Experimental Study on ASP Flooding Horizontal-Vertical Joint Development

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Abstract. ASP flooding oil technology, as a highly concerned method for improving oil recovery in recent years, has the advantages of high oil displacement efficiency and good environmental protection. Horizontal-vertical joint development technology is a method of achieving efficient oil-field development by optimizing well network layout, adjusting injection production parameters, and other means. It improves the pressure field and flow field distribution inside the reservoir, enhances sweep efficiency and oil recovery efficiency, thereby achieving the goal of increasing crude oil recovery rate. This article aims to explore the combined application effect and mechanism of ASP flooding oil technology and horizontal-vertical joint development technology through experimental research, providing new ideas and methods for efficient development of oil fields. The joint application of ASP flooding oil technology and horizontal-vertical joint development technology provides a new approach for efficient oil-field development. This joint application can not only improve the recovery rate of crude oil, reduce development costs, but also help reduce environmental pollution and achieve the sustainability of oil-field development.

Key words: ASP flooding; Horizontal-vertical joint; Oil field

1. Introduction

With the sustained development of global economy and the continuous growth of population, the demand for energy is increasingly strong, in which oil, as the "industrial blood", occupies a decisive position in the energy structure. However, the traditional oil exploitation methods gradually show their limitations in the face of complex geological environment and increasing oil recovery requirements [2]. Therefore, exploring efficient and environmentally friendly new technologies for oil exploitation has become an important topic in the field of scientific research. ASP flooding oil technology, as a method to enhance oil recovery, has the advantages of high oil displacement efficiency and good environmental protection [2]. It reduces the interfacial tension between oil and water and improves the mobility ratio of oil and water by injecting a ternary composite system composed of alkali, surfactant and polymer into the formation, thus improving the oil recovery [3]. However, in practical application, a single ASP flooding oil technology is often difficult to meet the diversified needs under different geological conditions and mining requirements.

Horizontal-vertical joint development technology is a method to realize efficient oil-field development by optimizing well pattern layout and adjusting injection-production parameters [4]. It improves the sweep efficiency and oil displacement efficiency by improving the pressure field and flow field distribution in the reservoir, thus achieving the purpose of improving crude oil recovery [5]. In order to meet the increasing energy demand and meet the challenge of traditional oil exploitation methods, it is very important to explore and develop efficient new oil exploitation technologies. ASP flooding oil technology and horizontal-vertical joint development technology, as two potential EOR methods, have been widely concerned in the field of oil exploitation. The purpose of this article is to explore the joint application effect and mechanism of ASP flooding oil technology and horizontal-vertical joint development technology through experimental research, and provide new ideas and methods for efficient development of oil fields.

2. Principle and present situation of horizontal-vertical joint development technology

With the deepening of oil-field development, many old oil-fields are faced with problems such as decreasing production and increasing water cut. How to improve oil recovery and prolong the stable production period of oil-fields has become an urgent problem to be solved [6]. Horizontal-vertical combined technology is a comprehensive oil-field development strategy, which combines geological, engineering, economic and other factors to achieve efficient oil-field development by optimizing well pattern layout and adjusting injection-production parameters [7, 8]. Its core idea is to maximize the oil recovery under the premise of ensuring the economic benefits of the oil-field.

2.1 The principle of horizontal-vertical joint technology

The principles of horizontal-vertical joint development technology mainly include:
(1) Well pattern optimization: According to the geological characteristics and development requirements of the reservoir, the well pattern layout is planned reasonably, so that the parameters such as the distance between wells and the well pattern density can be optimized.
(2) Injection-production adjustment: By adjusting the working systems of water injection wells and oil production wells, such as water injection rate and oil production rate, the distribution of pressure field and flow field in the reservoir can be improved, and the flow and accumulation of crude oil can be promoted.
(3) Strata division: For multi-layer reservoirs, the balanced exploitation of each stratum is realized by reasonably dividing the development strata, so as to reduce interlayer interference and improve the overall oil recovery.
(4) Composite flooding: On the basis of water injection development, chemical flooding, thermal flooding and other composite flooding technologies are introduced to further improve the oil recovery.

