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Nuclear Magnetic Resonance Measurements of Original Water Saturation and Mobile Water Saturation in Low Permeability Sandstone Gas *

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We use nuclear magnetic resonance (NMR) and centrifugation to measure the original water saturation and mobile water saturation of cores from the Xujiahe low permeability sandstone gas reservoir, and compare the NMR results with the corresponding field data. It is shown that the NMR water saturation after 300 psi centrifugation effectively represents the original water saturation measured by weighing fresh cores. There is a good correlation between mobile water saturation and the water production performance of the corresponding gas wells. The critical mobile water saturation whether reservoir produces water of the Xujiahe low permeability sandstone gas is 6%. The higher the mobile water saturation, the greater the water production rate of gas well. This indicates that well's water production performance can be forecasted by mobile water saturation of cores.

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The original water saturation and its mobility have a significant impact on the flow of gas and water in a low permeability sand gas reservoir and thereby the production performance of the reservoir. Original water in gas reservoir consists of bound water and mobile water. The flow of mobile water in development process reduces gas relative permeability, and easily causes water lock, which is a phenomenon that some gas is surrounded by water, so leading to exploitation of low permeability gas reservoirs more difficult. Thus, the accurate determination of original water saturation and mobile water saturation is an initial step to reasonable development of low permeability sandstone gas reservoirs.

Nuclear magnetic resonance (NMR) is an effective tool to study physical properties of rock and fluid in reservoir.[1−3] These physical properties including pore structure and wettability provide crucial information for calculating porosity, permeability, and mobility of fluid in situ.[4−9]

In this Letter, NMR measurements combined with centrifugation are used for a rapid and accurate determination of original water saturation and mobile water saturation. The NMR original water saturation measuring results are contrasted with the data measured from the same fresh cores to verify its accuracy, and the relationship of mobile water saturation with the gas well water production performance is given.

The original water saturation of fresh cores from Xujiahe low permeability sandstone gas reservoir is determined by weighing after drying. Then these core samples are saturated with standard saline, and NMR transverse relaxation time T_2 of every core is measured. After that, cores are centrifuged at centrifugal force 50 psi, and T_2 is measured again. Then cores are centrifuged again but at 100 psi, and finally T_2 is measured. Repeat the above steps, but centrifugal force is 100 psi, 150 psi, 200 psi, 250 psi, 300 psi, 350 psi and 400 psi. The NMR water saturation is calculated with T_2 accumulation after centrifugation divided by T_2 accumulation of water saturated state.

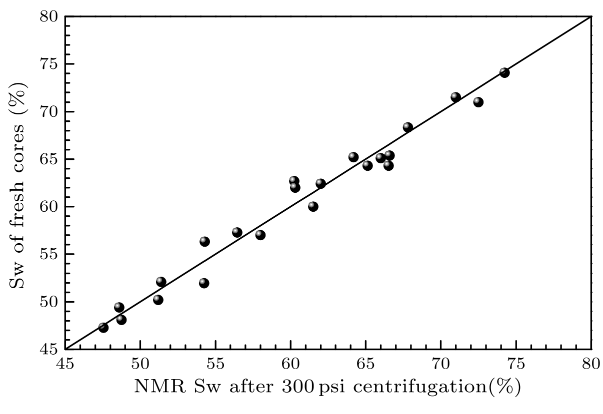

Fig. 1. NMR water saturation after 300 psi centrifugation, almost equal to the water saturation of fresh cores.

Contrasted the NMR water saturation of cores after every centrifugation with the data measured from fresh cores, it's found that NMR water saturation after 300 psi centrifugation is almost equal to the water saturation of the fresh cores, as shown in Fig. 1. This indicates that the NMR water saturation after 300 psi centrifugation effectively represents the original water

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saturation of reservoir of the Xujiahe low permeability sandstone gas.

