Development technology status of low permeability sandstone oil reservoirs

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Abstract. The development of oil in low permeability sandstone resources is of great significance. The paper first presented the present situation of domestic and foreign technologies in water injection, gas injection, stimulation and enhanced oil recovery of low permeability sandstone reservoirs. Then the main problem in the development of oil reservoirs with ultra-low permeability was analyzed. Finally, the paper proposed the trend of the future development of these oil reservoirs.

1. Water injection in low permeability sandstone reservoirs

Water injection is currently the most used secondary oil recovery method in the world's oil fields. Injecting water can not only replenish formation energy but also drive oil to ensure long-term stable production of oil fields. Oil produced by water injection in the UK and Canada accounted for more than 90% of the total.

1.1 Water injection experiments

The experimental methods commonly used in water flooding research include conventional core flooding, microscopic analysis, CT scanning [1], combined analysis of centrifugation and nuclear magnetic resonance as well[2].

Chen et al. (1997) considered that rock minerals, pore structure, injection multiples, residual oil saturation and other factors affect oil displacement efficiency. The sandstone micro-models show that most of the water-driven process in small pores and throats is piston-driven, and the oil displacement is always thorough. Most of the displacement is non-piston, and it is easy to form residual oil in the center of the pores. It is recommended to use the gas permeability of 1mD as the lower limit of the physical flow of the oil phase [3], and consider that the long 6 oil layers are weakly hydrophilic-neutral. The water flooding efficiency is 41%~57%. Zhang (2007) pointed out that the method of saturating oil and water injection in high and medium permeability cores are not suitable for low permeability cores, and recommended low-speed oil saturation and mild water injection in low permeability cores [4]. Wang and Sun (2010) pointed out that the pore structure characteristics and heterogeneity have great influence on oil displacement effect [5].

Xiong (2011) and Zhou (2013) carried out oil flooding and water flooding centrifugal analysis for cores from low permeability oil reservoir. They believed that cores with relatively high permeability has high oil recovery and oil mainly comes from medium and small pores for the ultra-low
permeability core. Therefore, increasing the displacement pressure can increase the recovery degree of ultra-low permeability pores, but it will also change the remaining oil distribution[6]. Gao (2013) reviewed that reservoir homogeneity, pore connectivity, and clay mineral occurrence have great influence on oil displacement efficiency, while physical properties are not directly related to oil displacement efficiency[7].

1.2 On-site water injection test

The effect of water injection is not only controlled by reservoir characters, such as reservoir heterogeneity, permeability and oil layer thickness, but also affected by water injection development process, such as development system, reservoir damage, fluid-solid coupling effect, etc. Thus it forms advanced water injection [8], crack expansion water injection, reduction of well spacing [9], it also forms a certain theoretical guidance in the seepage mechanism [10], water injection timing, water injection quality and other high-efficiency water injection technology and the way of well formation. At the same time, a variety of methods and means for reducing injection pressure, such as horizontal well technology, staged fracturing and acidizing technology, surfactant depressurization and injection technology, simultaneous water injection, advanced water injection technology, etc. have been developed.

The Chang 8 ultra-low permeability reservoir in the Huang 3 area of Jiyuan Oilfield with average porosity of 7.1% and average permeability 0.39mD is seriously short of injection. Xue Ting et al (2014) proposed using acid to resolve plugging and anti-scaling, optimizing the ground pipe network and other treatments have achieved remarkable on-site effects [11].

2. Gas Injection in Low Permeability Sandstone Reservoirs

For the oil layer with low-permeability or ultra-low permeability, it is difficult for the injected water to enter the matrix as the pore throat is extremely small. It is still difficult to maintain the balance of injection and production even under high-pressure water injection. Water injection in low-permeability reservoirs is a great challenge. Gas injection development has attracted more and more attention.

Scholars have pointed out that the development of mixed-phase gas flooding in tight reservoirs is better [12]. Compared with water flooding, gas flooding recovery can be increased by 5.9%~18.2%. However, due to gas flooding effect and gas source limitation, China's gas injection technology develops slowly, and there are small number of mine test projects.

Although the application of gas injection technology has large potential in low-permeability reservoirs, there are still many problems that need to be conquered, such as whether the reservoir has gas injection conditions [13], gas source, premature gas breaks during injection.