2.2 Advantages and challenges of horizontal-vertical joint development technology

Horizontal-vertical joint development technology has the following advantages:
(1) Strong comprehensiveness: This technology comprehensively considers geological, engineering, economic and other factors, and can realize comprehensive optimization and efficient development of oil fields.
(2) Flexibility: According to different reservoir types and geological conditions, the corresponding horizontal-vertical joint development technical scheme can be formulated.
(3) Significant economic benefits: By implementing the horizontal-vertical joint development technology, the stable production period of the oil-field can be prolonged and the oil recovery rate can be improved.
However, horizontal-vertical joint development technology also faces some challenges in practical application:
(1) Technical complexity: This technology involves the comprehensive application of knowledge in many fields and various technical means, which requires higher professional quality and comprehensive ability of technicians.
(2) Higher investment cost: The implementation of horizontal-vertical joint development technology often requires higher investment cost, including the expenses of drilling, completion, water injection, oil production and other links.
(3) Environmental risk: In the process of implementing horizontal-vertical joint development technology, it may cause certain impact and damage to the environment, such as formation pressure change caused by water injection and environmental pollution caused by chemical oil displacement agents.

3. Methodology

In the traditional in-station treatment process, the external liquid first enters the three-phase separator. Three-phase separator is a device used to separate crude oil, natural gas and produced water into different phases [9]. This step is very important, because different phases need different treatment methods. After separation, the crude oil is sent to the export furnace by the export pump. The export furnace is used to heat crude oil to reduce its viscosity and improve its fluidity, thus facilitating transportation and storage. Moreover, the separated water is sent to the water mixing furnace through the water mixing pump. The water mixer heats the water and then mixes it back into the crude oil to reduce the viscosity of the crude oil and improve its fluidity. In the four-in-one treatment process, the foreign liquid from the station also enters the three-phase separator for separation first [10]. However, different from the traditional process, the separated crude oil and water no longer enter the export furnace and the water mixing furnace respectively, but directly enter a unified heating device. This equipment has the function of heating crude oil and water at the same time, thus eliminating the need for export furnace and water mixing furnace.
By integrating multiple functions into one device, the four-in-one processing flow greatly reduces the number of devices needed in the station [11]. Due to the reduction of the number of equipment, the investment and floor space required for the four-in-one treatment process are also reduced accordingly. The four-in-one processing flow improves the efficiency of in-station processing by simplifying the flow and improving the integration of equipment. This enables crude oil and water to be transported from the wellhead or gathering pipeline to the treatment station more quickly, and the treatment work can be completed more quickly. Reducing the number of equipment and simplifying the operation process not only reduces the risk of failure, but also helps to improve the safety of operation in the station. The comparison between the conventional process and the simplified process is shown in Figure 1.

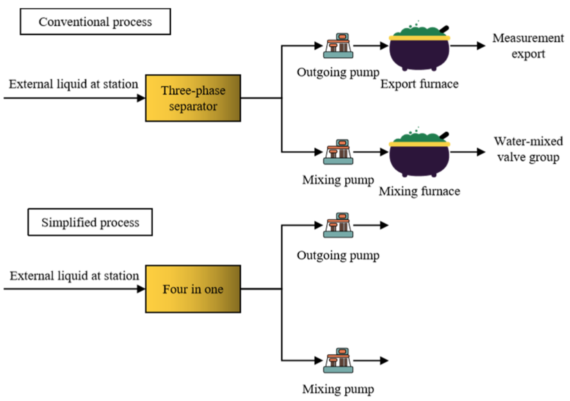

Figure 1 Comparison between conventional process and simplified process

In oil-field development, the combination span of strata refers to the vertical combination range of oil layers with different permeability, pressure, thickness and physical properties. The rationality of series combination is directly related to the development effect of oil-field [12]. An optimized layer series combination can balance the production pressure difference between oil layers, improve the overall liquid production, and thus realize the efficient development of the oil-field. When the combination span of layers is small, the pressure difference between oil layers is small, which is beneficial to the formation of stable pressure balance. This enables the production well to continuously produce under low pressure difference, and reduces the loss and energy consumption of equipment. In the case of multi-layer combined production, if the combination span of layers is too large, the pressure transmission between different oil layers will be blocked. When the high pressure layer transfers pressure to the low pressure layer, the pressure loss increases due to the large span, which reduces the production pressure difference of the low pressure layer and affects the liquid production.

