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Research on water injection development mode and technical countermeasures of bottom water reservoir

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Abstract

Bottom water reservoir is an important reservoir type in China, and its efficient development is of great significance for increasing reserves and production. In view of the problems of rapid energy attenuation, water flooding caused by bottom water coning and low recovery rate in the development of such reservoirs, this paper summarizes the principles and applications of conventional water injection and formation gravity water injection. On this basis, the technical countermeasures with the core of optimizing water injection parameters, reasonably selecting water injection mode and real-time dynamic adjustment are put forward to supplement formation energy, inhibit water coning and improve oil displacement efficiency. The case analysis shows that the implementation of targeted water injection technology can effectively enhance oil recovery and prolong the economic life of the oilfield. This paper summarizes the relevant research results, and points out that it is necessary to continue to deepen the innovation and research of water injection development technology in the future, so as to cope with the increasingly complex challenges in the middle and late stages of development and provide support for the efficient development of bottom water reservoirs.

Keywords

Bottom water reservoir; conventional water injection; formation gravity water injection; technical countermeasures

1. Introduction

With the continuous growth of global energy demand, the efficient development of oil resources is particularly important. Bottom water reservoir plays an important role in oilfield development. However, due to its special geological conditions, such as bottom water coning and water channeling, it faces many challenges in the development process. These challenges not only affect the economic benefits of the reservoir, but also limit the further improvement of oil recovery[1]. Therefore, it is of great significance to study reasonable water injection methods and development technology countermeasures to im-

prove the development efficiency of bottom water reservoirs. At present, domestic and foreign scholars have carried out a lot of research on the water injection development technology of bottom water reservoir, and have made some progress. However, there are still many problems in the practical application of the existing technology, such as the choice of water injection timing, the control of water injection rate, the optimal layout of well network, etc., which seriously restrict the development effect of bottom water reservoir. Therefore, this study aims to deeply analyze the geological characteristics of bottom water reservoirs, explore reasonable water injection methods, and propose effective development technology countermeasures in order to achieve the purpose of improving reservoir development efficiency and recovery rate[2]. With the oilfield development entering the middle and late stages, water injection technology has become an important means of bottom water reservoir development.

2. Water injection development principle of bottom water reservoir

Water injection development of bottom water reservoir is a technical method to improve oil recovery by injecting water into the reservoir to supplement formation energy, change pressure distribution and fluid flow state. According to the different water sources and driving methods, it is mainly divided into two types : external water injection development and formation artesian water injection development[3].

2.1. Development principle of injecting external water

By artificially injecting external water sources (such as seawater, fresh water or treated produced water) into the reservoir, the main principle is to supplement energy and improve oil recovery. With the exploitation of crude oil, the formation pressure decreases naturally, resulting in poor fluidity of crude oil and reduced production. Water injection can effectively supplement formation energy, restore or maintain reservoir pressure, provide continuous power for crude oil flow, and ensure production stability. The injected water is pushed forward in the pores of the reservoir, which can physically replace the crude oil on the rock surface and drive it to the production well. This process can not only improve the microscopic oil washing efficiency, but also expand the sweep range of injected water, reduce the retention of crude oil, and thus enhance the macroscopic recovery factor.

2.2. The principle of formation artesian water injection development

This method does not rely on external water injection equipment, but uses the natural pressure difference between the natural water source layer (such as active bottom water or edge water) and the reservoir, so that the water flows naturally into the reservoir area under the pressure difference drive. Its core principles and functions include supplementing energy, regulating water ridges and enhancing oil recovery[4]. Mining leads to a decrease in reservoir pressure, which forms a pressure difference between the reservoir and

the external water source layer. Under the action of this pressure difference, the water in the water source layer flows automatically to the low-pressure reservoir area, realizing the natural supplement of energy and delaying the pressure decline. In the bottom water reservoir, through reasonable well pattern and production system, gravity water injection can adjust the rising speed of bottom water, inhibit the premature coning of bottom water or the rapid breakthrough of ' water ridge ' to the production well, so as to avoid the sudden water flooding of oil wel[5-6]. In the late stage of natural energy shortage or development, artesian water injection provides a relatively low-cost continuous energy replenishment method, which helps to use remaining crude oil more effectively and improve the ultimate recovery of the reservoir.

