_{rw} = \frac{a}{\exp \left[ \frac{b x + c d + e x^3}{(f - x)(1 + gx)} \right]}
\]

Where, \(t\) is temperature, °C; \(x = 673.4 - 1.8t\); \(a = 2.210 \times 10^4\); \(b = 2.302585\); \(c = 3.243781\); \(d = 3.26014 \times 10^{-3}\); \(e = 2.00658 \times 10^{-9}\); \(f = 1.16509 \times 10^3\); \(g = 1.21547 \times 10^{-3}\).

3. Accuracy verification

According to the composition of the natural gas on the China-Russia eastern gas pipeline and the range of operating conditions at the initial stage of production, calculated the water content and dew point of natural gas under different conditions through programming, and compared with the calculation results of GB/T 22634-2008. Table 2 shows the composition of natural gas in the China-Russia eastern gas pipeline. Table 3 and Table 4 show the comparison between Li correlation and the GB/T 22634-2008 model.

**Table 2. The natural gas composition of China-Russia eastern gas pipeline.**

| CH₄ | C₂H₆ | C₃H₈ | C₄H₁₀ | C₅H₁₂ | H₂ | N₂ | CO₂ | He |
|-----|------|------|-------|-------|----|----|-----|----|
| 91.41 | 4.93 | 0.96 | 0.41  | 0.24  | 0.07 | 1.63 | 0.06 | 0.29 |
Table 3. Comparison between Li correlation and GB/T 22634-2008 model (When the water content is 60 mg/m³)

| P (MPa) | Water dew point (°C) | Li correlation | GB/T 22634-2008 |
|---------|----------------------|----------------|-----------------|
| 7.5     | -9.7                 | -10.0          |
| 8       | -9.3                 | -9.4           |
| 8.5     | -9.0                 | -8.8           |
| 9       | -8.8                 | -8.3           |
| 9.5     | -8.5                 | -7.8           |
| 10      | -8.3                 | -7.3           |
| 10.5    | -8.2                 | -6.8           |
| 11      | -8.0                 | -6.5           |
| 11.5    | -7.9                 | -6.1           |
| 12      | -7.8                 | -5.8           |

average error(°C) 0.95

Table 4. Comparison between Li correlation and GB/T 22634-2008 model (When the Water dew point is -5 °C)

| P (MPa) | water content (mg/m³) | Li correlation | GB/T 22634-2008 |
|---------|-----------------------|----------------|-----------------|
| 7.5     | 56.12                 | 54.42          |
| 8       | 53.69                 | 50.69          |
| 8.5     | 51.62                 | 48.12          |
| 9       | 49.84                 | 45.74          |
| 9.5     | 48.31                 | 43.71          |
| 10      | 47.00                 | 41.80          |
| 10.5    | 45.86                 | 40.16          |
| 11      | 44.89                 | 38.69          |
| 11.5    | 44.05                 | 37.25          |
| 12      | 43.33                 | 36.03          |

average error(mg/m³) 4.81

As can be seen from Table 3 and Table 4, the calculation results of Li correlation and the GB/T 22634-2008 model are not much different, and the calculation results of Li correlation are within the calculation error range of the GB/T 22634-2008 model. Therefore, Li correlation can be used to calculate the water dew point and water content of the natural gas on the China-Russia eastern gas pipeline.

4. Case analysis

Since the gas flowrate of the China-Russia eastern gas pipeline increased year by year at the Initial production, the smaller the gas flowrate, the lower the entrainment capacity of the droplets, and the easier it is to form water accumulation in the pipeline. Therefore, the total amount of water accumulation and the distribution of water in the pipeline under different water contents in the first year of pipeline products in winter were analyzed.

In the first winter of the pipeline's operation, the flowrate is 1489×10⁴ m³/d, the starting pressure is 7.52 MPa, and the gas temperature at the starting point of the pipeline is 15.7 °C. Natural gas water dew point requirements at the China-Russia trade junction: in winter, it is not higher than -20 °C under the pressure of 4 MPa, according to the conversion, convert it the corresponding water content is 40 ppm. Under the operating pressure and temperature conditions in the first year of winter, the converted saturated water content is 332 ppm.
The ppm value of water can be converted into mass content using the following formula:

\[ W_{\text{H}_2\text{O}} = \frac{ppm \times V 	imes M_{\text{H}_2\text{O}}}{M \times \rho} \]  

(3)

Where, \( W_{\text{H}_2\text{O}} \) is the water content of natural gas, g/m³; ppm\(V \) is the volume content of water under standard conditions or working conditions; \( M_{\text{H}_2\text{O}} \) is the molar mass of water, g/mol; \( M \) is the molar mass of water-containing natural gas, g/mol; \( \rho \) is the density of water-containing natural gas under standard conditions or operating conditions, g/m³.

Using the water content calculation formula combined with OLGA software to calculate the total amount of water accumulation and the distribution of water in the pipeline under different water contents in the first year of pipeline products in winter. Figure 1 shows the total water accumulation of the pipeline under different water contents and Figure 2 shows the distribution of fluid accumulation in the China-Russia eastern gas pipeline under different water contents.

![Figure 1. The total water accumulation of the pipeline under different water contents.](image1)

![Figure 2. The distribution of fluid accumulation in the China-Russia eastern gas pipeline under different water contents](image2)

It can be seen from Figure 1 that the total water accumulation in the pipeline increases with the increase of water content. Under the requirement of natural gas water dew point at the China-Russian trade junction, no free water is produced in the pipeline. However, due to the inevitable increase in water content at the initial stage of natural gas pipeline production and operation, the water produced in the pipeline can reach \(255 \times 10^3 \text{m}^3\) in the case of saturated water content in the first year of production.

It can be seen from Figure 2 that the water accumulation in the pipeline is mainly distributed in the ascending part of the low-lying pipe section. This is because due to the influence of gravity, the water is easy to accumulate in the low-lying pipe. The gas flow will have a driving force on the water accumulation in the low-lying place, but when there is more water accumulation or the pipeline height difference is larger, the driving force generated by the gas flow often cannot promote the water accumulation to rise over the rising pipe section. It can also be seen from the figure that where the height difference of the pipeline is greater, the water accumulation is more serious. The water accumulation in the pipeline section with a mileage of 53km - 134km is the most, and the water retention rate of the pipeline is up to 0.66, and the pipeline height difference in this section has reached about 200m, which is the section with the largest height difference in the entire pipeline.

5. Conclusions
For the natural gas composition and operating conditions of the China-Russia eastern gas pipeline, Li correlation with the Keenan-Keyes model is a suitable model for calculating the natural gas water content of the China-Russia eastern gas pipeline.

Under the winter conditions in the first year of production of the China-Russia eastern gas pipeline,
the total water accumulation in the pipeline increases with the increase of water content. The water produced in the pipeline can reach $255 \times 10^3 \text{ m}^3$ in the case of saturated water content in the first year of production.

Due to the influence of gravity and the driving force of gas flow, the water accumulation in the pipeline is mainly distributed in the ascending part of the low-lying pipe section. Where the height difference of the pipeline is greater, the water accumulation is more serious. In the pipeline section with a mileage of 53km~134km, the pipeline height difference reached about 200m, the water accumulation was the most serious, and the liquid holdup was as high as 0.66.

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