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Progress in Fracturing and Displacement Technology

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Abstract: This paper summarizes the exploration and development process of low-permeability tight reservoirs in major oilfields in China, and divides the development of fracturing and flooding technology of low-permeability tight reservoirs in domestic oilfields into four stages: matrix seepage and oil production, fracture matrix dynamic seepage oil production, fracture network fracturing storage and seepage oil production, and fracturing flooding oil simmering and oil production. At the same time, six aspects of fracturing and displacement technology are clarified: (1) volumetric fracturing technology; (2) Rupture pressure water injection technology; (3) Continuous large-displacement water injection technology; (4) Injection of a large amount of prepositioning technology; (5) Seepage and suction replacement technology of stewed wells; (6) Add pressure repellent technology. and a vision for the future of pressure drive technology.

Keywords: Fracturing displacement, Otospiration, Chemical agent oil displacement.

1. Introduction

With the development of oil and gas field exploration and development technology, China's oil and gas development has shifted from conventional reservoirs to low-permeability and tight unconventional reservoirs [1]. Hydraulic fracturing technology is an effective means for low permeability and tight oil and gas resources. Combined with water flooding and chemical flooding, it can improve the recovery efficiency of unconventional reservoirs to a certain extent, but there are still many development problems[2-4]. Conventional hydraulic fracturing procedures are complicated, the cost is high, the spread range of fractures is small, the transformation effect is not obvious, and the reservoir stimulation effect is low. There are some problems in conventional water flooding, such as unclear response characteristics, unclear main control factors, low proportion of response Wells, serious water channeling and flooding. Conventional chemical flooding shows that the displacement agent is easy to stay in the formation, resulting in the reduction of the displacement agent concentration and the weakening of the displacement effect. In order to effectively solve this problem, the "pressure-injection-production" integrated fracturing oil displacement technology, also known as "pressure flooding", is proposed in the oil field, which is to combine hydraulic fracturing technology, conventional water flooding development and chemical agent oil displacement to form a complete set of continuous low-permeability reservoir development technology. According to process technology and mechanism of action, pressure flooding is divided into forward pressure flooding and reverse pressure flooding[5-6].

The forward pressure flooding technology is mainly aimed at the low permeability reservoir. The oil displacement agent is injected from the injection well at the target fracture pressure, and the oil displacement agent is displaced into the formation pores around the fracture while the fracture is extended. At the end of the construction, no proppant is added to make the fracture close, and then the injection well and the production well are closed for oil-water replacement. After that, the injection well resumes the conventional continuous injection mode, and the fracturing injected displacement agent is further displaced to the end of the production well, and the reservoir recovery rate is improved by supplementing the formation energy and washing the oil with the displacement agent. This process has achieved certain economic benefits in Niuzhuang, Bonan and other blocks of Shengli Oilfield[7].

The reverse pressure flooding technology is mainly applied to the reconstruction of the third type of low permeability reservoir and the exploitation of tight oil and shale oil in Daqing oilfield. The produced well is fractured with low viscosity imbibition fluid as fracturing fluid, and imbibition agent is injected quickly during fracturing, and proppant is added to prevent fracture closure. And the well is braised, the imbibition fluid and imbibition agent are diffused in the fracture-matrix, and imbibition displacement of the crude oil in the reservoir is carried out, so as to improve the reservoir recovery.

2. Development History of Fracturing Oil Displacement Technology

2.1. Matrix dialytic oil production stage

Before 2000, China began the experimental and theoretical research on matrix imbibition on the basis of learning from the relevant research abroad. Yin Ding[8] first proposed a numerical simulation method considering the influence of fracture imbibition, and proved that the change of imbibition velocity conforms to the exponential decreasing law. Xiangyang[9] studied the experimental law of rock imbibition under different conditions through laboratory experiments such as volumetric method and weighing method, and realized that the imbibition of reservoir matrix has a certain effect on reservoir production, which belongs to the early theoretical stage of fracturing oil displacement technology in China.