The combination span limit of series refers to the maximum interval length of a set of series, which is closely related to the heterogeneity and sedimentary rhythm of the combined oil layers. For homogeneous reservoirs, it is assumed that a set of strata is composed of n sublayers, with the combined span of strata being L, the flowing pressure from each sublayer to the bottom of the oil well being $p_{w1}, p_{w2}, \dots, p_{wn}$, the static pressure of the formation being $p_{e1}, p_{e2}, \dots, p_{en}$, and the total output of the oil well being Q. Formulas for horizontal radial flow production of oil wells and multiphase pipe flow in wellbore:

$$Q_n = \frac{2\pi K h\left(p_{e(n)} - p_{w(n)}\right)}{\mu \ln(r_e/r_w)} \quad (1)$$

$$P_{e(n)} = P_{e(n-1)} + \frac{h(n-1)+h(n)}{2} \rho_w g \quad (2)$$

$$p_{w(n)} = p_{w(n-1)} + \int_0^{\frac{h(n-1)+h(n)}{2}} \left[\rho_m g + f_m \frac{\rho_m}{d} \cdot \frac{v_o^2}{2}\right] \quad (3)$$

It is deduced that the relationship between the total liquid production Q of oil wells and the combination span L of strata is as follows:

$$Q = \frac{2\pi K h}{\mu \ln(r_e/r_w)} \left[n(p_{e1} - p_{w1}) + (2^{n-1} - 1) h \times \left(\rho_w g - \rho_m g - f_m \frac{\rho_m}{d} \cdot \frac{v_o^2}{2}\right)\right] \quad (4)$$

Let $L = nh$, in the ultra-high water content stage $\rho_w \approx \rho_m$, the above equation can be simplified as:

$$Q = \frac{2\pi K h}{\mu \ln(r_e/r_w)} \times \left[n(p_{e1} - p_{w1}) - \frac{(2^{n-1}-1)L}{n} \left(f_m \frac{\rho_m}{d} \cdot \frac{v_o^2}{2}\right)\right] \quad (5)$$

According to the above theory, the combination span of strata mainly affects the liquid production by affecting the production pressure difference, and then affects the development effect.

The information gain of attribute A is defined as:

$$Gain(A) = I(s_1, s_2, \dots, s_m) - E(A) \quad (6)$$

Where $I(s_1, s_2, \dots, s_m)$ is determined by the entropy of the sample and is defined as:

$$I(s_1, s_2, \dots, s_m) = -\sum_{i=1}^{m} P(C_i) \log_2 P(C_i) \quad (7)$$

Where $P(C_i)$ is the probability that any sample belongs to C_i; m represents the number of sample categories; s_i is the number of samples belonging to class C_i; s is the total sample data.

Proper production pressure difference can ensure the effective flow of crude oil in the formation, thus improving the liquid production. Excessive production pressure difference may accelerate sand production and compaction of formation, resulting in formation damage and productivity decline. Therefore, it is of great significance to control the production pressure difference in a suitable range through reasonable layer series combination to protect strata and maintain productivity. For oil fields that need energy supplement (such as water injection development oil fields), the production pressure difference also affects the water injection effect. Appropriate pressure difference is helpful to the uniform advancement of water injection and effective replenishment of formation energy, thus increasing the liquid production.

