Water sensitivity evaluation of sandstone oil reservoirs with ultra-low permeability

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Abstract: The development of sandstone reservoirs with ultra-low permeability has become one of the most important energy resources worldwide. Such reservoirs suffer formation damage easily, such as water sensitivity, from foreign fluid during well drilling and completion for extremely poor physical properties. In order to deeply understand the damage degree of water sensitivity of there reservoirs, water sensitivity analysis of Chang 6 reservoir rock samples was carried out, including water sensitivity of block matrix and fracture rock samples. Results show that there are none or weak water sensitivity damage for block matrix while medium water sensitivity damage for fractured samples. The study is of significance to the reservoir damage control in ultra-low permeability oil reservoirs.

1. Introduction
The development of sandstone oil reservoirs with ultra-low permeability has become one of the most important energy resources worldwide [1]. Such reservoirs are extremely poor in physical properties with fine pore throat, low porosity, low permeability, high capillary pressure, partial development of micro-fracture, and ultra-low water saturation [2,3]. Therefore, it suffers formation damage easily, such as water sensitivity, from foreign fluid during well drilling and completion [4-6].

Water sensitivity is usually evaluated by the National Industry Standard SY/T5358-2002 (formation damage evaluation by flow test) to get fluid flow volume and then calculate water phase permeability [7]. However, for sandstone oil reservoirs with ultra-low permeability, the permeability is usually less than 1mD. It is difficult to get fluid flow in block matrix by traditional method. Some scholars suggested using pressure decay methods [8-10] to evaluate fluid flow ability in tight block matrix. The fundamental principle of pressure decay methods [8-10] is described as follows.

First let fluid fully fill in the core holders and pipelines. Then a specific initial flow pressure difference (usually 1MPa) is applied at the inlet end of the core holder. Fluid flows along the core under the pressure difference and the flow pressure would reduce gradually due to the fluid flows to the outlet end (Figure 1). Fluid flow speed will decrease with pressure decrease. The rate of pressure decay becomes faster with rock porosity and permeability increasing, and the pressure decay time will be shorter. Therefore, the flow pressure decay time can be used to evaluate the sample permeability. If the core is damaged and permeability decreases, the deceleration rate of flow pressure will reduce. As a result, the pressure decay rate can reflect changes in the reservoir permeability and can be used to
evaluate the fluid sensitivity. This method is mainly applied in block matrix with extra-low permeability and fluid flow is difficult to calculate.

This paper is targeted on the typical tight sandstone oil reservoirs in Ordos Basin, China, to investigate the permeability damages caused by foreign fluid. As the tight sandstone reservoirs develop micro-fractures, the formation damage will be evaluated with cracked samples and blocks. The cracked samples were evaluated by the National Industry Standard SY/T5358-2002 (formation damage evaluation by flow test) and the blocks were evaluated by the pressure decay methods [5-7].

2. Experimental section

2.1. Fluids and Materials

Simulated formation water was used as based fluid in tests, with the composition shown in Table 1.

| Chemicals | NaCl | CaCl₂ | KCl | MgCl₂ | Na₂SO₄ | NaHCO₃ |
|-----------|------|-------|-----|-------|--------|--------|
| Concentration(mg/l) | 62300.7 | 15254.2 | 5.0 | 1527.1 | 4.3 | 283.08 |

Core samples from chang6 formation in Triassic, Ordos Basin, China was used in the paper, shown in Table 2. Before the tests, cores were washed oil and salt, dried in oven, then cooled down to room temperature. In order to conduct sensitivity tests for fractured cores, samples were cracked into two parts and adhered then to measure permeability and porosity.

| Sample | Length (cm) | Diameter (cm) | Pore volume (ml) | Porosity (%) | Permeability (mD) |
|--------|-------------|---------------|------------------|--------------|------------------|
| J1     | 5.29        | 2.48          | 3.63             | 14.2         | 0.484            |
| J2     | 5.21        | 2.49          | 2.10             | 8.3          | 0.149            |
| JF1    | 5.12        | 2.50          | 10.23            | 27.17        | 65.8             |
| JF2    | 5.05        | 2.49          | 9.85             | 38.50        | 187.2            |

