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Technology Progress of Resistance Reduction and Increased Injection in Low Permeability Reservoirs

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Abstract

Low permeability reservoirs are the main object of future oil and gas exploration and development in China. To achieve the efficient development of low-permeability reservoirs, the classification, geological and development characteristics and main exploitation technology are systematically analyzed by comparing and analyzing the development characteristics of 68 low-permeability sandstone oil fields at home and abroad. At the same time, starting from the analysis of reservoir damage caused by minerals and crystalline salts in low-permeability reservoirs, this paper summarizes and analyzes the resistance reduction and increased injection characteristics of common formation modification, formation surface modification, and supporting drilling and completion technology. And the design and development of plugging + resistance reduction of surface modification is put forward for resistance reduction and increased injection technology, It provides a basis for the subsequent efficient replenishment of formation energy and greatly enhanced oil recovery in the low permeability reservoirs.

Subject Areas

Petrochemistry, Petroleum Geology

Keywords

Low Permeability, Extraction Technology, Development Characteristics, Formation Damage, Resistance Reduction, Increased Injection

1. Introduction

In the unique oil-bearing basins with continental deposits in China, they are generally characterized by poor reservoir properties, and rich low permeability oil and gas resources are developed accordingly [1]. After long-term unremitting exploration, the exploration of low-permeability resources in China has made great discoveries. Especially in the past 30 years, large-scale oil and gas reserves have been discovered in the oil and gas exploration of low-permeability sandstone, marine carbonate rock and volcanic rock, which have become the main body of oil and gas reserves. Through continuous development technology research and innovation, China's low-permeability resources have achieved effective development and formed the world-class low-permeability reservoir development technology series. The proportion of medium and low permeability output in China oil and gas output is becoming more and more important. With the improvement of exploration degree and the increasing demand for oil and gas resources, low permeability reservoirs will be the main object of oil and gas exploration and development in China in the future, and also the mainstream and inevitable trend of oil and gas industry development [2].

Low permeability reservoirs and medium-high permeability reservoirs have obvious differences in seepage mechanism, development mode, recovery method and economic benefits [3] [4] [5] [6] [7]. Low permeability reservoirs have low sedimentary mineral maturity, high clay content, fine particles, diagenesis compaction, low porosity, small permeability, dissolution hole and micro crack development, pore throat small (and small throat of proportion), strong heterogeneity, so oil and water seepage mechanism is different from the conventional reservoir. The fluid in the matrix exhibits characteristics of imbibition and low-speed non Darcy flow, with Darcy flow dominating the fluid in microfractures and severe pressure-sensitive effects. The reservoir characteristics and seepage characteristics of low permeability reservoirs lead to the big difficulty, low recovery and poor benefit of these reservoirs by conventional methods [8]-[25]. According to the statistics [8] [9], the oil recovery rate of low permeability reservoirs at home and abroad is only about 20% on average, and most of the crude oils remain in the reservoirs and cannot be extracted, so the low permeability and ultra-low permeability reservoirs have great potential to improve oil recovery.

Producing reserves of low permeability reservoirs is 1.49 billion tons in Sinopec, and the existing well network and well control degree are high, and the effective water injection problem is widespread. The contradiction of "Hard water injection and hard oil extraction" is prominent, and the average injection rate of single well is 27 m^3/d and the average liquid production per well is 7.1 t/d. The energy retention rate is low and the average pressure retention level is 68.8%, and the average recovery rate is only 16.6%. How to greatly improve the injection capacity and reasonably supplement the formation energy is the focus of low permeability reservoir development.

2. Low-Permeability Reservoir Classification and Development Technology

2.1. Low-Permeability Reservoir Classification

Low permeability reservoir is a type of reservoir divided according to the reservoir property. The understanding of low permeability reservoirs in the world is not completely consistent, and there is no unified classification standard. The low permeability standards and boundaries vary greatly in different countries in different periods and even in different fields. China's classification standards for low permeability cover general low permeability, ultra-low permeability and super-low permeability.

