

The Development Technology of Low Permeability Reservoirs

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Abstract. China is a country rich in low permeability oil and gas resources and has great potential for exploration and development. Over the past 20 years, a great discovery in low permeable sandstone, marine carbonate rock and volcanic rock exploration has been made and a series of international first-class development supporting technology has been formed. The mature technologies in low permeability oil-gas field include water injection, fracturing, gas injection, etc., and fine formation description and reservoir protection are the keys. All kinds of new technologies have been developed rapidly, such as multi-branch Wells, seismic imaging and cracks diagnosis technology, new fracturing technology and gas injection technology. In the developed countries, low permeability oil and gas field exploration and development has become increasingly mature. This article mainly introduced the development technology of low permeability reservoirs and its future development trend.

Keywords: Low Permeability Reservoirs, Development Technology, Development Trend

1. Introduction

In China there are many unique petroliferous basins mainly based on continental deposit, they generally have the characteristics of poor physical property in reservoir, directly responding to rich low permeability oil-gas resources. After long-term unremitting exploration, China has made great breakthrough in the exploration and development of low permeable reservoir. After continuous research and innovation, low permeability resources in China has realized effective scale exploration and series of first-class low permeability development technologies internationally. The proportion of low permeability oil-gas yield in China is gradually increased, and the position has become more and more important.

Low permeability reservoirs usually have the characteristics of low abundance, low pressure and low yield, so they are difficult to exploit effectively. In the prolific hydrocarbon areas of low permeability reservoirs, there are many technical and economic problems in combination adjustment of exploited oil fields which have restricted the effective and efficient development of low permeability reservoirs, especially the identification and evaluation of fracture-developed zone and relatively high yield zones, development of optimization plan, the drilling and production technology, reconstruction of reservoirs, production of oil wells, mining cost, and so on. How to develop the low permeability reservoirs effectively and economically has become the world's common concern.

2. Characteristics of low permeability reservoir

2.1 Concept of low permeability reservoir

Strictly speaking, the low permeable reservoir is a concept about reservoir, it generally refers to the low permeability reservoir, which is usually called tight reservoir in foreign countries. To further extension and expansion of the concept, the word "low permeability" contains the concept low permeability reservoir and low permeability oil-gas resource. Now days it general refers to the low permeability reservoir. Specifically, the low permeable oil-gas fields refer to oil-gas fields which have low porosity, small throat, bad fluid permeability, low production capacity and normally need to renovation before they can maintain normal production of oil-as fields. Currently the reservoir rocks includes sandstone, siltstone and arenaceous carbonate rock, limestone, dolomite and chalk, but mainly tight sandstone reservoir.

There is no unified standard and boundary about low permeability reservoir in the world, different countries make their own standards and boundaries based on the oil conditions and economic and technical conditions in different periods, so the range of variation is large. Also in the same country and same area, standard and concept of low permeability reservoir also keep developing and improving continually with improved knowledge. Currently in the oil industry in our country, the low permeability sandstone reservoirs generally will be divided into low permeability reservoir (50~10mD), special low permeability reservoir (10~1mD), ultra-low permeability reservoir (1~0.1mD) [2]. In China the physical property of continental reservoir is generally poor, and quite a number of low permeability oilfield reservoirs' permeability are under 10mD.

General information of low permeability reservoirs.

In recent 20 years, the production of low permeability oil-gas has been growing continually and becoming more and more important. In 2008, the production of low permeability oil was 0.71×10^8 t (including low permeability thick oil), account for 37.6% of the total output nationally. The proportion of low permeability production has been rising year by year. In recent three years, it respectively was 34.8%, 36.0%, 37.6%. Low permeability resources have been more and more important and are becoming the main body of development.

3. Technology of low permeability reservoir

3.1 Reservoir description technology.

It includes outcrop natural fracture description, core fraction description, imaging and conventional logging fracture description, reservoir production dynamic testing data characterization, 3D seismic and 4D seismic, cross-well seismic and cross-hole electromagnetic wave characterization, 3D visualization, comprehensive geology research and technology. Reservoir description technique is a qualitative, quantitative description and prediction on reservoir characteristics, is a major technology predicting remaining oil distribution and making decision. Due to different decisions, characterization of techniques and methods are also different in content and accuracy. To old oil fields, in order to determine the distribution of remaining oil, it must provide accurate distribution condition through integrated fine characterization to guide oil-gas field adjustment and improve the development effects.