2.2. Fracture matrix dynamic imbibition oil recovery stage

With the deepening of oil and gas exploration and development in China, we have a deeper understanding of reservoir structure. It is believed that matrix is the main storage space of reservoir fluid and fracture is the main flow channel of fluid. In the development of fractured low permeability reservoirs, it is found that fracture-matrix dynamic imbibition is an important oil recovery

mechanism[32-33] for this kind of reservoirs. Yang Zhengming[10] studied the imbibition mechanism of low permeability fractured sandstone reservoir by analyzing the influence of core length, core-fracture contact surface size, aging time, oil-water gravity and other factors on spontaneous imbibition. The triple exponential function model is improved. Ji Bingyu[11]derived the partial differential equation of oil-water displacement between matrix fractures under the influence of capillary force in the reservoir. The research shows that the stronger the wettability, the lower the permeability, the better the fracture development and the better the imbibition oil recovery effect. Wang Jial[12]u designed and experimentally studied the influence of factors such as oil-water viscosity ratio and displacement speed on the dynamic imbibition effect between fractures and matrix. Li Aifen[13] studied the influence of wettability, viscosity and other factors on imbibition. The results show that temperature affects imbibition indirectly by changing the viscosity of simulated oil. At this stage, Daqing Oilfield and Changqing oilfield carried out a large number of theoretical research and field application of water injection development of low permeability fractured reservoirs, which promoted the development of fracturing displacement technology in China.

2.3. Frac imbibition oil recovery stage

With the continuous development of oil fields, more and more oil fields are facing the problems of insufficient formation energy and decreasing liquid production. How to effectively restore formation energy is an urgent problem for old oil fields in China. In Daqing Oilfield, Jilin oilfield, Tuha Oilfield, Huabei Oilfield and Yanchang Oilfield, the formation energy replenishing and fracturing are combined to form the oil recovery technology[14] of "fracture-network fracturing - energy storage and seepage enhancement". With low sand ratio and large liquid volume, the pre-fluid can not only improve the fracture-forming density and fracture-expanding capacity, but also benefit the oil-water imbibition displacement and energy storage and enhancement. Horizontal well pre-energy volumetric fracturing technology for tight reservoir development can enhance fracture-forming capacity, improve matrix imbibition displacement, and increase single well production[15]. Taking the FL121 Ping2 well in Yanchang Oilfield as an example, the amount of fluid used in each single stage is 9100 m3, with 684 m3 of fluid in advance, 235 times more than that in the adjacent well, and the production after pressure is 8.9 t/d, 1.68 times [15] more than that in the adjacent well.

2.4. Fracturing displacement imbibition and oil recovery stage

At present, the physical properties of unconventional reservoirs are poor and the geological conditions are more complicated, so it is difficult to establish an effective displacement system between injection-production Wells. In order to solve this problem, the technology of fracturing displacement-braised well imbibition production has been widely applied. This technology mainly includes two ways: one is the injection well forward pressure flooding represented by Shengli Oilfield, the other is the production well reverse pressure flooding represented by Changqing Oilfield.

The pressure flooding operation was carried out in Niuzhuang, Binnan, Yihezhuang and other blocks in Shengli Oilfield. The cumulative pressure flooding water exceeded 200×104 m3, and the overall efficiency of the well was about 50%, achieving a certain increase[7] in production. In recent years, with the further exploration and development of tight oil, Changqing Oilfield has put forward an integrated fracturing technology of "pressure-increase-seepage". The technology firstly adopts the subdivision close cut volume fracturing technology to break the reservoir, and at the same time enhances the formation energy by pumping a large amount of pre-fluid, which effectively increases the formation pressure coefficient from 0.8 to 1.3. Finally, oil and water can be replaced in the fracture and matrix system through the imbibition technology of the braised well, thus greatly improving the oil displacement effect. The discovery of the 1 billion ton shale oil Qingcheng Oilfield in 2019 was due to the breakthrough [16]of related oil recovery technologies such as frac flooding and simmused well imbibition.