Scholars in the former Soviet Union called fields with permeability of 50-100 mD as low permeability fields. The United States Federal Energy Regulatory Commission called fields with permeability less than 100 mD as low permeability fields and reservoirs with permeability less than 0.1 mD as dense reservoirs [10]. In China, different classification schemes are put forward according to different research objects. Luo Tanze and Wang Yuncheng [11] (1986) proposed that the oil field with permeability less than 100 mD was called a low permeability oilfield. Yan Heng *et al.* [12] (1992) refered to the reservoir with permeability greater than l00mD as good reservoir, the reservoir with permeability of 10 - 100 mD as low permeability reservoir, and the reservoir with permeability of 0.1 - 10 mD as extremely low permeability reservoir. Li Daopin [13] (1997) believed that the upper limit of low permeability reservoir is 50 mD, and put forward the concept of ultra-low permeability, dividing the low permeability oilfield into three categories according to the average permeability of oil layer: General low permeability reservoir with average permeability 10 - 50 mD, ultra-low permeability reservoir with 1 - 10 mD, ultra-low permeability reservoir with 0.1-1mD, this classification method is recognized by most scholars.

Hu Wenrui [2] (2009) and others put forward the new low permeability classification standard according to the current situation of China's petroleum resources, economic and technical conditions and the exploration and development practice of low permeability reservoirs, that is, general low permeability (permeability 1 - 10 mD), ultra-low permeability (permeability 0.5 - 1 mD), ultra-low permeability (permeability <0.5 mD).

According to the starting pressure gradient, useful hole throat volume fraction, mainstream throat radius, dynamic fluid saturation, Changqing oilfield further subdivided for ultra low permeability reservoir based on the development experience of ultra-low permeability reservoir, that is, permeability 0.1 - 0.5 mD reservoir is class I of ultra low permeability, permeability 0.3 - 0.5 mD reservoir is class II of ultra-low permeability, permeability 0.3 - 0.1 mD reservoir is class III of ultra-low permeability, and less than 0.1mDis as invalid layer. The ultra-low permeability class II oil layer is also referred to as the 0.3 mD oil layer, which has been effectively developed by methods of horizontal Wells, fracturing and advance water injection. Oil layer with permeability less than 0.1 mD are subdivided into 3 parts: dense reservoir, average permeability: 0.1 - 0.01 mD; very dense reservoir with average permeability 0.01 - 0.001 mD; super-dense reservoir with average permeability 0.001 - 0.0001 mD.

2.2. Geological Characteristics of Low Permeability Reservoirs

The global low-permeability oil and gas resources are widely distributed, and a large number of low-permeability oil fields have been found in North America, Central Asia, North Africa, Northern Europe and other regions. China is rich in low-permeability oil and gas resources with various types. Reservoir rock types include sandstone, siltstone, sandy carbonate rock, limestone and dolomite, mainly low-permeability sandstone reservoirs.

Compared with foreign low permeability fields, China's low permeability fields have unique geological characteristics: ① Mainly continental deposition with complex sediment, multiple sources, small scale, large reservoir particle size distribution range, poor sorting, and low grinding degree. Due to uneven compaction and diagenesis, the reservoir's physical properties change dramatically in the later stage. ② The sediment mineral composition maturity and structural maturity are low. Different from the quartz-rich characteristics in foreign Marine reservoirs, the content of feldspar and cuttings is generally high, with the average content as high as 51.3%. The rock particle size distribution range is wide, the particle size is mixed, and the sediment is easy to compaction in the process of rock, resulting in the dense reservoir, which is known as "grindstone". ③ Under the influence of deposition, diagenesis or tectonic action, the primary intergranular pore and secondary dissolution pore are developed with narrow pore throat and poor connectivity, poor reservoir physical properties. And porosity is less than 15%, and matrix permeability is less than 20 mD. ④ Oil layer is sandstone interaction, and sand layer thickness is unstable, the interlayer heterogeneity is strong. ⑤ Crack is developed with mainly micro-cracks and latent cracks, which are generally in the closed state under the original formation conditions.⑥ The content of heavy components such as wax, asphaltene and gelatin in crude oil is high, generally 10% - 30%.

2.3. Extraction Technology and Development Characteristics of Low Permeability Reservoir

At present, the exploitation technology of low permeability oil fields mainly includes water injection and gas injection technology to maintain the formation pressure [14], and tertiary oil recovery methods changing reservoir and fluid physical or chemical properties, such as chemical flooding [15], mcrobial drive [15] [16], explosion in the layer [17] [18], shock wave method [19] [20], electrodynamic methods [21] [22] *et al.*, as shown in **Table 1**.

According to the statistics of the exploitation methods of 68 low permeability sandstone fields at home and abroad, including 44 general low permeability fields and 24 ultra-low permeability (including super-low permeability) fields, it

Table 1. Extraction techniques and characteristics for low permeability oil fields.