3. Reservoir stimulation of low permeability sandstone reservoirs

3.1 Acidifying technology

Acidifying technology includes acidification of micelle acidification, slow acidification of phosphoric acid, fluoroboric acid, authigenic acid, acidification of nitric acid powder, as well as thermal chemical deblocking process technology, repeated acidification technology, multi-pulse composite deblocking process, horizontal well acidification process, active agent deblocking technology, aerated foam acidification technology, combined technology of multi-pulse seaming and acidification [14].

3.2 Fracturing technology

3.2.1 Overview of fracturing technology. Hydraulic fracturing is an effective method to reform oil and gas layers and an important way to increase oil and gas production. Hydraulic fracturing was originally proposed as one way to increase production for single well. With the development of tight oil and gas reservoirs, the “large-scale hydraulic fracturing” technology has been developed. This
technology is considered to be a breakthrough in the field of fracturing technology, which promotes the development of oil and gas wells and the development of oil and gas reservoirs.

Hydraulic fracturing can reduce the wellbore flow resistance, change the fluid seepage state, reduce the energy consumption, increase the production of oil and gas wells and increase the water injection, and also relieve the near-wellbore damage, which is widely used and adapted to various oil types.

In foreign countries, more emphasis is placed on the basic research of fracturing, such as fracture morphology, expansion mechanism, and optimization of crack parameters.

### 3.2.2 Fracturing fluid technology

Hydraulic fracturing fluids can be water-based, oil-based, emulsified and foam systems, among which the most used fracturing fluid is water-based jelly fracturing fluid, accounting for more than 98%. Thickeners that commonly used in water-based fracturing fluid are polymers with high molecular weight. The thickener can be crosslinked with crosslinker to form super macromolecules, resulting in poor hydrolyzability. The fracturing fluid residue and the polymer can not be completely degraded and remain in the formation, which affects the seepage of the fluid and reduces the effect of fracturing.

The damage of the fracturing fluid to the reservoir includes clay expansion, disperse, migrate, water lock, wet reversal, and incompatible with formation fluids. Recently, a variety of low-damage fracturing fluid systems have been developed, such as viscoelastic surfactant (VES) fracturing fluids, low polymer fracturing fluids, low residual gums and low residue content. Low pH modified guar glue joint fracturing fluid, alcohol based fracturing fluid, CO₂ foam fracturing fluid and autogenous heat-pressurized "foam-like fracturing fluid", N₂ energized water-based fracturing fluid, low interfacial tension system can be used to mitigate water lock damage.

### 3.3 Physical method to increase production technology

Physical method stimulation technology includes various techniques to improve reservoir permeability, increase oil production, and enhance oil recovery, using physical theory and technology. Physical method stimulation technology has characters of strong adaptability, simple process, low cost, and obvious yield-increasing effect. The characteristics of non-polluting and complementary chemical flooding have been widely recognized by oilfields at home and abroad.

The physical method for increasing production has become an important branch of oil and gas field development technologies. Years of practice and research have formed a series of supporting equipment and technology, such as wave field treatment technology, electric field treatment technology, thermal field treatment technology, magnetic field stimulation technology, high energy gas fracturing technology, high energy water rotary jet technology, oil layer hydraulic slitting technology, hydraulic jet perforation technology.

### 4. Enhanced oil recovery in low permeability sandstone reservoirs

At present, the mature and well-documented tertiary oil recovery technologies include: (1) thermal oil recovery; (2) chemical flooding; (3) polymer flooding; (4) surfactant solution drive, which includes active water flooding, micelle flooding and alkali flooding; (5) mixed phase flooding; and (6) Microbial flooding.

In addition, low-permeability oilfield reservoir characteristics, seepage mechanism[16], and well network deployment have gained significant advance. Drilling technology and low-cost oil recovery technology gradually developed in low-permeability oilfields.

According to the statistics of oil fields in the world, the production method of low-permeability oil fields is dominated by water injection, followed by air injection. Extra-low permeability oil fields are also dominated by water injection, followed by air injection, natural gas injection and nitrogen injection, etc., as shown in figure 1. It can be seen that water injection will still be the main development mode of low permeability sandstone reservoir for a long time in the future and will take an important role in exploring extra-low permeability sandstone oil reservoirs.
5. Conclusions
In conclusion, the development of oil in low permeability sandstone resources is of great significance. Water injection, gas injection, stimulation and enhanced oil recovery are widely used in the development of low permeability sandstone oil reservoirs, of which water injection is the most popular one. Water injection will be the main development mode of low permeability or extra-low permeability sandstone oil reservoirs in the future.

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