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Current Situation Analysis and Adaptability Research of Fracturing-flooding for Low Permeability Reservoir

Shaoqing Liu, Wenlong Hou, Zhiyuan Wang

College of Petroleum Engineering, Xi'an Shiyou University, Xi'an, Shaanxi 710065, China

ABSTRACT

Pressure drive technology has been widely applied in the enhanced oil recovery of low permeability reservoirs in recent years. This technology improves the oil-water connectivity by injecting working fluid, effectively displacing crude oil. This paper discusses the mechanisms of pressure drive technology and its applications in selecting wells and layers, well pattern design, and optimizing well spacing. It is found that the diamond anti-nine-point pattern is the most effective in early-stage oil recovery, while the rectangular anti-five-point pattern is suitable for later-stage development. In addition, the optimization of injection volume and rate, as well as the combination of various monitoring techniques, is crucial for enhancing pressure drive effectiveness. The study also proposes key indicators for evaluating the adaptability of pressure drive, which can guide the efficient development of low-permeability reservoirs.

KEYWORDS

Low Permeability Reservoir; Fracturing-Flooding; Research Status; Adaptive Analysis.

1. INTRODUCTION

In recent years, the pressure drive technology has shown its potential in improving oil well productivity and oil recovery rate as a means of enhancing oil production for low permeability reservoirs. Low permeability reservoirs have entered the late development stage, with deep burial, scattered residual oil distribution, large differences in layer properties, high proportion of non-injectable and non-producible reserves, and a prominent contradiction between "not being able to inject and not being able to produce". The water drive performance of the reservoir is poor, and the reserves utilization is highly uneven, resulting in a low water injection-based oil recovery rate. It is urgently needed to conduct a study on the adaptability of pressure drive technology to form a complete pressure drive technology system for low permeability reservoirs, ultimately significantly improving the oil recovery rate of pressure drive well groups and guiding the large-scale promotion of pressure drive technology in low permeability reservoirs. This study first explores the mechanism of pressure drive technology in low permeability reservoirs, indicating that proper injection of working fluid can realize oil-water connectivity and effectively displace crude oil. In addition, the principles of selecting wells and layers are proposed, emphasizing the selection of isolated well points and well groups with good geological characteristics to improve pressure drive effect. Through the study of the optimal well pattern and well spacing, it is found that the initial stage oil recovery rate is the highest with diamond-shaped anti-nine-point well pattern, while the later stage suggests using a rectangular anti-five-point well pattern to adapt to different geological conditions. In terms of injection process parameters, the study shows that the optimization of injection volume, speed, and multi-stage layered pressure drive process is the key. Finally, the evaluation index of pressure drive technology adaptability of low permeability reservoir is put forward, including accumulated water, recovery degree, geological reserve utilization degree, etc., in order to provide scientific basis for efficient development of low permeability reservoir. Through the results of this study, the recovery efficiency of low permeability reservoir can be significantly improved, and new ideas and technical support for future oil and gas development can be provided.

2. THE MECHANISM OF FRACTURING-FLOODING TECHNOLOGY

Pressure flooding technology is suitable for low permeability reservoirs that can connect oil and water, and solves the problem of water absorption in low permeability reservoirs. Working fluid, which is no flowback fracturing fluid, water or surfactant, is injected from the end of the well at a condition close to or greater than the fracturing pressure of the reservoir. In the process of fracture expansion, the working liquid gradually penetrates into the formation pores along the fracture wall and contacts with the reservoir oil phase. The non-wetting phase is driven by the wetting phase, and the flow direction of the inhaled wetting phase is the same as that of the discharged non-wetting phase. After the completion of the fracture, direct water injection or after the diffusion of the braised well, the injection pressure will keep the fracture in the open state, increase the reservoir energy, and can effectively displace the crude oil to the production end. The existence of pressure drive fractures weakens the resistance of radial flow, increases the seepage area, shortens the effective distance between oil and well, and speeds up the response time of well.

Fig. 1 provides a The construction method diagram of forward pressure flooding technology.

