

Present Situation of Pressure Flooding Technology for Injection Enhancement in Low Permeability Reservoirs

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ABSTRACT

Low permeability reservoir generally exists low permeability, small pore pressure, high start-up pressure gradient and difficult injection. Energy injection technology for low permeability reservoir is always concerned by people. Based on the difficulty of "no injection, no production" in low permeability reservoir, pressure drive water injection technology is put forward. This paper introduces pressure drive technology according to literature investigation and current situation of pressure drive technology at home and abroad.

KEYWORDS

Low Permeability; Pressure Flooding; Research Status.

1. INTRODUCTION

With the development of oil and gas exploration and development theory and technology, more and more low permeability and ultra-low permeability reservoirs are put into development, and low permeability oil and gas fields are widely distributed in China. At present, 10% of onshore oil and gas reserves in China are low permeability oil and gas fields, and more than half of proven undeveloped reserves are low permeability reserves. These reserves are distributed in major oil and gas fields or major basins in China. Effective development of low permeability oil and gas resources has important strategic significance for ensuring sustainable development of oil and gas in China.

Low permeability reservoir generally exists low permeability, low pore pressure, high start-up pressure gradient and difficult injection, etc. Pressure flooding effectively solves the problem of low injection capacity in low permeability reservoirs, which is another technical breakthrough in water flooding development. It not only shows a broad prospect for low permeability reservoir development, but also provides a new idea for improving water flooding development effect for other reservoir types. With the continuous deepening of research and practice, pressure flooding technology continues to improve its matching, and will become the leading development technology for improving production efficiency and recovery efficiency in low permeability reservoirs in the future.

2. PRESSURE FLOODING TECHNOLOGY

Pressure flooding technology is also called fracturing oil displacement or energy storage fracturing technology, which is a reservoir reconstruction technology that uses fracturing hydraulic pressure to open the formation, quickly transports chemical displacement agent to the target formation along the fracturing fracture, reduces the filtration loss along the way, reduces the contact between chemical displacement agent and the formation along the way, reduces the adhesion loss along the way, increases the reservoir production degree and improves the oil recovery factor.

In pressure flooding technology, "pressure" refers to fracturing, i.e. creating fractures to form fluid flow channels; "displacement" refers to oil displacement, i.e. using oil displacement agent to displace crude oil from rock pores and fractures. Different from traditional hydraulic fracturing, which promotes fracture extension and creates long fractures, pressure flooding technology pursues delaying fracture extension, creating short and wide fractures, avoiding premature breakthrough of chemical agent front and increasing swept volume. At the same time, the injection conditions are also changed. Conventional hydraulic fracturing is constant rate injection, while pressure flooding is high pressure injection, and then soak well operation is carried out to make the pressure fully diffuse.

According to operation mode, action mechanism and field production mode, pressure drive technology can be divided into forward pressure drive and reverse pressure drive.

2.1. Forward Pressure Drive Technology

Forward pressure flooding is suitable for low permeability reservoirs that can realize oil-water connection, and solves the problem of difficult water absorption in low permeability reservoirs. During fracture propagation, working fluid gradually penetrates into formation pores along fracture wall and contacts reservoir oil phase, non-wetting phase is driven by wetting phase, and the flow direction of absorbed wetting phase and discharged non-wetting phase is the same. The existence of pressure drive fractures weakens radial flow resistance, increases seepage area, shortens effective distance between oil and water wells and speeds up effective time of oil well.

In 1990s, the pilot test of water flooding above formation fracture pressure was carried out for the first time in foreign oilfields, and in 2007, the pilot test was carried out in Shanshan oilfield in Xinjiang. With the continuous understanding of low permeability reservoir development, in order to further improve the well water absorption capacity and improve the production degree of low permeability reservoir, the forward pressure flooding injection fluid is not only clean water, but also surfactant, nano permeability absorbent and other oil displacement agents.

In recent years, some scholars have studied fracture dynamic propagation in the process of pressure flooding. Fracture propagation in pressure flooding is different from that in conventional fracturing. Traditional fracturing only focuses on the problem of creating fractures, and reduces the fluid loss as much as possible during fracture creation, so that it can effectively act on the fracture wall. However, in pressure flooding process, it is necessary to increase fluid loss, and effectively provide the fluid loss volume and fluid loss form during fracturing process and after fracturing. Therefore, it is necessary to re-characterize fracture propagation during pressure flooding.

