The Application of Movable Water Saturation in the Forecast of Gas Well Water Production and Reservoir Evaluation in Low Permeability Sandstone Gas

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Abstract: Gas wells production capacity is seriously affected by water in Xujiahe low permeability sandstone gas reservoir in Sichuan basin. The reason of water production is that there is movable water in reservoirs. A method of test movable water saturation using nuclear magnetic resonance is proposed. Movable water saturation can be used to forecast gas well water production feature. The critical movable water saturation whether gas well produces water is 6%. Gas well where movable water saturation is below 6% does not produce water; For movable water saturation between 6% to 8%, gas well yields a few water; For movable water saturation between 8% to 11%, gas well yields a lot of water; When movable water saturation is greater than 11%, the gas well produces water severely. Then movable water saturation is introduced into reservoir evaluation. A new reservoir evaluation method is proposed, which considers movable water saturation as an evaluation parameter. The classification and evaluation results are consistent with the gas wells production capacity.

Key words: Low permeability sandstone gas reservoir; movable water saturation; gas well water production feature; reservoir evaluation

Water saturation is generally greater than 50%, more than 80% of gas wells produce water, and production capacity is seriously affected by water in Xujiahe low permeability sandstone gas reservoir in Sichuan basin. Understanding of the mechanism of reservoirs producing water to predict gas wells water production feature, and establishing the appropriate reservoir evaluation method is important for improving the gas development effect and reducing development cost[1].

From the reservoir characteristics, we analyzed the Xujiahe low permeability sandstone gas reservoir water production mechanism, proposed the reservoir movable water saturation test by nuclear magnetic resonance (NMR) to predict gas wells water production feature, established a low permeability sandstone gas reservoir evaluation method using the fuzzy analysis and the gray analysis method, combined with the static and dynamic characteristics of reservoirs.

1 Reservoir water production mechanism

Xujiahe low permeability sandstone gas reservoirs are developed in the flat structure in the context of the typical lithologic traps gas (structure - lithologic gas reservoir), generally not developed cracks, only in the local area and dense layers. Xujiahe groups are divided into six layers vertically: the first layer Xu 1, third layer Xu 3 and fifth layer Xu 5 are the hydrocarbon source rock, which are mudstone, shale clip thin siltstone. The Second layer Xu 2, fourth layer Xu 4 and sixth layer Xu 6 constitute the main reservoirs, which are gray, fine-medium grained feldspathic lithic sandstone, lithic arkose and feldspathic sandstone. Controlled by sedimentary microfacies and diagenesis, reservoirs plane heterogeneity is strong[2-3].

Xujiahe reservoirs have low porosity, low permeability and high water saturation. Porosity is 0.5% ~ 15.55%, permeability is mainly in 0.001 ~ 5.0mD, and water saturation is distributed in 30% to 90%[4-6].

Constant speed mercury injection data showed that the mercury intrusion saturation of throat is larger than the mercury intrusion saturation of pore in Xujiahe cores (figure 1). This is implied that there are a large number of small throats in reservoirs, which control a lot of primary water, making the original water saturation very high. The primary water reservoir can be divided into bound water and movable water. Bound water is absorbed on the rock surface or located in the small throat, not transport in the production process. The presence of bound water reduces the gas flow channel. When the water saturation is greater than bound water saturation, there is movable water in reservoir. Movable water is mainly located in the pore. When production differential pressure is large enough, this part of the water can transport, with the formation of gas-water two-phase flow, greatly reducing the gas flow capacity. Meanwhile, the output of a large number of water in wells may also result in gas wells flooding, so greatly affecting the gas reservoir development effect. Thus analysis of movable water saturation is the key to study the water production mechanism in gas reservoirs.

