Discussion on evaluation method of water energy in strong water drive gas reservoir

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Abstract. In the process of gas reservoir development, as the pressure of gas reservoir decreases, water will invade into the gas reservoir and form a certain scale of water body, so it is very necessary to know the water body energy correctly. This paper takes strong water drive gas reservoir as an example, and uses equation of state method, pressure drop curve method and material balance method respectively to complete the water body energy evaluation of this block, so as to find the water body energy evaluation method suitable for strong water drive gas reservoir, which plays an important role in implementing water control measures.

1. Introduction
during the development of the strong water drive gas reservoir, with the production of natural gas and the decrease of formation pressure, the edge and bottom water gradually intrudes into the original gas-bearing area. The water produced by the gas reservoir increases the lifting difficulty of the gas well, increases the abandoned pressure of the gas reservoir, and thus reduces the recovery of the gas reservoir, thus complicating the development of the gas reservoir. Therefore, in order to better develop the strong water drive gas reservoir, the calculation of water body energy is very important. Through the discussion and comparison of water body energy research methods, this paper finds a water body energy evaluation method suitable for strong water drive gas reservoir, which provides a strong basis for carrying out drainage measures in the later period of gas reservoir.

2. Water energy evaluation method
By comprehensively comparing the water energy evaluation methods of conventional water drive gas reservoirs and combining the production practice of strong water drive gas reservoirs, three methods are found to qualitatively evaluate the water energy of gas reservoirs, which are PVT equation of state method, pressure drop curve method and dynamic method respectively.

2.1. PVT contour equation method
According to the PVT state equation, assumes that the gas reservoir in the condition of original formation pressure as the Pi, the original underground volume for Vi, raw material gas moles to n, the original deviation coefficient for Zi, production to a certain stage after the formation pressure is P, gas reservoir volume V, underground water influx as We absolutely, formation water output volume V underground water production, cumulative gas production volume V underground gas when the pressure P, then according to the principle of PVT state equation are:
2.2. Pressure drop curve method

In the early stage of gas reservoir development, water inflow is small and negligible. Equation can be written as the material balance equation of gas reservoir with constant volume:

\[ P = P_1 (1 - \frac{G_p}{G}) \]  

(2)

Figure 1. Pressure drop curve of water drive gas reservoir

Draw the pressure drop curve of water drive gas reservoir (figure 1), figure in implementing curve, the pressure drop for \( P \) dotted line for \( P \) curve line segment of the initial extension cord, solid line and dotted line of the vertical distance, namely \( P \) curve deviates from the initial linear section of distances, using \( \Delta P \) said:

\[ \Delta P = P_\omega = \frac{P}{Z} \omega \]  

(3)

According to the chart of pressure and cumulative gas production, the water body activity was evaluated. When the pressure drop curve starts to deviate from the straight line section, the activity degree of different water bodies in the region at that point is also different: \( R \leq 10\% \) indicates that water bodies are active; \( 10\% < R \leq 30\% \) indicates that the water body is moderately active. \( R > 30\% \) indicates that the water body is inactive.

2.3. Dynamic method

This method combines the theory of material balance with the specific development geological characteristics of gas reservoir, which can make full use of the dynamic data of gas reservoir. When the gas reservoir reaches a certain point in time, the cumulative underground volume of natural gas and water is equivalent to the sum of the changes in the underground volume of geological reserves, the changes in the volume of rock and bound water and the water invasion (\( W_e \)). The material balance equation of water drive gas reservoir can be obtained as follows:

\[ G_p B_g + W_p B_w = G (B_g - B_{gl}) + W_e + GB_{gi} \left( \frac{C_{W} S_{W} + C_f}{S_{gl}} \right) \Delta p \]  

(4)

Water invasion is the volume change of water body after pressure change, which can be expressed as: \( W_e = V_{PW} (C + C_f) \Delta p \). The multiple of water body is the ratio between water body volume and gas-bearing volume of natural gas, expressed as \( n = \frac{V_{PW}}{GB_{gi}/S_{gl}} \).

and get:  \( 1 = \left( 1 - \frac{G_p}{G} \right) \frac{P_l}{P/Z} + \left( n \frac{C_{W} + C_f}{S_{gl}} + C_e \right) \Delta p - \frac{W_p B_w}{GB_{gi}} \)  