Since the 1950s, foreign scholars began to study[17-21] the basic theory of imbibition displacement in fractured oil fields, obtained the relative permeability curve of displacement and imbibition type, proposed the double porosity medium model, analyzed the multiphase unstable flow in the double medium, and summarized the law of oil-water movement and imbibition mechanism. This provides a theoretical basis for the development of fracturing oil displacement technology in China. After four development stages of matrix imbibition, fracture matrix dynamic imbibition, energy storage and infiltration and fracturing displacement, China's fracturing oil displacement technology has been greatly improved.

3. The Key Technology of Fracturing Oil Displacement

3.1. Volumetric fracturing technology

At the end of the well, subdivision cutting volume fracturing technology is used to improve the degree of fracture control by limiting cluster perforation, dynamic temporary plugging and turning, increasing the reconstruction volume and other measures. Taking the reconstruction of shale oil reservoir in Qingcheng Oilfield of Ordos Basin as an example, the horizontal well spacing is 300~400 m, the horizontal section length is 1500~2000 m, the cluster spacing is reduced from 20~30 m to 5~10 m, and the seepage distance[22] is reduced. Using the variable-stick water-slip fracturing liquid system as the main body, the amount of fluid entering the ground in a single stage is 1500 m3 and the proppant is 140 m3. In terms of particle size, "small + medium + large" combination of quartz sand is used to ensure that the main fractures, branch fractures and micro-fractures can be supported at the full scale, so as to ensure long-term effective flow conductivity. In addition, the composite temporary plugging method of "temporary plugging agent + temporary plugging ball + temporary plugging knot" of different particle sizes and types is adopted, thus increasing the complexity of the joint network and improving the degree of crack control.

3.2. Fracture pressure water injection technology

Compared with conventional water injection, the displacement of pressurized water injection reaches 0.1-2.0 m^2/min. When injected near the fracture pressure (injection pressure is slightly higher than the fracture pressure), the rock stress increases, and the viscosity of clean water is lower than that of fracturing fluid, and a large number of micro-fractures are easy to form near the well during injection [23-24]. On the

other hand, a large amount of cold water is continuously injected into the formation to communicate natural fractures, while the low-temperature fluid produces thermal shock effect on the reservoir surface and locally generates strong tensile stress, resulting in a large number of micro-fractures in the rocks near the well, effectively expanding the swept volume [25-27].

3.3. Continuous high displacement water injection technology

Compared with conventional fracturing fluids, the lower the viscosity of injected water, the easier it is to percolate into the reservoir pores, resulting in increasing pore pressure, increasing the number of connected pores and throats, and increasing permeability and formation porosity to a certain extent[28]. Compared with conventional water flooding, pressure flooding adds new percolation channels and improves reservoir permeability. Conventional waterflooding often forms a "spindle shape" waterflood swept area; There are fractures at the bottom of injection-production Wells, and "fan-shaped" injection-production Wells are formed between the injection-production Wells, which greatly improves the effect range of injection. Compared with conventional water flooding, fracturing can add new seepage channels and improve the permeability of reservoir. Conventional water flooding often forms "spindle shape" water flooding swept area, while fracturing can form cracks at the bottom of injection-production Wells, thus forming "fan shape" water flooding swept area between injection-production Wells, which greatly improves the effect range of water flooding.

3.4. Injection of a large number of pre -fluid technology

In Qingcheng shale oil block of Changqing Oilfield, the pre-injection method of large liquidquantity is used to increase energy synchronously. The pre-injection fluid is injected first, and then the fracturing fluid is injected later for fracture-making and sand carrying. Or after normal fracturing is completed, a certain amount of pre-injection fluid is injected into the horizontal well to increase the energy after pressure, thereby increasing the formation pressure coefficient from 0.8 to 1.3, effectively making up for the disadvantage[15,22,29] of insufficient natural formation energy. After the construction, the effect of fracturing reform is obvious, which makes an important contribution to the stable production and storage of the oilfield.