3.2 Drilling technology.

It includes gas drilling, atomized drilling, foam drilling, underbalanced drilling and so on. Underbalanced drilling was also called underbalanced pressure drilling. This concept has been proposed at the beginning of the 20th century, but until early days in 1980s, with the appearance of well-control technology and equipment which prevent the blowout, it was possible to realize the development and application of the drilling technology. In the United States and Canada, underbalanced drilling has become the hotspot of drilling technology and increasingly combined with horizontal well, multilateral well, and slim-hole drilling technique combining. The proportion of underbalanced drilling in the United States has reached 30%.

3.3 Completion technology

It includes open hole completion, open hole horizontal well staged fracturing and intelligent well completion. Open hole completion method is to put the casing pipe to the top of paystreak to cement and make the productive interval bare. The technology is mostly better used in simple reservoirs, such as carbonate rock, hard sandstone and cementation layer. The advantage is that production layer bare area is large, the resistance of oil, gas flows into the borehole is small, but it is not suitable for multiple zones in different properties and different pressures. According to the time difference of drilling production layer and down into casing pipe, open hole completion method is divided into early open hole completion method and the late open hole completion method. Open hole horizontal well staged fracturing is a staged fracturing transformation of well completion. It can improve the level of permeability and reservoir capacity. In the intelligent well completion string, the flow of each branch can be controlled, if a branch borehole water was cut by more than 80%, it can shut down a branch hole production, therefore the intelligent well completion string can realize slicing and relief the contradictions of interlayer to improve development effect. Open hole completion method of

operation is relatively simple, widely used in oilfield development. Horizontal section open hole staged fracturing technology is a kind of transformation of reservoir, it can greatly improve the ability of reservoir permeability. Intelligent well completion string is used in oil well during middle and later periods of the development process and is a reliable means to improve development effect between the layers.

3.4 Simulation treatment.

Acid unblocking technology: Acid unblocking technology is using acid through minerals and inorganic scale near the wellbore area, and achieve the goal of reservoir unblocking. The disadvantage is that the chlorite is a typical acid-sensitive mineral which can react to acid to produce chemical precipitation, which is damage to the reservoir potentially.

Physical treatment technology: In the process of oilfield development, the near wellbore area would be polluted and damaged by the mechanical impurities caused by drilling, completion, fracturing, water injection and gas injection. Also the formation of scaling and wax would low down the formation permeability near wellbore area, hinder the convergence of crude oil to the wellbore and make the oil well production fell sharply, which would make a great gap between the actual capacity and its potential capacity. Some wells might become stripper well, shut down, and even death. But physical technology can solve the problem effectively. Oil increase mechanism of physical technology are mainly in five aspects.

3.5 Displacement technology.

It includes the elastic displacement, water injection, gas injection and water delivery note (Figure 1), artificial gas cap flooding and steam flooding. At present, because of the major environmental problems caused by CO₂, many oil companies begin to emphasis and develop CO₂ flooding technology (Figure 2).