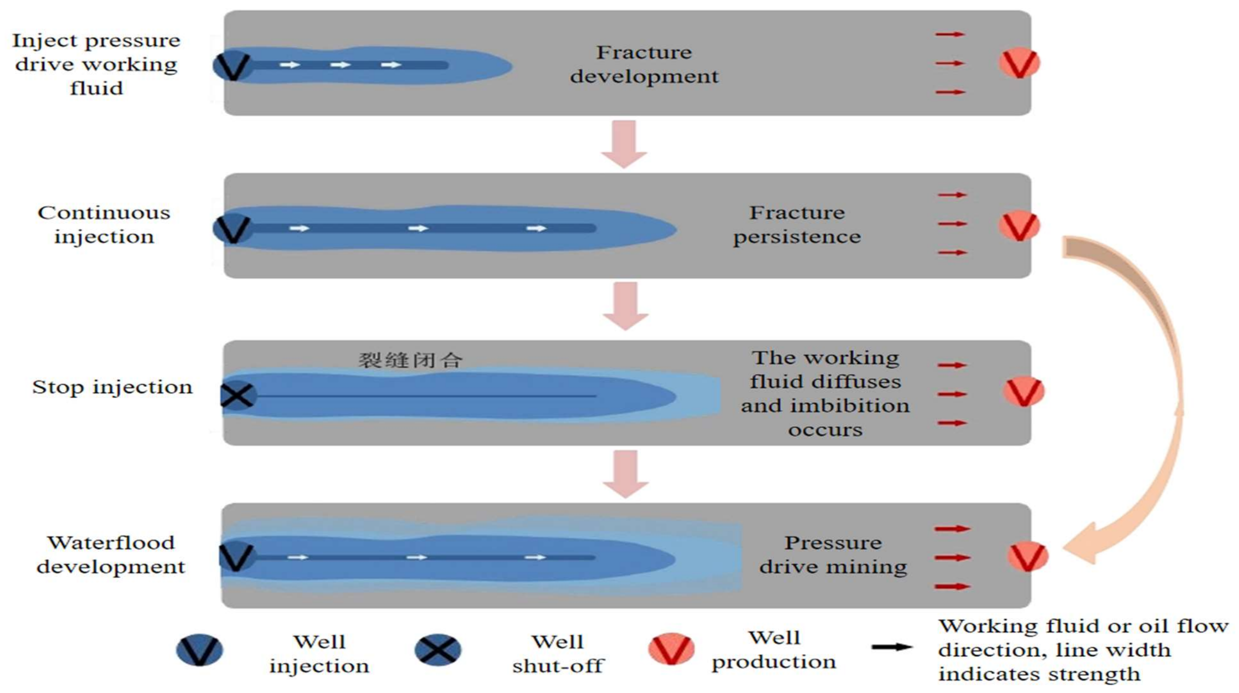

Fig. 1 Schematic of core flooding setup.

3. THE PRINCIPLE WELL AND LAYER SELECTION

Low permeability reservoir pressure flooding well selection is suitable for selecting isolated well points or well groups with relatively poor connectivity, which usually have no injection-production relationship or imperfect injection-production relationship or serious formation energy deficit.

(1) Well selection principle:

The well selection principle of pressure flooding operation is that the cementing quality is good, the fault is far from the target layer, and the target layer should be developed with a certain thickness, the distribution range is large, the remaining oil is rich, and the reserves of the well group or operation area are low. The Wells with low formation energy and slow energy recovery rate are selected for water injection Wells. Isolated well points with no injection-production pattern or incomplete injection-production relationship; The target layer has a certain reservoir size, relatively low production degree and relatively rich remaining oil. Because there are many kinds of reservoir sand bodies and serious cross distribution, the remaining oil is not evenly dispersed. Conventional chemical flooding effect is not good, but will retain some reserves advantage, through pressure flooding technology can effectively release this part of reserves; The larger the energy deficit is, the farther the percolation distance of the surfactant will be, the larger the effective sweep volume will be, and the greater the increase in recovery efficiency will be. Because isolated well points are far away from water injection Wells, the energy supply is small, and the remaining oil near them is rarely used. However, when the remaining oil is relatively enriched, the residual oil can be released to increase the reservoir utilization degree by using pressure flooding technology.