2.2. Reverse Pressure Flooding Technology

Field tests show that reverse pressure flooding has worse reservoir properties. (Ultra-low permeability, ultra-low permeability, tight reservoir) can achieve better recovery. Usually, it is difficult or impossible to inject water into this kind of reservoir for energy supplement during production, so it is necessary to fracture the oil well and carry out huff and puff production. Reverse pressure flooding is to use low viscosity working fluid with certain permeability and oil washing capacity to crack the formation from the oil well end, and the working fluid penetrates into the reservoir matrix along the fracture wall. After injection is completed, sand-carrying fluid is pumped and sand is added to support the fracture. After the completion of the whole pressure drive measure, soak the well to make the injected fluid fully contact with crude oil. If the reservoir can establish displacement pressure difference, inject water to supplement energy at the injection end of the well group to displace the crude oil diffused around the oil well fracture, wherein the production driving force includes water injection energy enhancement, pressure drive agent energy storage and reverse permeability capillary force. If water injection cannot be realized, the production end will rely on the energy supplemented by pressure drive agent for the formation and reverse permeability capillary force for production.

Reverse pressure flooding technology has been rapidly developed and tested in Daqing Oilfield, Changqing Oilfield, Huabei Oilfield, Tuha Oilfield, Shengli Oilfield, Huaqing Oilfield and Weizhou Oilfield. Li Zhihao et al. studied the remaining oil distribution characteristics of ultra-low permeability reservoir and designed the water injection development idea of utilizing natural energy after relying on overall volume fracturing in the initial stage and carrying out water injection stimulation + asynchronous injection and production energy supplement in due time in the later stage according to the reservoir characteristics of Huaqing Oilfield. They formed the volume fracturing technology of horizontal wells, integration of directional well pressure drive and fracturing conversion technology of water injection wells. 89 industrial test wells were developed, and the final recovery ratio was predicted to increase by 6.9%. Wang Jing et al. adopted the technology of adding sand fracturing after energy supplement with precursor oil for 2 wells to be abandoned, and the recovery effect was obvious, which confirmed that the pressure flooding technology could realize the function of improving recovery factor, and provided a new technical idea for improving the development effect of production well groups of Class III oil layers difficult to produce. Chen Gang et al. summarized the integrated pressure flooding and energy enhancement technology of "prepad + surfactant + volume fracturing" in combination with the tight reservoir characteristics of Wuqi Oilfield, and carried out pilot test in Wuqi Oil Production Plant. After pressure flooding, the daily oil production increased by more than 3 times compared with conventional fracturing, and the oil production effect was remarkable.

3. PRESENT SITUATION OF WATER INJECTION DEVELOPMENT IN LOW PERMEABILITY RESERVOIRS

High pressure water injection is always an important measure to increase and stabilize production in low permeability reservoir. The micro and macro geological characteristics of low permeability reservoir determine that high pressure water injection should be adopted for effective development. Low permeability reservoir has relatively poor reservoir physical properties, relatively high seepage resistance and certain start-up pressure, which leads to the decrease of water absorption capacity of water injection well, serious "pressure holding" near well, continuous increase of water injection pressure, limited pressure supply at injection end, and failure to establish effective pressure displacement system.

Pressure drive water injection technology uses surface high pressure pump group to pump injection program with ultra-high pressure, micro-fracture or even fracture pressure, injects a large amount of water in a short time, and then charges energy for oil well by shut-in, soaking well and pressure diffusion to improve development effect. During water injection engineering, a high pressure area near the bottom hole will be formed in low permeability reservoir, which is close to the fracture pressure of the formation. This kind of state will make the formation store a lot of energy, make the pores expand and communicate, and improve the reservoir properties near the well. A large amount of high pressure liquid injected into the formation will increase the percolation distance of the liquid, enlarge the swept volume, and redistribute the remaining oil. Meanwhile, the larger pressure difference of oil and water wells will lead to the increase of the drainage area.