(5)

Make \( \Psi = \frac{P_l}{P/Z} \), \( R = \frac{G_p}{G} \), \( m = \frac{W_p B_w}{GB_{gi}} \), \( K = n \frac{C_{W} + C_f}{S_{gl}} + C_e \) but \( \Psi \), \( m \), \( K \) plug type (5) tidy:
\[(m+1) - (1-R) \Psi = K \Delta p \quad (6)\]

Make \[Y = (m+1) - (1-R) \Psi \quad (7)\]

The \[Y = K \Delta p \quad (8)\]

Among them, \(n = \frac{C_w + C_f}{S_{pi}} + C_p\), which is related to water multiple, is slope \(k\). For finite water body, \(n\) can be regarded as a time-independent constant due to the short time involved in the whole water body. There is a linear relationship. For gas reservoirs with large water bodies, water invasion occurs slowly. Before the whole water body is affected and the whole water body energy is used, \(n\) should be a variable that increases with time. After the whole water body energy is used, \(n\) value remains unchanged.

3. Analysis and application of block XX calculation example

This block is an heterogeneous block edge and bottom water gas reservoir with large effective water body and strong heterogeneity inside the water layer. It is a strong water drive gas reservoir with low-position gas Wells mainly producing water. Therefore, it is necessary to find out an effective method to identify water energy and make clear the rule of producing water of gas Wells.

3.1. Analysis of application effect of equation of state method

According to the block geological reserves \(G\) converted into the volume of underground natural gas under the original conditions, the equation of state method can be used to calculate the water infiltration related results.

The analysis shows that the equation of state method can be used to calculate the water energy accurately under the condition that the geological reserves of gas reservoirs are clear.

3.2. Analysis of application effect of pressure drop curve method

Draw the pressure drop curve of water displacement gas reservoir by using the converted pressure and cumulative gas production over the past years (figure 2). The solid line in the figure is the pressure drop \(P_P\) curve, and the dotted line is the extension line of the initial straight line of the \(P_P\) curve. The vertical distance between the solid line and the dotted line, that is, the distance between the \(PP\) curve and the initial straight line, is based on the evaluation standard of water activity of the pressure and cumulative gas \(p\), \(10\% < R \leq 30\%\) in this block indicates that the water body in this block is sub-active.

![Figure 2. Pressure drop curve of block XX](image)

It is concluded that the pressure drop curve method can directly show the water body activity of a single well or block, but it is only applicable to Wells with fixed point pressure measurement data or accurate pressure determination.
3.3. Analysis of application effect of dynamic method

Making the overall consideration of the block, the original formation pressure \( P_i \) and the original formation temperature of the block are determined as \( T_i \). Through nuclear magnetic resonance analysis of 26 samples in this area, the distribution range of bound water saturation is determined. According to the theory of dynamic method, combined with block production and laboratory data, make the block water energy analysis, namely the relationship between \( Y \) and \( K \) curve (figure 3), can be seen from the figure3, as the pressure drop, the \( Y \) value increases, several basic scatter into a straight line, the slope change, no longer water invasion energy across the water, water is no longer. Get the slope \( K \), substitute it into \( Sw_i, C_w, C_f \), and calculate the water multiple \( n=14.9 \), indicating that the current water volume in this block is 14.9 times the underground volume of underground natural gas.

![Figure 3. Water energy analysis in block XX](image)

It is concluded that the method can be used to evaluate the water body energy from single well to block of strong water drive gas reservoir.

4. Conclusion

In this paper, three methods, namely, equation of state method, pressure drop curve method and dynamic method, were used to evaluate water energy in the strong water drive gas reservoir in block XX, and the following conclusions were obtained:

1) the equation of state method can be used to calculate the water invasion of the gas reservoir when the geological reserves are confirmed. Pressure drop curve method can be used to judge the activity of water body, but only for Wells with fixed pressure test data or pressure availability. The dynamic method is the best choice, which has a small workload but high reliability and can be used to determine the water body size of gas reservoir.

2) for gas reservoirs with good connectivity, the overall water body energy evaluation can be carried out, while for gas reservoirs with poor connectivity, water body research should be carried out in the form of well group or single well.

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