Identification method of early water influx in gas reservoirs

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Abstract. The formation water will directly lead to the loss of gas well productivity and the reduction of gas reservoir recovery, and will also have a serious adverse impact on the development of gas reservoirs. In the development of water flooding gas reservoirs, early identification of water invasion is a prerequisite for making full use of the dry period for production and actively implementing water treatment measures. At present, the identification methods of water invasion mainly include production water analysis, pressure drop curve identification, well test monitoring and simulation calculation. Based on the principles, adaptability, and existing problems of these methods, water intrusion identification should be carried out based on gas well geological information using multiple methods.

1. Introduction
In the development of water-driven gas reservoirs, gas well water discharge due to intrusion of edge and bottom water will not only increase the difficulty of gas reservoir exploitation, but also cause loss of gas well productivity, reduce gas reservoir recovery, and affect gas reservoir development benefits. Accurate judgment of the water invasion dynamics of gas reservoirs, especially the identification of early water invasion, is the basis for actively and effectively developing gas reservoirs. Based on different principles, current identification methods mainly include gas well water production analysis, pressure drop curve identification, and well test monitoring identification. This article systematically elaborates the identification principles, applicable conditions, and existing problems of these methods, and points out effective methods to identify water invasion in gas reservoirs.

2. Identifying water intrusions from water produced by gas wells
In the development of water flooded gas reservoirs and condensate gas reservoirs, in general, gas wells also produce water while producing gas. By analyzing the change of the water salinity and water-gas ratio, the source of water can be judged, and then the occurrence of water invasion can be analyzed.

2.1. The change of water-air ratio
Take X well as an example, Figure 1 is the variation curve of water-gas ratio produced by this well. At the beginning of production, the water-to-air ratio is relatively low. After the rapid rise phase, the water-to-air ratio remains at a high level.
2.2. Water sample determination
Formation water and condensate have different physical properties such as salinity. According to the determination of water samples, the type of water produced and the source of analysis can be judged, and then whether water invasion has occurred. Water sample measurement and water-gas ratio change analysis are also important methods for water intrusion monitoring in gas reservoirs. Generally, the premise of using these methods is after the formation water enters the gas well. However, in the actual development of gas fields, it is more necessary to find water intrusion before the formation water enters the well. In order to identify water invasion before formation water from gas wells, the relationship between pressure and cumulative gas production is often used to judge, that is, pressure drop curve identification.

3. Identifying water influx by pressure fall off curve
Due to the continuous intrusion of water from the edge and bottom of the gas reservoir, the pressure drop of the gas reservoir will gradually slow down. According to this principle, water intrusion can be identified.

3.1. Water sample determination
Due to the effect of side and bottom water, the apparent formation pressure of water-invaded gas reservoirs has a non-linear relationship with cumulative gas production. Through this feature, the occurrence of water intrusion can be easily and conveniently identified.
3.2. Apparent pressure derivative

In the early stages of waterflood gas reservoir production, when water intrusion is identified by formation pressure, the data is not sensitive. Based on derivative sensitivity characteristics, formation pressure derivatives $\frac{d(p/Z)_i}{dG_p}$ can be used to identify water intrusion.

\[
\frac{d(p/Z)_i}{dG_p} = \frac{G_i - G_{i-1}}{(p/Z) - (p/Z)_{i-1}}
\]

For closed gas reservoirs, $\frac{d(p/Z)_i}{dG_p}$ is constant; For water-invaded gas reservoirs, as cumulative gas production increases, $\frac{d(p/Z)_i}{dG_p}$ increases with

3.3. Extraction degree method

Based on the gas reservoir material balance equation:

\[
\psi = \frac{1}{1-\omega}
\]

\[
\psi = \frac{p_i/Z_i}{p/Z}
\]

\[
R = \frac{G_p}{G}
\]

\[
\omega = \frac{(W_e - W_pB_w)}{V_{gi}}
\]

According to this formula, indicating curve of water invasion for gas reservoir (As shown in Figure 3)

![Figure 3. Gas reservoir water intrusion indicator curve](image)

Constant volume closed gas reservoir without water invasion, $\omega=0$, Actually $\psi-R$ curve Is diagonal; When there is water invasion, $\psi-R$ curve above the diagonal. The more deviated from the diagonal, the stronger the water invasion. This method requires prior knowledge of gas reservoir dynamic reserves.