The compatibility of injected water and formation should be considered when designing water injection. Water injection should be able to inject into formation, and problems such as reservoir rock swelling, pore plugging and permeability reduction should be avoided. Compared with conventional fracturing water injection, water injection volume of pressure drive water injection is larger. The large water injection stage of pressure drive can be roughly divided into three stages: pressure-soak-production. Pressure drive water injection is mostly combined with asynchronous water injection mode. Asynchronous water injection and production is a periodic water injection method, that is, "no production during injection and no injection during production". During water injection, open water injection wells and close production wells to supplement formation energy while preventing injected

water channeling. The increase of formation pressure is conducive to opening fractures and connecting micro-fractures and improving formation permeability.

Water flooding is generally considered as one of the effective ways to enhance oil recovery in low permeability reservoirs. As early as the middle of last century, foreign oil and gas fields have begun to study water flooding development. Guthrie and Greenberger (1955) predicted water flooding recovery by analyzing the basic reservoir parameters of many oil fields, and finally obtained the empirical formula of recoverable reserves for oil field water flooding development.

Water flooding was first applied in Yumen Oilfield in 1950s, and it is still the main way of oil and gas field development in China. With the updating of technology, a series of water injection technologies are widely used in oil and gas fields, such as advanced water injection, periodic water injection, pulsating water injection, etc.

Many scholars have made in-depth exploration on new water injection development methods and related technologies. Liang Chenggang (2011) and others have established relevant mathematical models for North Sixteen Reservoir of Beisantai Oilfield as an example to elaborate the fracture characteristics and the influence on water injection technology equipment during water injection at near fracture pressure of reservoir, and demonstrated the feasibility of water injection at near fracture pressure of low permeability oil and gas reservoir. During water injection at near fracture pressure, micro fractures near the injection well are opened, and reservoir physical properties are improved. The volume of injected water increased.

Jiang Ruizhong (2011) improved the traditional nonlinear seepage model based on the capillary model, established a new single-phase nonlinear seepage model, and extended it to two-phase seepage. Combined with the nonlinear seepage theory and numerical simulation, he believed that the seepage in low permeability reservoirs was dominated by Darcy nonlinear seepage, and only a small part of the area near the well had quasi-linear flow.

Liu Hualin (2011) put forward the concept of effective driving pressure system according to the nonlinear seepage law and pressure propagation law of low permeability reservoir, and analyzed the influencing factors of injection-production pressure system and the influence of related reservoir parameters and development parameters on reservoir seepage. Based on the mirror principle, the calculation formula of the effective driving pressure system between injection-production Wells in the well pattern is derived, and the related theoretical chart is drawn. Based on the water drive characteristic curve and the basic principle of material balance, Hu (2013) derived the theoretical relationship between water drive displacement efficiency, volume sweep efficiency and water cut by using the expression of water drive displacement efficiency, the expression of water drive volumetric sweep efficiency and the relationship between average water saturation and water saturation at the production end. A new method for calculating displacement efficiency and volumetric sweep efficiency by using the dynamic data of water-driven oil field is proposed.

Liu Jian (2013) studied the development mode of carbonate buried-hill reservoir by using the numerical simulation method, optimized the production parameters of asynchronous injection-production development, and predicted the recovery degree of various development modes. The study showed that the asynchronous injection-production mode of this oil reservoir showed better development effect and was conducive to the establishment of an effective pressure displacement system.

Gao Wenxi (2016) considered the stress sensitivity of low permeability reservoirs under advanced waterflood development by laboratory test method. The results show that the permeability of core increases and the stress sensitivity is obvious with the advance water injection experiment, and the stress sensitivity is negatively correlated with the change of permeability. In the process of pressure relief, the decrease of permeability is greater than the increase of permeability in the process of injection boost. As the pressure continues to drop below the initial pressure, the experimental core

does not show obvious stress sensitivity. Through the analysis of the experimental data, the power function relationship between stress sensitivity and reservoir permeability is obtained. Yuan (2018) analyzed the reservoir connectivity and the law of water cut rise, established a new water cut rise model, optimized the timing of water injection and related production parameters, and achieved good results in the oilfield.