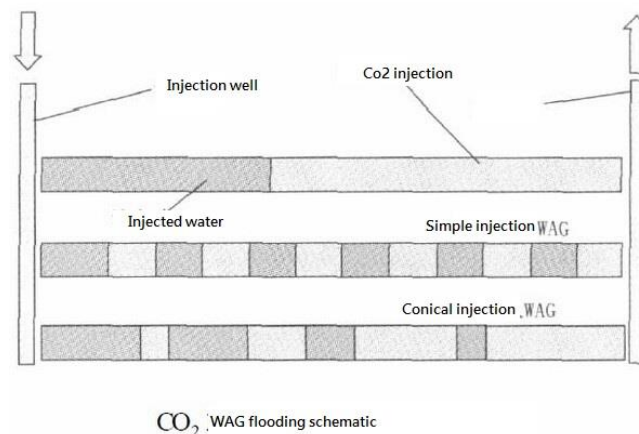


Figure1. CO₂ and water altering injection displacement

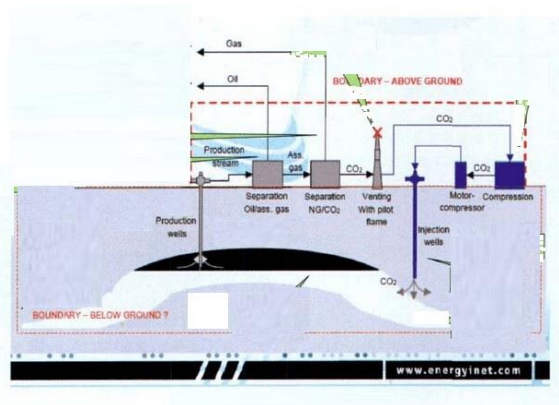


Figure2. American CO₂-EOR and storage process flow

Advanced water injection has a good effect on stress sensitivity reservoir. It is helpful to maintain the formation pressure of low permeability reservoir, establish an effective displacement pressure system, enhance effective wave and volume of injected water, reduce the damage caused by the formation pressure decline, inhibit the initial moisture content, and thus improve the single well production and ultimate recovery efficiency. Advanced water injection technology also needs to further study some questions during the water injection and mining process, basing on the development of oil field geological characteristics, including pressure, water injection intensity, injection timing and so on.

Air injection displacement is an economic and effective method of further excavating remaining reserves of low permeability oilfield [8]. Air injection exploitation of low permeability light oil is a creative new technology to improve oil recovery efficiency. Air has a wide source and is not limited by geography and space. Also gas source is most abundant and cheapest. The mining experience showed that it not only can be used as a way of secondary oil recovery, but also the tertiary oil recovery. The most important condition of air injection is that the reservoir temperature must be high enough and the oil must be active, so the oxygen can be consumed by low temperature oxidation, avoided explosion and serious corrosion in the production system caused by the presence of oxygen.

The combination of deep profile control and surfactant oil displacement technique is a new oil water control stabilization technology, which is using surfactant flooding to improve oil recovery after deep correction. Research results show that [9], after treatment of deep gel profile control, surfactant flooding can further improve oil recovery to a certain extent. The reason is that gel and chemical oil displacement agent can improve the displacement efficiency and function of sweep volume, it also has good synergy. That is to say that gel can play the role of changing deep fluid flow direction, and make the subsequent injection of surfactant system and water effectively enter the low permeability formation with low development extent, which play a full role of improving oil recovery in areas of high concentration residual oil.

4. Development trend of low permeability oil-gas exploration

4.1 High quality reservoir prediction technology of low permeability reservoirs.

For the prediction of high quality low permeability reservoir, it is mainly about the prediction and recognition of natural fractures in high quality low permeable reservoir. The research on quantitative distribution prediction and evaluation of permeability reservoir fracture is in the forefront of the oil-gas geology research fields, many distinctive research methods have been formed. In recent years, with the rapid development of logging and seismic technology, there have been a great progress in identification and prediction of cracks both at home and abroad by using well logging and seismic geophysical data. The mainly research methods and means are basing on the main control factors of the natural fracture, exploring relationship between geological statistics and studying fracture distribution prediction qualitatively (or semi-quantitatively) under the guidance of geological knowledge.

4.2 Microscopic pore structure analysis technology.

Currently the oil-gas reservoir microscopic pore structure analysis technology mainly include: real sandstone microscopic model displacement experiment technology, nuclear magnetic resonance (NMR) movable fluid analysis technology, constant speed mercury intrusion pore analysis technique and computed tomography (CT) scanning technology. Real sandstone microscopic model displacement experiment is new method in recent years. It mainly uses true sandstone micro model water flooding to study micro water flooding mechanism, residual oil formation mechanism and fractures' effects on water flooding efficiency. Nuclear magnetic resonance (NMR) imaging can observe rock cores in 3D, from different perspective, different steering, arbitrary slice direction, arbitrary slice thickness. By images we can judge the connectivity by directly observe the distribution features of fractures, small holes, cavern inside the core, the measuring aperture, micro crack width and the size of the diameter of caverns. Constant speed mercury can separate the throat and pore area in the rock, provide each sample's effective throat volume, number, radius distribution, and effective pore volume, number, radius distribution and effective distribution of throat and pore radius ratio.