T_2 cutoff value is determined by the T_2 spectrum of saturated cores and after 300 psi centrifugation. Then, the bound water saturation and mobile water saturation are calculated as demonstrated in Fig. 2. The area surrounded by the T_2 spectrum after 300 psi centrifugation, i.e. T_2 cutoff value and relaxation time axis less than T_2 cutoff, is representation of bond water information, while the area surrounded by the T_2 spectrum after 300 psi centrifugation, i.e. T_2 cutoff value and relaxation time axis greater than T_2 cutoff, is representation of mobile water information. Thus bound water saturation and mobile water saturation are calculated by

$$S_{bw} = \frac{A_{bw}}{A_{bw} + A_{mw} + A_g} \times 100\%, \quad (1)$$

$$S_{mw} = \frac{A_{mw}}{A_{bw} + A_{mw} + A_g} \times 100\%, \quad (2)$$

where S_{bw} and S_{mw} are the bound water saturation and the mobile water saturation respectively. A_{bw}, A_{mw}, and A_g are the areas representing of bond water information, mobile water information and gas information respectively, as demonstrated in Fig. 2.

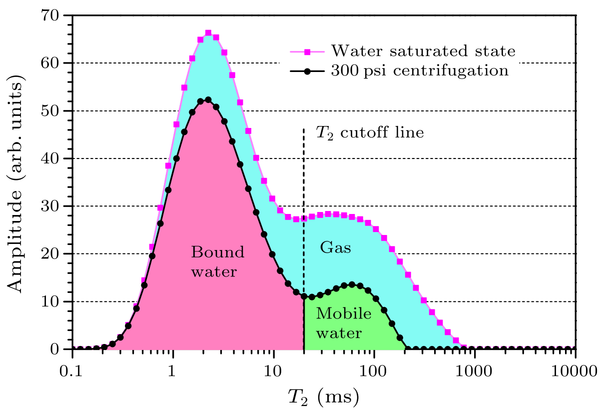

Fig. 2. The T_2 spectrum of water saturation state and 300 psi centrifugation to calculate bound water saturation and mobile water saturation.

Use average mobile water saturation of cores from the same well to represent mobile water saturation of the reservoir controlled by that well. It is found that there is a good correlation between mobile water saturation and the water production performance of corresponding wells. As shown in Fig. 3, the higher the mobile water saturation, the greater the water production rate of gas well is. When mobile water saturation is greater than 11%, the corresponding wells are water flooded.

The low permeability reservoirs are divided into four types depending on mobile water saturation: type-I reservoir, almost no water production, where mobile water saturation is less than 6%; type-II reservoir, some water production, where mobile water saturation is between 6–8%; type-III reservoir, a lot of water production, where water production is between 8–11%; type-IV reservoir, water production severely, where mobile water saturation is larger than 11%. The critical mobile water saturation of whether a gas well produces water is 6%. This indicates that well's water production performance can be forecasted by mobile water saturation of cores.

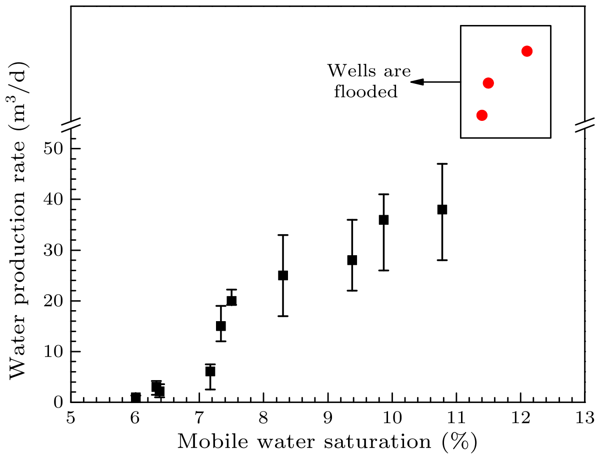

Fig. 3. Water production rate of gas wells with the mobile water saturation of reservoir.

The present result may be useful for selective perforation, increasing gas production capacity, and reducing the risk of water production.

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