Wang Yang (2019), based on the analysis of actual mine data in Ordos Basin, established a fracture diagnosis and inversion method for water injection induction in low permeability reservoirs, and believed that the water injection process led to the activation of reservoir micro-fractures and the formation of advantageous channels.

Wu Zhongbao (2019) et al., combined with volumetric fracturing technology and imbibition oil recovery theory, proposed a new development model of water injection huff and huff and asynchronous injection-production imbibition oil recovery in volumetric reservoir, studied the mode of imbibition oil recovery in different well types and water injection modes, realized the change of displacement mode, and showed good results in field practice.

Zhang (2020) proposed a development model of unstable alternate injection-production to address the problem of uneven vertical production in the process of waterflooding in fault-block reservoirs. Considering the influence of formation heterogeneity, Zhang proposed a new injection-production optimization method by placing a regulator in the well to close or open a certain formation position in real time, so as to optimize injection-production parameters.

Liu Peiliang (2020) et al., taking fractured-cave reservoir as the research object, made an in-depth analysis of the reasons for the low swept efficiency of waterflooding. Drawing on the idea of hydraulic fracturing in shale gas development, they proposed a method of simulated fracturing water flooding to increase the injection pressure to fracture pressure, establish a seepage channel between Wells and karst caves, effectively expand the swept volume of waterflooding and improve the development effect.

SaadatM (2020) systematically studied the effects of injection rate, injection volume, micromodel structure, initial water saturation, brine concentration and composition. The results show that the higher the injection rate, the stronger the emulsification and agitation, which leads to the instability of displacement, and the recovery rate of low salinity water is higher than that of high salinity water.

Ding (2021) proposed a nano-fluid permeable oil displacement system, which is very stable under reservoir conditions and can effectively expand the sweep volume ratio of low-porosity and low-permeability reservoir matrix. Under flowing conditions, the system can decompose the tight oil into "nano-oil droplets" which are easy to displace from the matrix. The system has good interfacial activity, which can greatly improve the oil displacement effect of microporous matrix. The core NMR evaluation results show that the oil displacement system can more effectively displace the crude oil in the medium/micro-pores, effectively improve the swept volume of water drive and the efficiency of oil displacement, and supplement the formation energy.

Liu Chao (2021) took heavy oil reservoirs in offshore oil fields as an example to study the change rule and mechanism of reservoir physical properties in the process of waterflood development, and the research showed that compared with the pre-waterflood development, the content of clay minerals in the reservoir was reduced, the physical properties of the reservoir were improved (the permeability was significantly improved), and the wettability was also stronger.

Lin (2022) established a reservoir conceptual model through numerical simulation to characterize the impact of dynamic changes in reservoir parameters on oil recovery in the production process. Time-varying permeability intensifies the heterogeneity of the reservoir and affects the wettability at the same time, which significantly improves the water drive recovery.

Di Shiyong (2022) took fractured tight oil reservoir as the research object, based on rock mechanics theory, clarified the propagation mechanism and law of natural fractures induced by tight oil reservoir

in the process of injection huffling development, and combined with numerical simulation method, numerically characterized the fracture propagation process and analyzed the principle of unstable water drive. Taking the actual field as an example, the effects of injection huff and unstable injection development are analyzed. The productivity of horizontal Wells can be effectively improved by changing injection huff to unsteady water drive cycle injection.

4. RESEARCH STATUS OF PRESSURE DRIVE TECHNOLOGY

Since 1950, foreign scholars began to study the theory of imbibition displacement in fractured oil fields, put forward a two-hole medium model, analyzed its multiphase unsteady flow characteristics, and organized the oil-water movement and imbibition law, which provided a theoretical basis for the research of domestic pressure displacement technology.

Domestically, in 2017, Daqing Lamadian Oilfield carried out the first field experiment of "pressure flooding technology" in China and achieved success, with a daily increase of 98 tons of fluid and 3.2 tons of oil, achieving a good production increase effect, and subsequent water flooding studies have proved that the increase of fluid and oil of pressure flooding is better than that of ordinary fracturing.