4. Case analysis

In petroleum engineering, heterogeneous reservoir is a common challenge. The permeability of these reservoirs changes in different positions and directions, which leads to uneven fluid flow and increases the difficulty of production. For heterogeneous reservoirs, models with different permeability ratio are established, including positive and negative rhythms and compound rhythms (permeability is 180×10^{-3}~$600\times10^{-3}\mu m^2$). The numerical simulation results of the ideal model show that for this kind of heterogeneous oil layer, the upper limit of the combined span of layers is about 60 m. This means that in the process of exploitation, the combination span of strata should be avoided as much as possible to ensure that the fluid can flow out of the reservoir more effectively. This discovery is of great significance for optimizing well location layout and formulating reasonable mining strategy. Through these numerical simulation studies, petroleum engineers can understand the characteristics of heterogeneous reservoirs more deeply, and then design more effective production schemes (Figures 2 and 3).

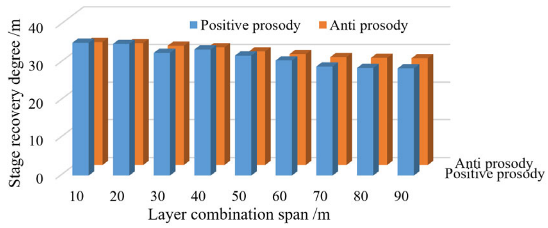

Figure 2 Relationship between formation and span of oil layers with different rhythms and development effect

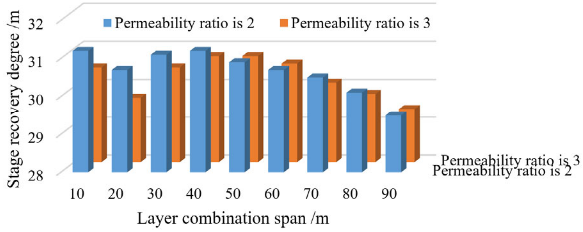

Figure 3 The relationship between the formation and span of different permeability ratio oil layers and the development effect

In petroleum industry, sedimentation process is an important step to treat oily wastewater, and its main purpose is to separate oil from water by gravity. In order to optimize this process and determine the minimum effective liquid level of sequencing batch sedimentation process in the oil collection stage, a manual liquid level reduction experiment was carried out. The experiment was carried out in a settling tank with a designed minimum liquid level of 3.0 meters. According to the sequencing batch sedimentation mode, the tank usually starts to produce water after reaching this level. In this experiment, the researchers continued to manually lower the liquid level after the effluent was finished to observe the effect of doing so on the effluent. The test results are shown in Table 1.

Table 1 Minimum liquid level test data of sequencing batch settling tank

Distance between liquid level and tank bottom/m	3.2	2.6	2.4
Sedimentation effluent ρ (oil)/(mg L^{-1})	19.8	20.6	17.5

The results show that when the settling tank reaches the designed minimum liquid level (3.0 meters), the oil mass concentration of the settled water is 19.8 mg/L. This shows that under normal circumstances, the system can effectively remove most of the oil in wastewater. When the liquid level is further reduced by 0.8m (at this time, the liquid level is the same as the elevation of the main settling water pipe, so it cannot be further reduced), the oil mass concentration of the settling water is reduced to 17.5mg/L.. This result shows that the system can still effectively remove oil from wastewater even if it is lower than the designed minimum liquid level.

As an important treatment equipment, sequencing batch settling tank is equipped with floating oil collection system, aiming at recovering oil from wastewater to the maximum extent. By detecting the oil content of the recovered liquid, important information about the oil discharge of the floating oil collection system of sequencing batch settling tank can be obtained. From the results shown in Table 2, the system has shown remarkable effect in the process of oil discharge for 4 hours.