(2) Formation selection principle:

The injection well selects the formation with low injection fluid volume and high starting pressure. Through pressure flooding, efficient oil displacement agent is injected into the reservoir at one time to increase formation pressure and quickly reach the starting pressure. According to the research of Daqing oilfield, the formation energy should be high, the formation pressure holding level should be greater than or equal to 65%, the water content of small layer should be less than 90%, the recovery degree should be less than 20%, the remaining oil saturation should be greater than or equal to 30%, and the permeability should be medium and low, between (50~300) ×10−3μm2. The division of the interval should be based on the logging interpretation results and the longitudinal distribution of the reservoir, and at the same time, to ensure that there are main layers in each section.

4. FRACTURING-FLLODING WATER INJECTION PROCESS PARAMETERS

4.1. Well Network Pattern

The numerical simulation of pressure flooding in low permeability reservoirs with different well patterns is carried out by considering square inverse five-point pattern, equilateral inverse seven-point pattern, square inverse nine-point pattern and rhombic inverse nine-point pattern under the same area condition. It is found that the final recovery degree of rectangular inverse five-point pattern is the highest, followed by diamond inverse nine-point pattern, and square inverse nine-point pattern is the lowest, which are 19.5%, 17.2% and 14.6%, respectively. The oil-well ratio of the reverse nine-spot pattern is 3:1, which is higher than that of the reverse five-spot pattern (1:1), and more production Wells can be maintained in the initial stage of production, which is convenient to improve the oil production speed. At the same time, the rhomboid inverse nine-point well pattern deployed along the direction of principal stress widens the well spacing in the direction of fracture, reduces the lateral spacing, delays the flooding of the production well in the direction of fracture, and facilitates the uniform advance of injected water. In addition, the well pattern adjustment has greater flexibility, and in the middle and late stages of development, the corner well can be diverted to form linear water injection along the fracture, that is, the rectangular reverse five-point well pattern. Considering the final production degree and oil production rate, it is recommended to adopt rhomboid-shaped anti-nine-point well pattern in the initial stage, and rectangular anti-five-point well pattern in the middle and later stages. The well pattern direction is along the direction of the maximum formation principal stress. In the actual reservoir engineering design, it is difficult to deploy regular well pattern due to many factors such as structure of working area, fault system and distribution pattern of oil-bearing area. At this time, vectorized well pattern design can be carried out according to reservoir distribution pattern, reservoir physical property, thickness, connectivity, fracture direction and other factors to achieve uniform effect.

4.2. Well Spacing

The design of injection-production well spacing adopts the method of pressure profile design. The pressure profile consists of three components: the fracture section of oil well, the pressure drive section of water well and the interwell matrix section. The fracture section of an oil well refers to the section with high conductivity caused by fracturing of an oil well, in which no loss of pressure conduction is approximately considered. Water well pressure drive section refers to the section with high conductivity caused by water well pressure drive fracture, in which there is approximately no loss of pressure conduction. The interwell matrix section refers to the pure matrix section without fracturing and pressure drive fracture diversion, and the pressure conduction loss in this section is related to the physical properties and starting pressure in the section. The optimization of injection-production well spacing should focus on two objectives, namely pressure drive effectiveness and economic efficiency. The effect of injection and production well distance pressure flooding refers to the pressure difference from well to well formed in the development of pressure flooding, which is not lost during the flow process in the matrix section between Wells, and finally forms an effective pressure difference to supplement the energy of the well. The economic efficiency of injection-production well spacing means that the well pattern density after pressure flooding deployment meets the economic benefit requirements, and the controlled reserves of a single well × pressure flooding recovery efficiency > the economic limit accumulated oil production at the evaluated oil price. In order to meet the requirement of effective well spacing pressure flooding, it is necessary to divide the well spacing into oil well fracture section, well pressure flooding section and interwell matrix section respectively for calculation, and then combine with different injection and production directions to form.

4.3. The Formation Pressure Frator

The water injection design is one of the main factors affecting the effect of pressure flooding. The water injection is less, the increase of formation pressure coefficient is small, and the oil well productivity is low. The oil recovery rate is affected by the high water injection, the expansion range of pressure flooding fracture network is large, and the sweep volume of well group is reduced. Therefore, it is necessary to optimize the injection volume of pressure flooding.