3. Influencing factors of water injection development in bottom water reservoir

3.1. Bottom water coning

Bottom water coning refers to that in the process of water injection development, due to the pressure of the water body at the bottom of the reservoir, the water body coning upward along the high permeability path, and finally breaks through the oil-water interface into the oil layer, resulting in water production in the oil well. Bottom water coning is usually related to the geological characteristics of the reservoir, such as fracture development, bottom water activity and reservoir heterogeneity. In the reservoir with better fracture development, the bottom water coning speed may be faster, and the water production rate of the oil well will gradually increase, which will reduce the oil production of the oil well, which will adversely affect the effect of water injection development. Therefore, in the process of water injection development, it is necessary to pay close attention to the situation of bottom water coning and take corresponding measures to control and adjust[7-8].

3.2. Gas-water channeling in water injection process

Gas-water channeling is also an important factor in the process of water injection. Gas-water channeling during water injection refers to the mixing of injected water and original oil and gas to form uneven flow, resulting in oil and gas breaking through the production boundary of production wells in advance. It even affects the mining effect of the whole reservoir. In order to prevent the occurrence of gas water channeling, it is necessary to carry out detailed geological research and prediction of the reservoir before water injection development, and formulate reasonable water injection schemes and measures.

3.3. Difference of gas-water interface

The difference of gas-water interface will also affect the effect of water injection development, which is caused by the heterogeneity of reservoir, the existence of fracture net-

work or the complexity of geological structure. Due to the complex and changeable geological conditions of bottom water reservoirs, there may be large differences in gas-water interfaces. This difference may lead to uneven distribution of fluid in the process of water injection, thus affecting the effect of water injection. The inhomogeneity of gas-water interface increases the difficulty of dynamic monitoring and prediction of oil and gas reservoirs, which may lead to inaccurate development strategies[9]. It is necessary to adjust the water injection strategy according to the actual distribution of the gas-water interface, such as changing the location of the water injection well, the water injection rate or adopting selective water injection. Therefore, in the process of water injection development, it is necessary to carefully monitor and adjust the gas-water interface to ensure the smooth progress of water injection development.

4. Water injection development technology countermeasures of bottom water gas reservoir

In the process of water injection, it is necessary to strictly control the parameters such as water injection volume, water injection speed and water injection pressure to ensure the best water injection effect. At the same time, it is necessary to monitor the water injection process in real time, including the monitoring of pressure, temperature, flow and other parameters, so as to adjust the water injection strategy in time.

4.1. Optimization of water injection parameters

4.1.1. Control the speed of water injection

In the water injection development of bottom water reservoirs, adjusting the water injection rate is an important means to optimize reservoir management and improve oil recovery. By adjusting the speed of water injection, the propulsion rate of water body can be controlled to avoid or slow down the impact of water invasion on oil well productivity.

4.1.2. Adjust water injection pressure

In the process of water injection, the injection pressure can indirectly reflect the plugging of water channel between injection and production wells. By adjusting the water injection pressure, the distribution of formation energy can be optimized and the development efficiency of the reservoir can be improved[10]. For ultra-low permeability reservoirs, the use of large differential pressure asymmetric coupling injection-production technology, that is, pressure-driven water injection, can solve the problem of untapped reserves development, and greatly improve the injection capacity and oil well production ; improving the bottom hole pressure of production wells, plugging water invasion channels, and reducing bottom water energy can effectively inhibit bottom water, thereby improving the effect of water injection development. However, too high water injection pressure may lead to formation fracture, while too low water injection pressure may not achieve the expected development effect. Therefore, in the process of water injection, it is necessary to monitor the changes of water injection pressure and formation pressure in real time,

adjust the amount of water injection according to the actual situation, and keep the water injection pressure within a reasonable range.