Oil recovery method	Characteristics
Water injection	Low cost, mature technology, wide application.
Gas injection	Compared with water injection, high inspiratory index, reduced starting pressure, high injection capacity, easy gas flow, and key gas source.
Microbial drive	The investment cost is low, the energy consumption is less, oil recovery mechanism is complex, difficult to control, the effective bacteria reproduction will block the formation, produce H_2S and other harmful gases.
Chemical drive	The cost is relatively high, the polymer viscosity is high in the low permeability reservoir and injection ability is poor, and the application of the surfactant agent and its compound system has a large space for development.
Explosion in the layer	The hydraulic fracturing technology is used to press the deflagration drug into the oil layer crack, which produces a large number of cracks around the main joint after the deflagration.
Shock wave method	The vibration force is introduced into the stratum to reduce the capillary force, reduce the fluid adhesion of the rock, and merge the oil droplets.
Electrodynamic method	Using the DC electric field to the oil layer electric drive, electrochemistry and electric heating, improve the seepage characteristics and fluid flow characteristics of the oil layer, less investment, simple equipment, convenient construction, no pollution.

shows that water injection accounts for 71% of the exploitation of low permeability fields, accounting for 65% of the ultra-low permeability reservoirs [23]. In recent years, horizontal wells, large fracturing, advanced water injection and other technologies have been successfully used in the development of ultra-low permeability reservoirs, which makes the daily oil production of a single well significantly increased, and the proved reserves of ultra-low permeability reservoirs greatly increased [24]. The water injection development practice shows that the water injection will also be extended to the ultra-low permeability reservoir development. However, the single well production of ultra-low permeability reservoir is lower and worse [24], even if the water injection is effective, it will lead to high injection resistance, or even no water or serious under injection is injected due to poor physical properties and fine pores and throats, etc.

The development characteristics of low permeability reservoirs include: ① Insufficient natural energy, low production wells, and low oil recovery speed. The formation pressure conduction coefficient is small, and the pressure propagation is slow. In the initial stage, oil well has the characteristics of "insufficient liquid supply and rapid production decline", and the natural production capacity of the oil well is low, generally less than 10 t/d. ② Water injection is difficult to replenish energy and has a low recovery rate. The oil reservoir is generally boundless bottom water or the side bottom water is weak, and the natural energy supply is insufficient. The primary recovery rate is generally 6% - 10%, after water injection development, the reservoir reservoir recovery rate can be increased to 20% - 25%. ③ The water injection well has low water absorption capacity and poor water injection effect. The mineral content of clay in the reservoir is high, it lead to oil layer damage with water expansion of clay minerals and poor compatibility of injected water, resulting in further reduction of water absorption capacity, continuous increase of water injection pressure and continuous decrease of water injection. ④ Due to strong stress sensitivity, pressure cracks and natural cracks are easy to close. In low permeability reservoirs, the initial production speed is high but the decreases fast due to the reduced porosity and permeability by the strong pressure sensitivity, and the later oil rate is less than 0.5%. After water injection development, the oil rate is generally low. For example, the oil production index was 0.319 t/(d·MPa·m) in Fan 18-3 blocks in Shengli Oilfield in June 2007, and decreased to 0.154 t/(d·MPa·m) in April 2008.

3. Formation Damage of Low Permeability Reservoirs

3.1. Mud and Clay Mineral Damage in Low Permeability Sandstone Reservoirs

The sandstone reservoir contains mud and a variety of clay minerals. The former is mainly very fine grain sedimentary mineral particles, while the latter is commonly kaolinite, montmorillonite or illite-smectite mixed-layer, illite, chlorite, etc. Different clay minerals and combination types have different sensitivity to fluid. For example, montmorillonite meets fresh water expansion, chlorite appears iron hydroxide precipitation which meets hydrochloric acid, and illite produces potassium fluorosilicate which meets hydrofluoric acid, which will destroy the reservoir permeability, and affect the output of crude oil, and is the key factor of reservoir permeability damage [26].

Particle plugging damage refers to the mud and kaolinite mainly self grain granular clay minerals (feldspar alteration products) in the reservoir is with free and scattered state, and has irregular movement with fluid flow, crystal itself is false hexagonal "pages" aggregate with larger surface area. Once the fluid is scattered, it is easy to gather in the reservoir throat, causing reservoir permeability damage and reducing crude oil output. The key factor to control this kind of damage is the flow rate of formation fluid. The dispersed flow of kaolinite crystal requires a certain starting flow rate. When the fluid flow speed is less than the critical value, kaolinite sticks to the particle surface or half-filled pores, which has little impact on the original permeability of the reservoir. When the fluid flow speed is greater than or equal to the critical value, kaolinite particles will move with the fluid in a large range, causing serious damage to the permeability of the reservoir, or even no liquid production at all. Many commercial discoveries are limited to a large scale aggregation of kaolinite and cannot be extracted.