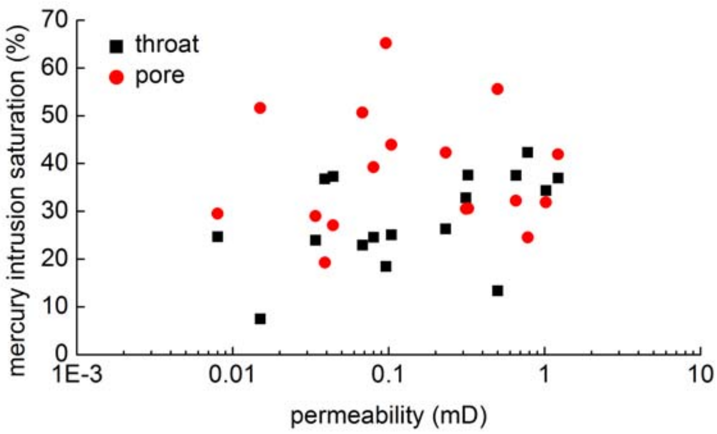

Fig. 1 Mercury saturation into the pore and throat of Xujiahe reservoir samples

2 Movable water saturation test method

The principle of testing movable water saturation using NMR in low permeability sandstone gas reservoir is: contrasting the water saturation after different centrifugal force with the original water saturation, then 300psi centrifugal force is determined to construct original water saturation in Xujiahe reservoir. After by 300psi centrifugal, T_2 cutoff line can be calculated using NMR T_2 spectrum after centrifugal and T_2 spectrum of saturated water conditions. In Figure 2, the two lines are the T_2 relaxation time spectrum of core saturated with water status and after 300psi centrifuged. Area surrounded by T_2 spectrum after 300psi centrifugation and T_2 spectrum of saturated state shows the original gas saturation information; Area surrounded by T_2 spectrum after 300psi centrifugation and horizontal lines is on behalf of original water saturation information; Area surrounded by right part of T_2 cutoff value, 300psi T_2 spectrum and horizontal line shows movable water information, which can calculate movable water saturation of the experimental rock samples[7].

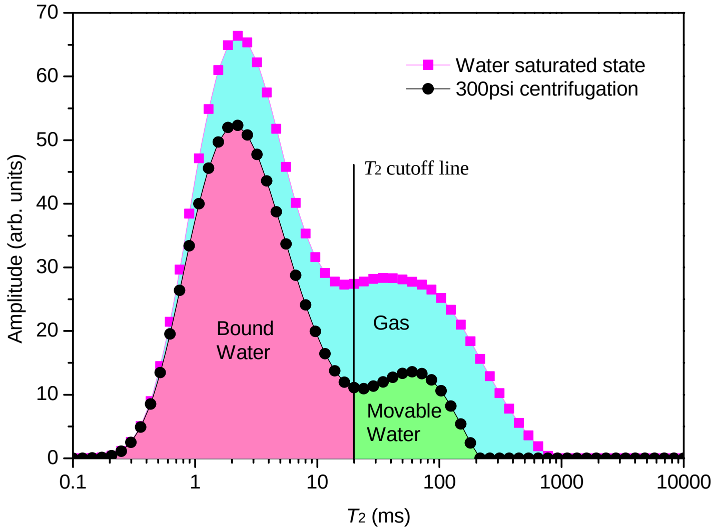

Fig. 2 Diagram of testing and calculating NMR movable water saturation

Movable water saturation of 62 cores form Guang'an Xu 6 layer, Guang'an Xu 4 layer and Hechuan Xu 2 layer is measured. Movable water saturation of different layer is showed in figure 3. Movable water saturation of cores from Guang'an Xu 4 layer is 9.4% ~ 13.9%; Movable water saturation of cores from Hechuan Xu 2 layer is 6.3% ~ 13.0%, slightly lower than Guang'an Xu 4; The movable water saturation of cores from Guang'an Xu 6 layer are the lowest, 5.1% ~ 11.7%. Overall, movable water saturation of Guang'an Xu4 layer and Hechuan Xu 2 layer are mostly greater than 8.0%, while most of Guang'an Xu 6 are less than 8.0%.