4.4. Injection Rate

Reservoir physical property and injection-production well spacing should be considered in the design of pressure drive water injection rate for low permeability reservoir. In the case that the reservoir physical property is poor and the economic limit well distance can not establish displacement, it is necessary to increase the distribution range of fracture zone by increasing the pressure flooding speed to achieve the purpose of establishing displacement. When the reservoir physical property is good, the displacement between oil and water Wells can be established without pressure flooding fractures, and the pressure flooding water injection rate should be reduced to inhibit the fracture formation and improve the recovery rate.

4.5. Multiple Cyclies of Layered Fracturing-flooding Technology

The low permeability reservoir of Shengli Oilfield is buried about 3000m, the reservoir temperature exceeds 120℃, and the pressure of pressure flooding is high, which requires high stability of pressure flooding pipe string. In addition, the cost of pressure flooding is high, so the reuse of pipe string is an important means to reduce the cost of pressure flooding. Through the optimization of pipe structure and the research of high temperature stratified sealing technology, the formation of the highest four layers of large channel multi-round stratified pressure drive pipe string, the pressure 50MPa, temperature 150℃, to achieve balanced displacement of high and low pressure layer, the effective use of high pressure layer. 101 Wells have been carried out in the mine, and the sealing efficiency is 91.7%.

5. LOW PERMEABILITY RESERVOIR PRESSURE DRIVE TECHNOLOGY MONITORING METHOD

5.1. Leading Edge Monitoring Method (Pressure, Medium)

In the process of pressure flooding of low permeability reservoir, the opening and injection of injection well, the adjustment of injection pressure and the switching of well of oil well will cause formation fluid pressure fluctuation, and the pressure front will move forward or shrink backward, which will cause new fractures to occur, and small vibration will be propagated around the monitoring well. In order to receive such micro-seismic waves, monitoring sub-stations will be arranged around the monitoring well. The data of pressure drive sweep range and dominant orientation are obtained.

5.2. Dynamic and Static Logging Test (Electroimaging Logging)

Electro-imaging logging is the best method to detect fractures, which can clearly show the existence state of underground fractures through longitudinal high-resolution characteristics. According to the imaging logging data, the fracture parameters (length, density, width and opening degree) and fracture occurrence can be obtained, and the fracture effectiveness can be evaluated.

5.3. Microseismic Monitoring

The results of microseismic monitoring show that the microfracture zone produced by pressure flooding in Wells presents a uniform expansion process, which is significantly different from the long fracture formation process under fracturing conditions, and this kind of fracture helps to expand the conformation coefficient while improving the water injection capacity.

5.4. Fluid Level Monitoring

The installation of the oil well level monitor in the pressure drive well of low permeability reservoir is convenient to optimize and adjust the production parameters according to the dynamic change of the oil well dynamic level, and the intermittent pumping production of the oil well can be carried out according to the recovery of the dynamic level, so as to reduce the lifting energy consumption.

5.5. Pressure Monitoring of Pressure Drive Well -- Reconstruction of Well Test Vehicle

The application of the new technology of pressure detection in pressure drive well can run multiple Wells at one time, has simple operation, stable and reliable performance, and saves manpower and material resources. The direct reading pressure measurement method is widely used in oil and water well pressure measurement. And the device has good expansibility, can be used in a variety of test projects, to develop a wider range of test market to provide the necessary equipment support.

5.6. Monitor Well Monitoring

In the process of pressure drive interference test, the pressure drive well is used as the exciting well and the monitoring well is used as the reflection well. The downhole direct reading pressure gauge is used to monitor the formation pressure change of related Wells in real time, so as to grasp the process of pressure flooding in time and adjust the parameters of pressure flooding. The dominant direction of fracture conduction is evaluated by the interference well test interpretation method to improve the accuracy of the evaluation of pressure drive fracture scale and displacement fluid sweep range.

6. STUDY ON ADAPTABILITY OF PRESSURE DRIVE TECHNOLOGY IN LOW PERMEABILITY RESERVOIR

The indicators to reflect the effect of pressure drive development in low permeability reservoir should be as follows:

(1) When the same degree of recovery is reached, the amount of accumulated water injected into the reservoir reflects the good or bad pressure drive effect of low permeability reservoir. When the same recovery degree is reached, the lower the accumulated water injected into the reservoir, the better the pressure drive development effect of the low permeability reservoir is. On the contrary, the more accumulated water injected into the reservoir, the worse the pressure drive development effect of low permeability reservoir.