The clay film prone to expansion is the "membrane" shaped monundillonite or illite-montmorillonite mixed-layer mineral formed by the mud components in the original sediment adhering to the particle surface during the process of particle handling. Due to the neutral sedimentary water environment in the early stage of diagenesis, the clay film is mostly composed of montmorillonite. With the deepening of burial, it generally experiences the transformation process of illite-montmorillonite with the 10% mixed layer ratio of montmorillonite 90%. The clay film composed of montmorillonite is the most strongly expanded, which can expand to 5 - 8 times of the original volume in the freshwater environment. With the decrease of the mixing ratio, the expansion ability of the "membrane" changes from strong to weak, but with the increase of compaction degree, the reservoir physical characteristics (such as formation permeability or porosity) become worse and worse, even the weak clay expansion can cause serious permeability damage to the reservoir. Generally shallow reservoir or heavy oil mass often associated with a large number of expansive clay minerals. In Sand four subsection and Kongdian Formation—Mesozoic of Jiyang Depression, "red" formation is with low porosity and low permeability characteristics, and special eneesis environment, and expansive clay is relatively concentrated, so weak clay expansion may cause strong blockage reservoir seepage channel.

Needle and sheet clay "bypass" damage is the "bypass" structure of pointer with sheet structure of illite or illite-montmorillonite mixed layer (sometimes coil, slab structure) truss formed between two or more particles. This morphology can block the flow of fluid between the pores and throat, and the mobile particles may also be blocked here, to form stasis, thus greatly reducing the reservoir permeability. This type of blockage is common in deep super-low permeability reservoirs. Most low permeability sandstone are mostly distributed in illite, but not all illite products are "bypass", and most illite sheets are irregular in the reservoir, which will also cause adverse effects on the permeability of the reservoir.

3.2. Crystal Salt Damage in Low Permeability Sandstone Reservoirs

In addition to the skeleton particles, the type, quantity and sensitivity of the filling mineral in the pore and throat dominate the development conditions of the reservoir property. Among them, the influence of crystalline salt on porosity and permeability of the reservoir cannot be ignored, and its distribution is wide with diverse types and uneven content. The most common types of crystalline salt minerals are calcite (calcium carbonate), dolomite (calcium and magnesium carbonate), siderite, sulfate, and iron-containing carbonate cement.

The original formation water in Jiyang depression is mostly salt water and brackish water, starting from the stage of shallow burial, that is, the formation of large crystalline salt. In the process of deep buried water, the solubility and mineralization are constantly changing due to the foreign waters mixing of discharged water from mudstone compaction, deep heat source water and fracture flow water, resulting in the emergence of a series of crystals and the dissolution of early crystalline salts. Because these action types all occur in the reservoir pores and throat, they have obvious influence on the storage properties of sand body.

The diagenesis such as cementation, filling, replacement, dissolution and re-precipitation of crystalline salt will also cause damage to the permeability of the reservoir. There are mainly five damage types, including pore embedding (plaque distribution), throat-crack vein filling, particle ring cement bonding, iron ion immersion and acid sensitivity [26].

① Pore-embedded damage: it mainly occurs between the granular skeleton of the reservoir, and with the change of the climate, the evaporation further reduces the solubility of the unconsolidated or weakly consolidated sand, and the crystallization salt deposits in the pores, the skeleton particles are compacted together with the crystalline salt, the pore volume is further reduced, and the crystalline salt gradually fills the pores, which eventually makes the sandstone mass become more dense and makes the permeability reduced. If this type of crystallization salt is not affected by the late diagenesis-fluid, it does not contain iron, and the crystallization particles are relatively thick, generally coarse crystal-giant crystal blocks. In the later development stage, it is broken, deformed and embedded due to compaction, sometimes presenting the false appearance of original sedimentary particles.

② Throx-fissure vein filling injury: external fluid in the diagenetic period carries a large number of calcium, iron, magnesium and other cations into the sand body, the original crack or through the throat in the sand body is its main migration path, and the cation crystallization process mainly occurs on this path. Often see the pulse-filled crystalline salt with early residual oil and gas transport markers (asphaltenous overlap). Such damage will block the reservoir throat and the original diversion gap, greatly reducing the seepage performance of the reservoir.