2.2. Methodology

① Connect the experiment devices as shown in Figure 1. ② Prepare the experimental fluid and core samples. ③ Cores were first vacuumized and saturated with formation water for 40 hours. ④ Sample was loaded on the core holder, then confining pressure and temperature was applied. ⑤ Apply an initial pressure difference at the upper flow end by N₂ and close valves in the front of the micro vessel. The pressure data at different times can be gathered by pressure sensor. When the pressure drop was greater than half of the initial pressure, stop the test. ⑥ The sub formation water with the salinity half of the formation water was used to displace formation water in the core. When the volume of the sub formation water passing through the core was greater than 2PV, the displacement can be stopped and close the
valve. Repeat step ⑤ with the same initial pressure difference and gather the pressure decay time. ⑦ Repeat the above ⑤⑥ with distilled water until the end of the experiment.

Water sensitivity index can be calculated as follows.

$$D_w = \frac{T_w - T_f}{T_f} \times 100\%$$  \hspace{1cm} (1)

Where $D_w$ was the Water sensitivity index; $T_f$ was half-life period of pressure by formation water, min; $T_w$ was half-life period of pressure by distilled water, min.

In order to connect with the current industry standard, the evaluation standard of pressure decay index for water sensitive damage was shown in table 3.

| Water sensitivity index (%) | <5 | 5~30 | 30~50 | 50~70 | 70~90 | >90 |
|-----------------------------|----|------|-------|-------|-------|-----|
| Sensitivity degree          | None | Weak | Medium weak | Medium strong | Strong | Extremely strong |

### 3. Results and discussion

#### 3.1. Water sensitivity of the block matrix sample

The water sensitivity test results of the block matrix samples are shown in table 4. It indicates that the damage of distilled water to the permeability is none to weak. In the study area, there are less expansive minerals, such as smectite. So the water sensitivity damage is weak. However, some minerals may be dissolved and the permeability increase in the experiment.

| Sample | $T_f$ (min) | Formation water | Sub Formation water | Distilled water | Water sensitivity index(%) | Degree |
|--------|-------------|-----------------|--------------------|----------------|---------------------------|--------|
| J1     | 10.8        | 10.6            | 12.68              |                | 15.04                     | Weak   |
| J2     | 61.95       | 50.73           | 59.65              | -3.86          |                           | None   |

#### 3.2. Water sensitivity of fractured rock samples

The experimental results are shown in table 5. It can be seen that the water sensitivity of fracture rock sample is from medium weak to medium strong, which is related to the decrease of seepage capacity caused by the scattered particles on the fracture surface blocking the fracture.

| Sample | $K_f$ (mD) | $K_w$ (mD) | $K_{mf}$ (mD) | $K_{mf}/K_f$ (%) | Degree         |
|--------|------------|------------|---------------|------------------|---------------|
| JF1    | 8.89       | 6.11       | 5.33          | 59.90            | medium weak   |
| JF2    | 55.12      | 37.32      | 24.95         | 45.26            | medium strong |

Once the water sensitive damage occurs in the reservoir, the expanded clay particles will finally fall off and disperse in the pore throat. If they cannot flow out with the fluid, part of the pore throat will be blocked. Meanwhile, the mineral will be hydrated and there is a thick water film on the mineral surface, which makes the effective flow channel narrow and increases the water flow resistance. Generally speaking, reservoirs with low permeability shows more obvious water sensitive damage effect and the injection capacity decreases.

### 4. Conclusions

The paper investigated the water sensitivity damage of block matrix and fractured samples from Chang 6 reservoir, Ordos’s basin, China, by pressure decay methods and National Industry Standard SY/T5358-2002, respectively. There are none or weak water sensitivity damage for block matrix while medium water sensitivity damage for fractured samples. It is suggested that formation friendly fluid
should be used during well drilling and completion to avoid formation damage for ultra-low permeability oil reservoirs.

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