(2) Under the same cumulative water volume in the injected reservoir or the same injection multiple of pore volume (the ratio of cumulative injected water volume to the total pore volume of the reservoir), the degree of recovery reflects the good or bad pressure drive effect of low permeability reservoir. Under the same injection ratio of pore volume, the higher the recovery degree, the better the pressure drive development effect of low permeability reservoir. On the contrary, the lower the recovery degree, the worse the pressure drive development effect of low permeability reservoir.

(3) In the process of pressure drive development of low permeability reservoir, the degree of exploitation of geological reserves and the relative size of recoverable reserves (the ratio between the recoverable reserves predicted for a specific reservoir and the recoverable reserves that the reservoir should achieve in a certain development period) are both important indicators to reflect the pressure drive effect of low permeability reservoir.

The first two aspects consider the relationship between the degree of recovery and the cumulative injected water from the perspective of water injection utilization. The effect of pressure drive development in low permeability reservoir is different because the accumulated water injected in oilfield development has different effects in a certain period. In the initial stage of waterflood development, the injected water is mainly used to maintain formation pressure, and at the same time, it is also to improve the volume conformation coefficient of pressure drive oil in low permeability reservoir, and constantly increase the control degree of geological reserves, so that the entire geological reserves are placed in the recoverable geological reserves, laying the foundation for obtaining higher recoverable reserves. In the middle and late stage of waterflood development, in addition to the above two functions, the injected water also gradually improves its oil displacement efficiency and plays a major role. Therefore, the evaluation of injection water utilization rate is an indispensable aspect to measure the effect of water injection development. In addition, the evaluation of the relative size of used geological reserves and recoverable reserves is the concern of oilfield waterflood development. In the process of oilfield waterflood development, water cut rise rate reflects the change of water cut with the degree of recovery. The ultimate purpose of all the adjustment measures in oilfield development is to increase the recoverable geological reserves and increase the recoverable reserves. The use of geological reserves and recoverable reserves is a comprehensive reflection of "volume conformance coefficient" and "oil displacement efficiency" in waterflood development. The degree of exploitation of geological reserves in a reservoir mainly depends on the volume conformance coefficient. The higher the volume conformance coefficient, the higher the degree of exploitation of geological reserves, and the better the pressure drive development effect of low permeability reservoir. On the contrary, the lower the volume conformance coefficient, the lower the degree of exploitation of geological reserves, and the worse the pressure drive development effect of low permeability reservoir. The relative size of recoverable reserves in a reservoir is determined by volume conformance and displacement efficiency. Only under the condition of "higher volume conformance coefficient and higher displacement efficiency" can the relative size of recoverable reserves be large.

To sum up, the indicators reflecting the effect of pressure drive development in low permeability reservoir should include: pressure drive reserve control degree, pressure drive reserve utilization degree, recoverable reserves and recovery efficiency, water cut and water rise rate, water retention rate, water consumption, pressure drive index and energy retention degree.

7. CONCLUSION

The main conclusions are as follows:

(1) Low permeability reservoir pressure drive well and layer selection is suitable for selecting isolated well points or well groups with relatively poor connectivity, and injection Wells select formations with low injection fluid volume and high starting pressure. The target layer has a certain reservoir size, relatively low production degree and relatively rich remaining oil.

(2) Through the study of well pattern and well spacing optimization, it is found that rhombic reverse nine-point well pattern has the highest recovery rate in the initial stage, while rectangular reverse five-point well pattern is recommended in the later stage to adapt to different formation conditions. In terms of water injection process parameters, the optimization of water injection volume, speed and multi-round stratified pressure flooding process is the key.

(3) Front monitoring, microseismic monitoring, hydrodynamic level detection, etc., can evaluate the pressure flooding effect in real time and optimize the operating parameters. Finally, the evaluation index of pressure drive technology adaptability of low permeability reservoir is put forward, including accumulated water, recovery degree, geological reserve utilization degree, etc. Eight aspects.

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