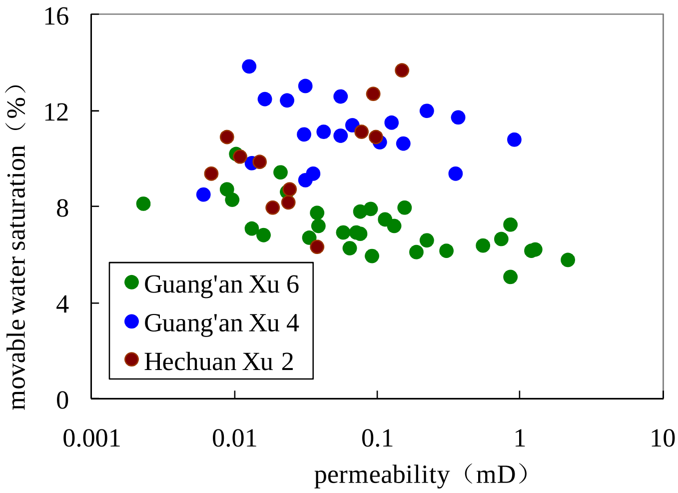

Fig. 3 Movable water saturation of Xujiahe reservoir samples

Gas wells field production data show that water production of Guang'an Xu 6 layer is smallest, mostly less than $2m^3/d$; gas wells water production of Guang'an Xu 4 layer is highest, mostly is 10 ~

50 m^3/d; water production of Hechuan Xu 2 layer is between in Guang'an Xu 6 layer and Guang'an Xu 4 layer.

3 Method of forecast water production feature of gas wells

Reservoir movable water saturation is the mean of movable water saturation of cores from the some reservoir. The relationship between reservoir movable water saturation and the water production of corresponding gas wells was analyzed. It was found that there is a positive correlation between gas well water production and reservoir movable water saturation (Fig. 4). Movable water saturation can be applied to predict gas well water production feature. Criteria of gas well water production forecasting are as shown in Table 1. The critical movable water saturation whether gas well produces water is 6%. Gas well where movable water saturation is below 6% does not produce water; For movable water saturation between 6% to 8%, gas well yields a few water; For movable water saturation between 8% to 11%, gas well yields a lot of water; When movable water saturation is greater than 11%, the gas well produces water severely.

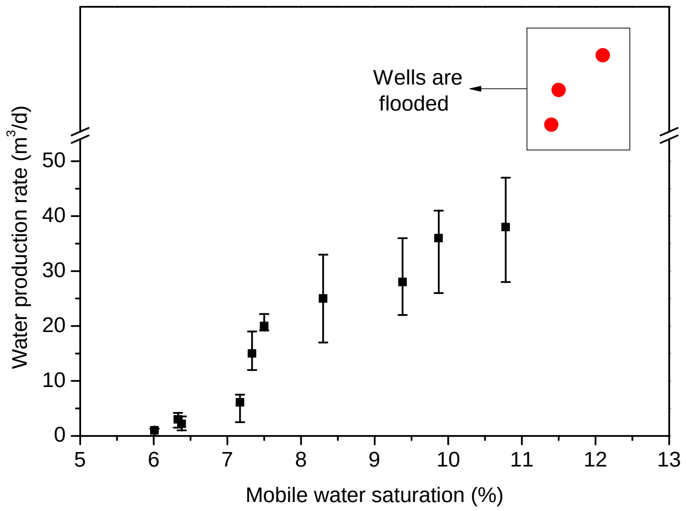

Fig. 4 Relationship of gas well water production and movable water saturation

Table 1 Criteria of gas well water production forecast

S_{mw} (%)	Feature of gas well water production
<6	no water (0m^3/d)
6~8	litter water (0～20 m^3/d)
8~11	a lot of water (20～40 m^3/d)
>11	severely (>40 m^3/d)

4 Comprehensive reservoir classification and evaluation method

Conventional reservoir evaluation method does not consider the influence of water production on productivity[8, 9]. So the accuracy of conventional reservoir evaluation on *Xujiahe* low permeability sandstone gas reservoirs is only 50%. According to the static and dynamic features of Xujiahe reservoirs, a new reservoir evaluation method is proposed, which considers movable water saturation as an evaluation parameter, which has four evaluation parameters, including porosity ϕ, permeability K, gas saturation S_g and movable water saturation S_{mw}. This method is established by fuzzy analysis and gray correlation analysis[10,11].