③ Grain ring mud cement bonding damage: sediment in addition to debris particles, also accompanied by a large amount of mud. The surface of the skeleton particles often develops a mud film. In the diagenesis period, the mud film is affected by the fluid environment, and is often mixed with some fine crystals or crystallization. As a result, the adhesion to the particles is getting stronger and stronger, and the volume is "getting bigger and bigger", which eventually leads to throat occlusion, pore narrowing and reduced permeability.

④ Iron ion immersion damage: mud composition is a kind of alteration product, the most easily to primary rock minerals are micite, blblite and other dark minerals, these minerals contain iron ions, so the compaction of the liquid mostly carry iron ions. Iron ions into the sand body is the most easy to immerse into the crystal salt lattice, forming iron-containing calcite and iron-containing dolomite, and even forming siderite. Once the crystalline salt soaked with iron is dissolved by organic acid and working acid in the later stage, a large number of iron ions will be free. When the pH value is greater than 3.98 (indoor experimental experience value), iron hydroxide precipitation will produce, blocking the reservoir pore and throat, and damaging the permeability of the reservoir.

⑤ Acid-sensitive damage: the acid-sensitive damage of crystalline salt is mainly for the sensitivity of soil acid series. Soil acid is a commonly used and essential acidification liquid in oil fields. The purpose is mainly to use hydrochloric acid to dissolve carbonate, and use hydrofluoric acid to dissolve silicate silicic fillings such as clay. But there is a contradiction in this principle, namely the carbonate and clay minerals in the reservoir for acidification, due to the hydrochloric acid and crystalline salt reaction is very fast, so the acid into the first reaction is hydrochloric acid, the calcite and dolomite dissolved dissolution, and release a large number of calcium, magnesium, iron ion, the cation because of free, is easily captured by fluoride ion, form a lot of potassium fluoride silicate silicate sediment, the throat form secondary blockage, damaging reservoir permeability.

4. Resistance Reduction and Increased Injection Technology of Low Permeability Reservoirs

At present, the commonly used methods of resistance reduction and injection increase in oil fields include reservoir stimulation, reservoir surface modification, and the application of supporting drilling and completion technology, etc., which are often used together. It is necessary to analyze and study the characteristics and water injection characteristics in ultra-low and super-low permeable sandstone reservoirs. The reason for bad flow and big water injection resistance is complex in ultra-low/super-low permeability sandstone reservoirs, it may be the reservoir itself with poor physical properties, and fine pore throat, which is more likely to cause boundary effect resistance. And the lower the permeability of the reservoir, the finer the pore throat. Improving the interface properties can reduce the boundary effect of all kinds of resistance. Theoretically, starting from the interface properties, by changing the oil/water interface and rock surface properties and reducing the liquid-liquid and solid-liquid interaction, it can reduce the restriction of the boundary effect on the flow, improve the oil/water relative permeability, and reduce the reservoir damage, reduce the later injection resistance, and improve the development effect of ultra-low permeability reservoir.

4.1. Stimulation Technology of Step Dissolution and Removal of Low Permeability Sandstone Reservoirs

Matrix acidification or fracturing stimulation is the main process method to improve the permeability of low permeability reservoirs. However, for the low permeability reservoir with various clay minerals and salt crystals, the traditional acidification method aims to solve the pollution of the near well zone, which cannot improve the matrix permeability in a large range, and the stimulation effect is often not obvious. The conventional method of fracturing and stimulation cannot be modified according to the damage mechanism of the reservoir filling, so the efficiency is low. At the same time, the mechanical force in the fracturing process causes the local deposit inside the reservoir, resulting in the decrease of matrix permeability and damaging the permeability of the reservoir.

To stimulation the matrix by acidification and increase production of the low-permeability sandstone reservoir that has already been damaged, it is necessary to develop an acid-soluble formula that can effectively dissolve clay minerals and crystalline salts for the "constituent elements" of the reservoir rock. In addition to expanding the pore volume of the reservoir, it can also effectively protect the pore structure of the rock. Due to the various types of gap filling minerals, if the chemical properties of the particle are composited with the rock structure, it cannot completely dissolve and remove the gap filling. The main purpose of the acidification (the acid fracturing) is to effectively dissolve the main interstitial material components that have a significant blocking effect on fluids, effectively improve reservoir permeability. The reaction residue of the dissolved filling must be separated from the rock structure (removal) to effectively improve and protect the connectivity between the pores, thus forming the "step by step dissolution and removal" stimulation improvement technology [26].