3.5. The technique of imbibition and displacement of the braised well

Whether at the end of the well or the end of the well, after the completion of the construction will go through 15~60 days of braised well. In the process of well braising, under the action of rock capillary force, osmotic pressure caused by salinity, and clay mineral hydration expansion stress, oil and water imbibition occurs, oil and water displacement is fully realized in the fracture matrix, fracturing fluid enters small pores, and crude oil is replaced in high permeability areas such as pressure fractures, water saturation in the fracture gradually decreases, liquid period is shortened after well opening, and initial water cut is reduced[32,33]. Through the injection, transfer and diffusion of energy, oil-water imbibition replacement can improve the displacement efficiency[30].

3.6. Adding pressure displacement agent technology

Adding a chemical pressure flood agent is a very important step in the pressure flood injection process. This method can improve oil recovery effectively by using the principle of chemical flooding[34-35]. The commonly used pressure flooding agents include active pressure flooding agents, imbibition extraction agents and pressure flooding viscosity reducing agents. Active pressure flooding agents can change the reservoir wettability at the injection well end, which helps to increase the injection water at the near end of the injection well and control the flow at the far end. At the end of the well, it can change the reservoir wettability and reduce the adhesion of crude oil, which is conducive to oil stripping and improve oil recovery. It can also remove the oil-water boundary layer and expand the effective pore radius, making it easier for oil and water to flow.

In general, fracturing displacement technology can be summarized as "pressure" and "displacement" two technical mechanisms. Among them, "pressure" uses subdivision and cutting volume from the well end and continuous water injection from the well end to supplement the formation energy to achieve the effect of expanding the swept volume. The "drive" increases the oil washing efficiency by the way of imbibition displacement and pressure drive chemical agent, so as to improve the oil recovery.

4. Outlook

Fracturing displacement is a commonly used technology to increase oil and gas permeability by injecting high-pressure fluids to widen rock fractures. In the future, with the continuous improvement and innovation of technology, fracturing oil displacement technology will be more intelligent, efficient and environmentally friendly. Some of these include:

(1) Intelligence: The use of the Internet of Things, cloud computing and other technologies to achieve real-time monitoring and control of the fracturing process to improve production efficiency and safety.

(2) High efficiency: by optimizing the fracturing fluid formula and construction process, changing the fracturing method, improving the fracturing effect, while reducing resource consumption and cost.

(3) Environmental protection: the use of environmentally friendly fracturing fluid to reduce pollution to the environment, while using circulating water technology to achieve the conservation and reuse of water resources.

In summary, the future fracturing displacement technology is expected to improve oil and gas production at the same time, to achieve intelligence, high efficiency and environmental protection.

5. Summary

(1)According to the exploration and development history of low permeability tight reservoirs in major oil fields in China, it can be seen that the development of hydraulic fracturing and displacement technology of low permeability tight reservoirs in domestic oil fields in China has experienced four stages in the past few decades. The first stage is matrix imbibition oil-water displacement oil recovery, which mainly uses the permeability and adsorption capacity of the matrix to achieve oil-water displacement, so as to

achieve the purpose of oil recovery. The second stage is the fracture-matrix dynamic imbibition oil recovery, this stage introduces the fracture technology, through the construction of cracks to increase the permeability of the reservoir, so as to improve the mining efficiency. However, the sustainability of this method is in question due to the lack of fracture stability. The third stage is the fracture-mesh fracturing, which introduces the fracture-mesh fracturing technology to increase fracture stability and reservoir permeability by injecting solid particles and liquids into the fracture. This method can effectively improve oil recovery, but the cost is high. The fourth stage is the imbibition and oil displacement of frac flooding, this stage uses a variety of technical means, including fracturing technology, chemical pressure flooding agent, etc.

(2)According to the development history of pressure flooding in low permeability tight reservoirs in China, the technical characteristics of fracturing oil flooding are summarized in six aspects; ① volumetric fracturing technology; ② fracturing pressure water injection technology; ③continuous large displacement water injection technology; ④ injection of a large number of pre-fluid technology; ⑤ the technology of imbibition replacement for the braised well; ⑥Adding pressure displacing agent technology

(3) Combined with the development history of fracturing displacement technology, the future fracturing displacement technology is expected to improve oil and gas production at the same time, to achieve intelligence, high efficiency and environmental protection.

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