Reservoirs controlled by 18 gas wells were classified and evaluated by the new reservoir evaluation method. Reservoir evaluation criteria and evaluation criteria plate are as shown in table 2 and table 3.

Table 2 Reservoir classification and evaluation criteria

Type of reservoirs	Fuzzy evaluation value	Gray evaluation value
I	0.86~1.00	0.87~1.00
II	0.65~0.86	0.65~0.87
III	0.33~0.65	0.50~0.65
IV	0~0.33	0.33~0.50

Table 3 Reservoir classification and evaluation criteria Plate

K (mD)	ϕ (%)	S_{mw} (%)	S_g (%)			
			>60	45~60	30~45	<30
>0.5	>13	<6	I	I	II	IV
		6~9	I	II	II	IV
		9~12	II	II	II	IV
0.1~0.5	10~13	<6	II	II	II	IV
		6~9	II	II	III	IV
		9~12	II	III	III	IV
0.01~0.1	6~10	6	III	III	III	IV
		6~9	III	III	IV	IV
		9~12	III	IV	IV	IV
<0.01	<6		IV	IV	IV	IV

The reservoir is divided into four categories: first type, the best reservoir, fuzzy evaluation value is between 0.86 ~ 1.00, gray correlation value between 0.87 to 1.00, with strong ability to produce gas, ratio of produced water and gas small, and good development effect; second reservoir with good properties, fuzzy evaluation value is between 0.65 to 0.86, the value of gray correlation between the range of 0.65 to 0.87, with good gas production capacity; The third type of reservoir with poor reservoir properties, the fuzzy evaluation value 0.33 ~ 0.65, gray correlation value 0.50 ~ 0.65, gas production is weak, more water production, and poor development effect; fourth type of reservoir, fuzzy evaluation value is between 0 to 0.33, the value of gray correlation between the range of 0.33 to 0.50, with very low porosity and permeability, and high water saturation and movable water saturation, no industrial development value.

The classification and evaluation results were compared with the production capacity of corresponding gas wells in Table 4. The results show that the classification and evaluation results are highly consistent with the gas wells production capacity, accuracy rate close to 90%. Results of fuzzy analysis and gray correlation analysis were consistent. Applications Fuzzy analysis and gray correlation analysis method, compared with each other, can increase the accuracy of reservoir evaluation.

Table 4 compared the results of reservoir classification and evaluation with wells capacity

reservoirs	General evaluation results	Fuzzy evaluation results	Grey Evaluation of results	Daily gas production（$10^4 m^3/d$）	Daily water production（m^3/d）	Capacity evaluation results
GA 002-23	I	I	I	12.00	0.85	I
GA 002-39	I	I	II	5.70	2.00	II
GA 108	II	II	III	5.00	3.00	II
GA 002-43	II	II	III	0.90	12.00	III
GA 113	I	III	III	0.32	10.00	III
GA 126	II	III	III	0.64	8.64	III
HC 5	III	III	III	1.00	2.00	III
HC 108	III	IV	IV	0.35	15.00	III
GA 5	II	IV	IV	0.10	43.00	IV
GA 107	IV	IV	IV	0.10	4.00	IV
TN 6	III	IV	IV	0.10	30.00	IV
HC 1	IV	IV	IV	0.06	6.00	IV
GA 101	IV	IV	IV	0.20	28.00	IV
GA 112	IV	IV	IV	/	/	IV
GA 109	II	IV	IV	/	/	IV
GA 102	IV	IV	IV	/	/	IV
GA 17	II	IV	IV	/	/	IV
HC 127	III	IV	IV	/	/	IV

5 Conclusion

(1) Movable water saturation test by NMR can be used to predict gas wells water production feature in Xujiahe low permeability sandstone gas reservoirs.

(2) A new reservoir evaluation method is proposed according to the static and dynamic features of Xujiahe low permeability sandstone gas reservoirs, which considers movable water saturation as an evaluation parameter.

(3) New reservoir classification and evaluation is reliable and practical, with good help to rich region optimization in Xujiahe reservoirs.

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Technical category: supply—unconventional gases

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