The acidification (acid fracturing) formula developed based on the principle of "step-by-step dissolution and removal" takes slow-release acid as the main body. By replacing supramolecular solvent, dissolving silicate uses a composite system of ammonium hydrogen fluoride + fluoroboric acid + fluorophosphoric acid, and step-by-step dissolution, step-by-step implementation. ① This method avoids not only the cation crystallization problem caused by the acid dissolution contradiction between minerals in the traditional acid use, but solves the hydrochloric acid after dissolving the iron-bearing carbonate and chlorite, free iron ion precipitation problem. ② Creating favorable conditions for the effective dissolution of the kaolinite, The Kaolinite has a relatively large specific surface area, and the corrosion compound acid in acidified formula has strong wettability to kaolinite wafer, although extremely acidic. However, it has a large contact wetting area with the kaolinite wafer, which is able to rapidly occupy the cluster wafer surface of kaolinite, and slowly dissolves and gradually engulfes the kaolinite residues, solves the kaolinite in the traditional acidification process but the thorny problem of the skeleton particles being dissolved first. ③ The protection of byproducts such as potassium fluorosilicate can take full advantage of the complexation of supramolecular solvents, and the solvent is independently synthesized by integrating organic solvents such as xylene and cationic additives such as nickel, zinc, chromium, copper and barium. It can not only decompose the crystalline salts but are able to complexe the metal cations and inhibit their precipitation, and also able to decompose mineral residues into smaller particles. After the particles are complexed, the continued acid is pushed into the deeper space of the reservoir matrix and dispersed.

Over 100 wells (success rate close to 100%) with increased injection and production have confirmed the reliability and applicability of the technology in Shengli, Jianghan oilfield, solving the traditional technical problems with timely reflux of residual acid, and construction can be in the well to acid basic present neutral without return row production operation, which has a broad promotion value.

4.2. Molecular Membrane Injection-Increased Technology of Low Permeability Sensitivity Reservoirs

In low permeability sensitivity reservoirs, strong water sensitive, speed-sensitive characteristics and unstable injected water quality cause the prominent problem of high water injection pressure and insufficient water injection to meet the injection requirements. For this problem, the acidification treatment technology is proposed to remove near well zone blockage, by injecting a cationic group to improve the wetting of the reservoir, and improve the water absorption capacity of the reservoir, further improving the water flooding recovery.

Molecular film agent has a strong hydrophilic and oil-friendly ability. With an aqueous solution as the transmission medium, a very thin molecular deposition film is preferentially absorbed between the core pore throat and the water film, which makes the wettability of the rock reverse [27]. The influence of core wettability on the water relative permeability is shown in **Table 2**. Compared with water wet cores, oil wet cores have slightly higher water phase permeability in the residual oil stage. It can make the original water film adsorbed on the surface of the pore thin, fall off with the injection water flow, thus eliminating the water lock damage, and can effectively expand the pore size, improve the water permeability of the core. The existence of molecular membrane can make the injected water not contact with the rock surface, can prevent the expansion and migration of clay particles, and effectively reduce the water injection pressure. Molecular film agent is colorless, tasteless, non-toxic, no harm to people, no corrosion to equipment pipeline casing, valves, will not cause chemical pollution to the formation and underground water source, has salt resistance, acid and alkali resistance, can prevent swelling and clay particle migration.

Table 2. The influence of core wettability on the waterrelative permeability.

Core number	Permeability, md	Porosity	Irreducible water saturation	Residual oil saturation	Relative permeability of water phase	Wetting angle
1	24	0.18	0.36	0.2	0.62	30
2	25	0.16	0.38	0.25	0.61	30
3	26	0.19	0.31	0.27	0.63	138
4	31	0.16	0.36	0.2	0.62	85
5	55	0.22	0.33	0.24	0.32	138
6	56	0.24	0.34	0.26	0.25	30

In 2020, the technology was successfully applied in four wells in Xinjiang Kara may Oilfield. The efficiency of molecular membrane agent was 100%, and the injection pressure decreased by 4.95MPa on average. This technique can effectively solve the problem of difficulty in injecting water into injection wells due to the clay expansion in the later stage.