4.1.3. Regulation of water injection

In the process of water injection development of bottom water reservoir, the regulation of water injection volume is a crucial link, which directly affects the oil recovery, development effect and economic benefit. The regulation of water injection volume mainly includes water injection timing and water injection rate; well pattern optimization : the start time of water injection has a significant impact on the effect of oilfield development. According to the natural energy size, geological characteristics and economic benefits of the reservoir, the best timing of water injection is determined.

The control of water injection rate is very important for maintaining reservoir pressure and improving oil recovery. Reasonable water injection rate can slow down the non-uniform invasion of bottom water and achieve balanced mining. By optimizing the layout of water injection wells and production wells, the water injection rate can be controlled more effectively and the development efficiency of the reservoir can be improved.

4.2. Selection of reasonable way of water injection

4.2.1. Water injection at different locations

The selection of water injection methods for bottom water gas reservoirs is mainly based on geological characteristics, mining objectives and economic benefits, as well as the convenience and feasibility of operation and management. Common water injection methods for bottom water gas reservoirs include edge water injection, central water injection, annular water injection and point water injection.Table 1 shows the advantages and disadvantages of different water injection positions and their applicable conditions[11].

Table 1. Comparison of advantages and disadvantages of different water injection positions

The way of water injection	Advantages	Disadvantages	Applicability
Edge water injection	uniform displacement ; the pressure is maintained well ; effective suppression of water cone	Slow effect ; high engineering quantity and cost	The reservoir is stable and the structure is gentle.
Central water injection	Quick effect ; the well pattern is relatively simple.	Uneven spread ; high risk of central well	The structure is relatively complete, the shape is approximately circular, and the reservoir homogeneity is good.
peripheral injection	Strong pertinence ; the water control effect is good	The well pattern is complex ; management is difficult.	Bottom water gas reservoir with strong heterogeneity, large area and multiple pressure systems.
Point water injection	The effect is very fast ; high accuracy	High risk, improper design is easy to form dead gas area	The heterogeneity is very strong, and there are gas reservoirs with local high permeability zone or serious water cone.

When choosing a specific water injection method, other factors such as formation conditions, fluid properties, and mining history need to be considered. In addition, with the

progress of science and technology and the accumulation of experience, new water injection methods and technologies are constantly emerging. Therefore, in practical application, we should innovate and try to achieve the best development effect and economic benefit according to the specific situation.

4.2.2. Horizontal well water injection

Water injection in horizontal wells is a kind of oil recovery technology to increase reservoir pressure and displace crude oil by injecting water into horizontal wells. It is mainly used in the middle and late stages of reservoir exploitation, and has a significant effect on solving the problems in the process of horizontal well drilling, completion and reservoir exploitation. This technology has the advantages of reducing costs, improving production efficiency and increasing reserves. By injecting water into horizontal wells, the overall pressure of the reservoir can be increased, thereby promoting the flow and production of crude oil. The injected water can push the crude oil out of the wellhead, so that the crude oil can be produced more fully and the recovery rate can be improved. At the same time, appropriate water injection can form a pressure balance to prevent excessive water flooding into the reservoir and protect oilfield resources[12].

Compared with the traditional oil recovery process, the horizontal well water injection process has significant advantages, such as reducing water flooding and increasing oil recovery efficiency. However, it also faces some challenges and problems, such as high construction complexity and inaccurate water injection control. Therefore, it is necessary to conduct in-depth analysis and research in practical applications to better utilize its advantages and solve existing problems.