4. Identification of water intrusion using the material balance method

Based on water flooding material balance equation:

\[
G(B_g - B_{gi}) + W_e = G_p B_g + W_p B_w
\]

Can identify water intrusion. Assumed water influx $W_e=0$, Let $G_a=G$, Then $G_a = \frac{G_p B_g + W_p B_w}{B_g - B_{gi}}$, $G_a-G_p$ Relationship diagram based on production data, If the graph is a curved upward curve, it indicates water intrusion, If there is no water invasion, the $G_a$ value should be constant(Figure 4).
Figure 4. Ga and Gp relationship curve

According to the results of numerical simulations, the formation pressure of the water-invaded gas reservoir and the cumulative gas production may have a linear relationship in the development of the entire gas reservoir. This increases the risk of judging water invasion in gas reservoirs from the above identification methods based on pressure data.

5. Identification of water intrusion using the material balance method

Gas reservoir water invasion is a dynamic process, and its changes must be reflected in dynamic monitoring data. According to the well test theory, the characteristic response of the well test curve boundary caused by static geological factors will not change in multiple well tests of a well, that is, the boundary properties and boundary distance obtained from the well test analysis will not change with time. If the water flooding gas reservoir is active with water invasion, the movement characteristics of the natural water invasion boundary during development will be reflected to varying degrees in the multiple well test analysis curves of gas wells near the water boundary in different periods. In actual well test interpretation analysis, composite formation test models and linear discontinuous boundary test models are commonly used to analyze natural water boundaries. Because the water intrusion front is constantly changing during the gas well production process, the boundary distances of different periods of the same gas well calculated by well test analysis methods are also different. Well-tracking comparison analysis at different periods can judge the strength and speed of water invasion in gas reservoirs. The unstable well test analysis method is an important method for early identification of water invasion. This method requires gas wells to be tested several times in different periods, which is the main limitation in the application of this method, and the reliability of well test interpretation is also a problem.

6. Conclusion

Identification of early water invasion in gas reservoirs is an important part of accurate evaluation and efficient development of gas reservoirs. Water sample detection and water production analysis methods are only applicable after gas well water. The pressure drop curve analysis method is the most commonly used method, but this method has a great risk in the early identification of water invasion, and is only applicable after the curve segment of the pressure drop chart appears. The well test analysis method is based on production data and dynamic monitoring data. The well test analysis method is based on production data and dynamic monitoring data. Due to the complexity of gas reservoirs, in order to reduce the risk of identification, different methods should be applied at different stages, combining dynamic and static, combining geological data, and integrating the most water intrusion information to identify the early water invasion of gas reservoirs.

References

[1] Ancell K L, Manbart T A. Secondary Gas Recovery form a Water-drive Gas Reservoir[C]. SPE 16944, 1987

[2] He Xiaodong, Zou Shaolin, Lu Xiaomin. A preliminary dicussion on mechanism and recognition of water invasion characteristics in edge water gas reservoirs[C]. Natural Gas Industry, 2006,
26(3):87-89

[3] Stehfest H. Numerical inversion of laplace transforms algorithm 368[J]. Communication of the ACM, 1970, 13:47

[4] Wu Di, Huang Bingguang, Li Shunchu, et al. Pressure distribution solution of sealed reservoir with composite dual permeability[J]. Journal of Southwest Petroleum University, 2007, 21(6):700-705.

[5] Wang Wenhuan. Three-zone composite well test model of condensate gas reservoir in stress-sensitive sandstone[J]. Petroleum Exploration And Development.