4.3. Nanometer Active Pressure Injection Raising Process

Nano SiO_2 powder is a new type of enhanced injection agent [28], with strong hydrophobic nature and oleophilicity, it can adsorb on the rock surface, change the wettability of the rock, reduce the flow resistance of the injected water in the pores, reduce the injection pressure, and improve the injection speed.

Due to the high energy state of its surface and the extreme instability of the surface atoms in nano SiO_2 powder, it is easier to adsorb on the sandstone surface, thus changing the wettability of the rock, effectively reducing the thickness of the water film on the rock surface, and expanding the effective radius of the flow channel. Owing to the particles nano SiO_2 powder are small, and their discrete particle size reaches 10 - 500 nm, which can enter a lower permeability reservoir, with a wider treatment range, and the adsorption process will not cause side effects, resulting in secondary blockage. Nano SiO_2powdermaterials isolate the rock surface from water to avoid hydration expansion and diffusion of clay minerals.

Yanbian oilfield has the characteristics of low permeability, low porosity and strong reservoir heterogeneity, and many injection wells can not meet the injection requirements under near rupture pressure. In order to improve the development effect of water injection, nano SiO_2 powder is carried out a pressure reduction and increased injection test. During the test, the wellbore was cleaned first to ensure that the well bore is clean, and then the cleaning agent was injected into the reservoir to remove the blockage and pollutants near the well, and make the nano SiO_2 powder is easily adsorbed on the rock surface. The final injection of the nano SiO_2 powder is performed mixture, replaced with clear water. By the nano powder treatment of 21 injection wells in Yanbian oilfield, the successful ratio and treatment efficiency reached 100%, the average injection pressure of single well was reduced by 0.84 MPa, and the average injection of single well increased by 19.1 m^3/d, 40110 m^3 within 100 days。

4.4. Surfactant Resistance Reduction and Increased Injection Technology

Due to the special structure and excellent interfacial activity [29], surfactants are often used to reduce the oil-water interface tension of low permeability reservoir, change the wettability of rock surface, emulsify and disperse crude oil, change the rheology of crude oil, reduce the thickness of boundary layer, improve the seepage capacity of oil and water phase, reduce the residual oil saturation and injection pressure, and achieve the purpose of reducing resistance and increasing injection.

Research methods are most indoor experiments for surfactant resistance reduction and increased injection, which focus on screening and development of whether surfactant can reduce resistance injection and resistance injection effect, through a variety of surfactant general composite agents to achieve resistance injection effect. In the ultra low permeability reservoir, the improved recovery and resistance reduction mechanism lacks understanding, more in use for empiricism and pertinence is not strong. In view of the serious problem of water phase trap damage in tight sandstone reservoirs, the interface modification and the rock surface wettability can be used to prevent phase trap damage, promote the fluid reflux into the well and improve the oil and gas recovery. At present, the application research on water injection is mostly aimed at the reservoirs with air permeability above 1 mD.

Surfactant resistance reduction and increased injection technology has achieved good results in indoor test and field test, indicating that it is a new technology suitable for resistance reduction and increase injection in low permeability oilfield. However, this technology is still in the development stage in China, and the on-site application is not very common, and the cost is high, so there is still a large space for research and progress. In the future, it is necessary to deepen the research on surfactant resistance reduction and injection technology in optimizing surfactant, reducing the cost of surfactant synthesis, and integrating multiple technologies.

4.5. Shrinkage Expansion, Resistance Reduction and Injection Enhancement Technology

It is mainly used for high clay mineral content and easy water-sensitive reservoirs [30]. The shrinkage expansion agent is a chemically synthesized polymer cationic compound, which modifies the clay lattice through physical and chemical reactions with clay minerals so that it does not expand after encountering water; the expanded clay lattice releases water molecules and reduces the lattice. Through multi-point adsorption, these modified clay materials are firmly combined with the original formation minerals, so as to avoid the damage caused by clay ore expansion and migration to the formation.

The ionic group of the shrinkage expansion agent is oxidized, which can destroy the lattice of clay, so that the clay after water absorption releases the absorbed water, shrink the expansion volume, and restore the capillary hole of the formation. The shrinkage expansion agent molecule has polar functional groups that interact with water molecules. When it is added to water, its hydration group is combined with water molecules. When clay particles in contact with its aqueous solution, rely on hydrogen bond or electrostatic suction adsorption similar clay particles, because the shrinkage expansion agent has enough high molecular weight, and has a large linear unfolding ability and suitable molecular structure, it can not only adsorb on a sodium soil particles and can further connected to the adjacent clay particles, multiple clay particles connected or bridge together, so as to prevent clay dispersion, maintain the stability of the clay, to achieve the purpose of resistance increase injection.