Thus a detailed analysis of pore throat development characteristics of the sample (throat, porosity, pore throat radius ratio) can be given. CT scanning technology can observe the whole piece of the internal structure of core, mineral distribution and flow conditions in a few seconds without changing the external forms and core conditions.

4.3 Fracturing technology.

Hydraulic fracturing is the first and most common technology in the low permeability reservoir development. The purpose of hydraulic fracturing treatment is providing a long and narrow crack with large surface area. The primary purpose of hydraulic fracturing of is to improve the connection between the reservoir and wellbore fluid. In recent years, some progress have been made, including the viscoelastic surfactant fracturing fluid and limiting fracturing completion. Besides, coiled tubing layered fracturing technology, relative permeability fracturing fluid (RPM) treatment technology, repeated fracturing technology, and horizontal well fracturing technology are also the important development direction of fracturing technology in recent years.

4.4 Horizontal wells and multilateral wells technology.

As a mature technology of low permeability oil development, horizontal well has been widely used in the oilfield. For low permeability oil field, the position, extension length and extension direction of horizontal section in the reservoir are the key factors in the production. Therefore, during the process of building horizontal wells, a new technique should be applied to guarantee that horizontal well will drill into according to the best trajectory. Multi-branch Wells drilling technique is a new technique that using a single borehole (main shaft) to drilled out several branches. Currently, the commonly used multi-branch system mainly includes the reentrant branch system, double string multi-branch system, branch reentrant system and branch tieback system.

4.5 Advanced water injection technology.

Advanced water injection refers to a flooding pattern that when betting water injection before putting the oil injection well into operation, the oil saturation in drainage area is no less than the original oil saturation oil well production, formation pressure is higher than the original formation pressure and establishing an effective injection-production displacement system. Early water injection can keep formation pressure at a high level, which make the corresponding oil production be stable at a high level. Advanced water injection technology development has the following characteristics: (1) establish an effective pressure displacement system, and a single well can obtain a higher yield ; (2) reduce the permeability damage caused by formation pressure decline;(3) improve relative permeability of oil phase;(4) improve ultimate recovery.

4.6 Exploding load stimulation treatment.

In production of low permeability reservoirs, there has been a lot of technology development, such as borehole explosion, nuclear explosion, and high energy gas fracturing, loose explosion. But inner explosion stimulation treatment technology has a widest application foreground. The technology is using hydraulic fracturing technology to press the appropriate explosives into rock cracks, ignite explosives there, so as to generate a lot of cracks around the main crack, and achieve the goal of improve the formation permeability. Released energy of explosion has three forms: detonation, deflagration (both collectively referring to explosion), and burning. Deep made seam formation is characterized by high pressure, high energy, and load space narrow. According to mechanics principle, no matter how high the hydrostatic pressure is, it can't fracture rock, only high deviatoric stress can fracture rock. Hydraulic fracturing technology can meet all these characteristics, also the experience of blasting engineering shows that explosive can satisfy these basic characteristics too.

5. Conclusion

In order to exploit low permeability reservoir effectively and obtain good economic benefit, the development direction should towards to the application of slim-hole wells, horizontal wells, multi-branch wells, underbalanced drilling, and low density drilling fluid and large hydraulic fracturing technology, which all aim at protecting the oil layer. Slim-hole horizontal Wells and CO₂ foam acidizing fracturing technology, new technology application significantly improve the single well production achieved less Wells of low permeability oilfield high yield and lower cost. Dense pattern,

reservoir protection, hydraulic fracturing, horizontal well and branch development technology and slim-hole technology direction of development technology for low permeability oilfield development.

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