Table 2 Floating oil collection effect of sequencing batch settling tank

Oil drain time /h	0	0.5	1.0	2.0	3.0	4.0
Sedimentation effluent ρ (oil)/(mg L^{-1})	355	28.2×10^4	18.5×10^4	3.51×10^4	2411	259

In the initial stage of the oil discharge process, that is, within 1 hour, the oil content in the recovered liquid quickly reached more than 20%. This shows that the floating oil collection system can recover oil from wastewater very efficiently at the beginning. With the process of oil drainage, the oil content in the recovered liquid gradually increases. After 4 hours, the oil content in the recovered liquid tends to be stable. Within 4 hours, the floating oil collection system has completed most of the oil recovery work. This also means that the system has high treatment capacity and can treat a large amount of oily wastewater in a relatively short time. By effectively recovering and treating these oils, the petroleum industry can not only reduce the potential pollution to the environment, but also realize the recycling of resources, thus reducing costs and improving economic benefits.

5. Conclusion

In the face of complex geological environment and increasing oil recovery requirements, traditional oil exploitation methods gradually show their limitations. Therefore, this article discusses the joint application effect and mechanism of ASP flooding oil technology and horizontal-vertical joint development technology through experiments. The combination of these two technologies provides new ideas and methods for efficient development of oil fields, which has important theoretical and practical significance. ASP flooding oil technology is an innovative oil displacement method. By injecting a specific combination of chemicals, the viscosity of crude oil is effectively reduced, and its fluidity is improved, thus increasing the oil recovery. Horizontal-vertical joint development technology realizes efficient development of oil field by optimizing well pattern layout and injection-production parameters. This technology makes full use of the heterogeneity of geological reservoirs, and through reasonable injection-production strategy, it maximizes the oil recovery, while reducing development costs and environmental risks. The joint application of ASP flooding oil technology and horizontal-vertical joint development technology provides a new way for efficient oil-field development. This combined application can not only improve the oil recovery and reduce the development cost, but also help to reduce environmental pollution and realize the sustainability of oil-field development.

References

1. Ge Y, Li S, Zhang X. Optimization for ASP flooding based on adaptive rationalized Haar function approximation[J]. Chinese Journal of Chemical Engineering, 2018, 26(8):1758-1765.
2. Liu Z, Li S, Guo L, et al. Integrated spatiotemporal modeling and mixed-integer approximate dynamic programming for ASP flooding[J]. Journal of Process Control, 2021, 105(2):179-203.
3. Ghosh P, Sharma H, Mohanty K K. ASP flooding in tight carbonate rocks[J]. Fuel, 2019, 241(5):653-668.
4. Ruan Q. Experimental analysis of the detection effect of yeast on high concentration ASP flooding wastewater[J]. Boletin Tecnico/Technical Bulletin, 2017, 55(15):546-553.
5. Ge Y, Li S, Chang P, et al. Optimization of ASP flooding based on dynamic scale IDP with mixed-integer[J]. Applied Mathematical Modelling, 2017, 44(4):727-742.
6. Dawei Z, Zhongxi C, Lu R, et al. Study on stability of produced water in ASP flooding based on critical micellar theory[J]. Polymer bulletin, 2022, 2022(1):79.
7. A M W, B M Z A, B X L. Adsorptive removal of oil drops from ASP flooding-produced water by polyether polysiloxane-grafted ZIF-8[J]. Powder Technology, 2021, 378(5):76-84.
8. Li J, Wang H, Hu J, et al. Development Performance and Pressure Field Evolution of ASP Flooding[J]. Advances in Polymer Technology, 2020, 2020(11):1-22.
9. Li S, Ge Y. A Numerical Computation Approach for the Optimal Control of ASP Flooding Based on Adaptive Strategies[J]. Mathematical Problems in Engineering, 2018, 2018(6):1-13.
10. Pashapouryeganeh F, Zargar G, Kadkhodaie A, et al. Experimental evaluation of designed and synthesized Alkaline-Surfactant-polymer (ASP) for chemical flooding in carbonate reservoirs[J]. Fuel, 2022, 321(2):124090.
11. Biyanto T R, Matradji, Sawal, et al. Application of Killer Whale Algorithm in ASP EOR Optimization[J]. Procedia Computer Science, 2017, 124(5):158-166.
12. Sui X, Chen Z, Kurnia I, et al. Alkaline-surfactant-polymer flooding of active oil under reservoir conditions[J]. Fuel, 2019, 262(2):116647.