Well Wei 79-1 has conducted shrinkage expansion, resistance reduction and injection enhancement technology in Pucheng Oilfield on February 6, 2010 with 45 m^3 of the shrinkage expansion agent. The maximum injection pressure of site construction decreased from 35 MPa to 28 MPa with reducing 7 MPa, and the daily injection volume was the original 4 m^3 up to 40 m^3 withdaily increased water volume 36 m^3. After normal water injection, the oil pressure is stable at 28MPa, the validity period is 180d, and the injection reduction effect is obvious.

4.6. Dual Hydrophobic Treatment Agent for Reducing Resistance and Increasing Injection Technology of Super-Low Permeability Reservoirs

Due to super-low permeability reservoir with micro porous development and small average throat radius, to weaken the surface/interface resistance caused by high permeability interface properties and the difference of capillary uneven displacement, stating from the perspective of changing the rock surface properties, it is explored to change rock surface wetting for hydrophobic, oil hydrophobic treatment agent for super-low permeability sandstone reservoir resistance injection method [31]. The anti-resistance injection treatment agent needs to meet: 1) the treatment agent has small molecular weight, which can realize the requirement of ultra-low permeability reservoir injection, does not block the reservoir, and has low use concentration; 2) the target reservoir temperature and pressure requirements, with a long stability time; 3) stably adsorb on the surface of rocks, reduce interfacial tension, and change the wetting properties of rock surfaces; (4) the adsorption can be stable for a long time under the action of humidity and hydrodynamic force.

Through the influence of treatment agent on oil / water interface tension and rock wetting and the relationship with resistance increase injection, it is found that fluoride can be both hydrophilic and oily rock treatment, changed to neutral wetting (hydrophobic, oil hydrophobic) can greatly reduce the seepage resistance, can greatly reduce the oil/water interface tension (reduce 3 - 4 orders of magnitude) and gemini surfactant has a similar effect. The duplex surfactant with low interfacial tension and the fluoride with wetting modification have good antihypertensive injection effect, and the fluoride surface modification at lower permeability, the core drag reduction injection effect is better, indicating that the surface modification is more suitable for ultra-low permeability sandstone reservoirs.

5. Understandings and Suggestions

The reserves of low permeability reservoir in Sinopec generally have the problem of effective water injection, and the energy retention rate is low. How to greatly improve the injection capacity and reasonably supplement the formation energy is the focus of low permeability reservoir development.

The low permeability reservoir has poor liquidity and high water injection resistance, so it is also necessary to explore the method and mechanism of low permeability reservoir from reservoir fluid property, reservoir damage and interface modification, and the influences of reservoir fluid property, reservoir damage and interface modification and their interactions are considered, so as to guide the process optimization and realize long-term injection increase.

In view of the problem of poor injection and production capacity of low permeability reservoir, it is also necessary to develop the resistance reduction and injection increase system which can greatly reduce the seepage resistance of oil and water and improve the injection and production capacity, and to tackle the chemical auxiliary water flooding technology of low permeability reservoir.

The existing injection increase technology is difficult to solve the problem of "water injection, oil production" in low permeability reservoirs in the long time. It is also necessary to design and develop the surface modification and resistance modification technology of plugging + resistance reduction, so as to realize long-term pressure reduction and injection increase and improve the development effect of water flooding.

6. Conclusions

1) China is rich in low-permeability oil and gas resources with various types including sandstone, siltstone, sandy carbonate rock, limestone and dolomite, and mainly low-permeability sandstone reservoirs, which are developed by water injection and gas injection technology to maintain the formation pressure and tertiary oil recovery methods changing reservoir and fluid physical or chemical properties.

2) Formation damages of low permeability sandstone reservoirs contain mud and clay mineral damage and crystal salt damage, which damage reservoir permeability and increase seepage resistance, thereby increase the injection pressure and affecting the injectability of the injection wells.

3) Resistance reduction and increased injection technologies contain many types, such as stimulation technology of step dissolution and removal, molecular membrane injection-increased technology, surfactant resistance reduction, and increased injection technology, which can reduce the restriction of the boundary effect on the flow, improve the oil/water relative permeability, and reduce the reservoir damage, reduce the later injection resistance, and improve the development effect of ultra-low permeability reservoir.

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Conflicts of Interest

The author declares no conflicts of interest.

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