4.3. Real-time optimization of water injection scheme

4.3.1. Establish a dynamic monitoring system

The dynamic monitoring system of water injection development is the key to ensure the safety and efficiency of water injection and optimize the development effect. The system realizes the whole process control by real-time monitoring and analysis of water injection wells, formation pressure and fluid flow state. The monitoring of water injection wells is the core. Through real-time acquisition of pressure, flow and other data, we can grasp their working status and find problems in time. Formation pressure monitoring directly reflects the water injection effect and formation stability, and provides a basis for evaluating the effect and adjusting the scheme. Fluid monitoring uses tracer, logging and other technologies to track underground fluid flow and oil-water interface changes to guide water injection optimization. In addition, it is necessary to establish a reliable data transmission network to realize real-time sharing of monitoring data, and to analyze and process with professional software to extract key information to scientifically support development decision-making and dynamic adjustment.

4.3.2. Adjust water injection development strategy

According to the results of problem diagnosis and identification, the corresponding strategy adjustment and optimization measures are formulated. This may include adjusting water injection pressure, water injection volume and water injection rate, optimizing the layout and number of water injection wells, and taking other technical measures to improve the effect of water injection development[13]. Develop a detailed implementation plan, including the specific value of the adjustment parameters, operation steps and time arrangements. Ensure that the implementation plan is operable and implementable. According to the implementation plan, the water injection development strategy is adjusted, and the changes of key parameters such as formation pressure and fluid flow state are continuously monitored. Through real-time monitoring and data feedback, ensure the effectiveness of the adjustment measures, and according to the actual situation of the necessary fine-tuning.

5. Problems and challenges faced by water injection development

5.1. Uneven displacement

The permeability difference inside the reservoir is large, and the injected water will preferentially break through to the production well along the high permeability strip with the smallest resistance, resulting in high water cut or even water flooding of the oil well soon, while the low permeability area has no water, and the crude oil cannot be driven out[14]. The key is to shift from ' general water injection ' to ' precise targeting ' regulation. It is also an important means to block high permeability channels by chemical flooding, or to change the direction of water flow by reconstructing injection-production well network.

5.2. Bottom water interference

For the bottom water reservoir, the pressure drop caused by production will make the bottom water coning upward, resulting in violent flooding of oil wells. In the later stage of development, the injected water may form a joint force with the active edge and bottom water, which further aggravates the flooding. The core is to control the water cone shape and supplement energy. The frontier method includes CO2 injection or nitrogen injection. The former can supplement energy and push the bottom water back, while the latter can break through the water cone and reconstruct the airflow channel[15].

5.3. Economic and environmental challenges

Fine water injection, advanced monitoring and treatment technologies mean higher investment and operating costs. In the period of low oil prices, how to ensure the economic benefits of technology investment is a major challenge. How to effectively integrate multi-source heterogeneous data such as geology, earthquake, production and monitoring, and use big data and artificial intelligence technology to realize intelligent optimization of water injection is the future research direction. The treatment and reinjection of produced water need to meet increasingly stringent environmental regulations to prevent

groundwater pollution.

6. Conclusion

(1) Water injection development mainly includes external water injection development and formation artesian water injection development. By supplementing the formation energy and improving the principle and function of reservoir recovery, compared with the development of external water injection, the economic benefit of formation artesian water injection is higher, but the specific choice of water injection mode should be combined with the actual geological conditions of the reservoir.

(2) The main influencing factors of water injection development in bottom water reservoirs include bottom water coning, gas-water channeling during water injection and the difference of gas-water interface. In view of water injection development, this paper puts forward the development strategy of optimizing water injection parameters and selecting reasonable water injection mode.

(3) Water injection development mainly faces the problems of uneven displacement and bottom water energy interference and coning caused by layer heterogeneity, and also faces major challenges in economy and environment.

References

[1] Zhang ,W. Long, M. Zhou Y B, et al. Establishment and application of waterflooding development chart for bottom water reservoir without interlayer [J]. Special reservoirs, 2020,27 (2) : 115-119. DOI : 10.3969 / j.issn.1006-6535.2020.02.018.

[2] Dang S S, Sun Z X, Pei S, et al.. Layered water injection control of multi-layer sandstone reservoirs in Hutubi Formation of Luliang Oilfield [J].Xinjiang Petroleum Geology, 2023,44 (4) : 465-471, DOI : 10.7657 / XJPG20230411.