Wang Jing (2020) et al. studied the fracture propagation law and seepage mechanism of the pressure flooding process, and conducted a pressure flooding test in the old oil area of Shanshan with sand fracturing after the pioneer oil replenishing, which proved the practical feasibility of the pressure flooding process to enhance oil recovery.

Bai Xiaohu et al. (2021) proposed an integrated fracking, energy replenishment and oil displacement repeated transformation technology, which combined energy replenishment and fracturing, and imbibition displacement and braising well, respectively, to achieve effective fracture expansion and crude oil stripping from pores, and achieved good recovery results in field transformation experiments in the Ordos Basin.

Wu Xiaoyun et al. (2021) established a model to study the fracture propagation law of pressure drive, and concluded that the fracture half-length increased with the increase of injection volume and injection displacement at the beginning of fracture, and the increase slowed down in the later period.

Xu Yonghui et al. (2021) analyzed the pressure distribution characteristics at both ends of injectivity and production through multiple sets of experiments, clarified the pressure flooding water injection mechanism of low permeability reservoir, and obtained the pressure flooding water injection design method based on the principle of material balance.

Wang Feng et al. (2022) introduced a feasible supporting scheme for pressure flooding process by optimizing injection parameters, equalizing sweep volume, optimizing string structure and stimulation measures.

Liu Yikun et al. (2022) simulated the mechanisms of seepage, energy storage, oil washing and flowback of pressure flooding agent, and studied the production increase mechanism of pressure flooding.

Fan Chao et al. (2022) established a numerical reservoir model of pressure flooding, conducted historical fitting of actual production data, studied the mechanism and main parameters of pressure flooding, and concluded that pressure flooding development can quickly supplement formation energy, improve reservoir physical properties and expand swept volume.

Wang Qiang and Zhao Jinzhou (2022), by establishing a multi-process and multi-phase flow model for fracturing and braising well production, proposed an optimization method for the braising time after fracturing with multiple clusters of horizontal stages for shale oil, analyzed the influence of injected fluid volume, permeability, porosity and displacement on the braising time, and concluded that the time when the increment slows down is the optimal braising time.

Zhang Yifei et al. (2022), through the pressure flooding model experiment, concluded that radial vertical cracks distributed in a plane shape would be formed during pressure flooding.

At present, many new low permeability oil fields and old low permeability oil fields that have been exploited for a long time have serious formation energy deficit, poor reservoir physical property, and low reservoir utilization degree. Pressure flooding can overcome the problem of "no injection", achieve a substantial increase in injection, and then quickly supplement formation energy and improve recovery. However, from the perspective of the current oilfield applications at home and abroad, good engineering application results have been achieved mainly in low permeability reservoirs, and the "engineering application" in the oilfield field has gone ahead of the "theoretical research". At the same time, the theoretical research on "technical limits" of pressure flooding technology is relatively lacking, especially the combination of laboratory experiment results and field application is relatively small.

5. CURRENT SITUATION OF PRESSURE DRIVE NUMERICAL SIMULATION METHOD

S.M. dumabo et al. (2014) found that increasing the time of brazing would increase the effective permeability. Many domestic researchers adopted numerical simulation methods in the process of studying fracture-brazed Wells to study the influence of brazing time on reservoir stimulation. Wang Ling (2022) et al., from petrochina Liaohe Oilfield Company, used CMG's IMEX module to establish a hydraulic fracturing model, compared the changes of oil saturation in different braising times, and obtained the optimal braising time of the simulation results. Wang Qiang and Zhao Jinzhou et al. (2022) established a multi-process and multi-phase flow model for fracturing and brazing well production, proposed an optimization method for the brazing time after fracturing with multiple clusters of horizontal stages of shale oil, analyzed the influence of injected fluid volume, permeability, porosity and displacement on the brazing time, and found that the optimal brazing time is negatively correlated with permeability and porosity, etc. It has a nonlinear positive correlation with the injected fluid volume and an approximate linear positive correlation with the flow rate.

In oilfield practice, reservoir numerical simulation software is used to simulate multiple groups of different injection volumes by controlling variables such as permeability and displacement, and select the most appropriate water injection volume by analyzing the changes in the cumulative production and daily oil production of production Wells.

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