[3] Su H Y, Mu L X, Han H Y, et al.Analysis of the mechanism and influencing factors of gravity water injection [J].Petroleum exploration and development, 2015,42 (5) : 632-637. DOI : 10.11698 / PED.2015.05.10.

[4] Liu X Z, hang L J, Yang Z P, et al. Analysis of artesian water injection development and influencing factors [J]. Daqing Petroleum Geology and Development, 2013,32 (6) : 67-70. DOI : 10.3969 / J.ISSN.1000-3754.2013.06.014.

[5] Tang Y L, Wang Q, Li E P, et al. Feasibility of gravity water injection technology for Bachu Formation reservoir in Tazhong 4 oilfield [J]. Xinjiang Petroleum Geology, 2016,37 (1) : 74-77. DOI : 10.7657 / XJPG20160114.

[6] Zheng X J, Zhong W, Duan H Z, et al. Feasibility study on waterflooding development of strong bottom water reservoir [J]. Fault block oil and gas field, 2015,22 (2) : 234-236,250. DOI : 10.6056 / dkyqt201502022.

[7] Sun E H, Guo J M, Tan Jie, et al. Analysis of influencing factors of waterflooding development of bottom water reservoir with interlayer [J]. Journal of Chongqing University of Science and Technology (Natural Science Edition), 2020,22 (04) : 30-34 + 69.DOI : 10.19406 / j.cnki.cqkjxyxbzkb.2020.04.007.

[8] Huang C J, Wu D X, Wang J Y, et al. Evaluation of water injection development effect of Jurassic edge and bottom water reservoir [J].Petrochemical application, 2015,34 (03) : 55-57 + 62.

[9] Jiang Y L, Tian S C, Tang X M.Influencing factors of water injection development in gas cap and bottom water reservoir-Taking Wei 8 fault block as an example [J].Petroleum Journal, 2012, 33 (2) : 284-287.

[10] Duan J J, Li J, Yao Z J, et al. Water injection development characteristics and water injection optimization of bottom water reservoirs in Yan 'an Formation-Taking Block D as an example [J].Petrochemical Technology, 2017,24 (5) : 80. DOI : 10.3969 / j.issn.1006-0235.2017.05.061.

[11] Zheng S Q, Kang Z J, Cheng X J, et al. Water flooding development characteristics and improvement measures of fractured-vuggy carbonate reservoirs in Tahe Oilfield [J].Oil and gas geology and recovery, 2022,29 (6) : 95-104. DOI : 10.13673 / j.cnki.cn37-1359 / te.202201022.

[12] Jin X, Qu L R, Zhang T, et al. Study on the water breakthrough law and its main controlling factors of low permeability reservoirs with edge and bottom water in waterflooding development-Taking BLC oil area in Ordos Basin as an example [C]. / / 2020 International Conference on Oil and Gas Field Exploration and Development (IFEDC2020) Proceedings. 2020 : 1-13. 10.3969 / j.issn.1006-0235.2017.05.061.

[13] Sun E H, Yang D D, Yang W, et al. Numerical simulation study on the influence of interlayer parameters on the water injection effect of bottom water reservoir-taking Bohai A reservoir as an example [J].Petroleum Geology and Engineering, 2020,34 (3) : 71-75. DOI : 10.3969 / j.issn.1673-8217.2020.03.014.

[14] Zhang Y F, Zeng X, Luo E H, etc. Study on injection-production mechanism of complex fault-block reservoirs based on water-flooded characteristic zoning [J].Western prospecting project, 2024,36 (09) : 64-67.

[15] Song Z J, Zeng D G, Han X, etc. The experimental mechanism of water invasion and CO2 injection to control water cut and enhance oil recovery in carbonate gas reservoir with edge water-taking Puguang gas reservoir as an example [J].Fault block oil and gas field, 2025,32 (04) : 676-684.