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Research Progress on Injection Allocation and Regulation Methods of Injection Wells

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Abstract: Based on the research of the above problems, from the four aspects of calculating recoverable reserves, formulating reasonable well pattern forms, calculating the allocation amount and regulating measures, the corresponding calculation methods are summarized, and the principles, application steps, calculation formulas and conditions applicable to different reservoirs of each method are explained in detail. This paper provides a theoretical basis and foundation for further research on injection well matching and regulation methods, alleviating environmental pressure and achieving sustainable development.

Keywords: Water Injection Development; Reasonable Allocation; Regulatory Measures.

1. Introduction

With the advancement of science and the development of the petroleum industry, a large number of methods have been derived for the rational allocation of oil field injection. However, in actual oil field production, there is no detailed knowledge system to summarize, integrate and classify these methods as a detailed plan to guide the development of oil field water injection. This leads to many problems arising in the process of water injection development not being effectively solved, and sometimes even the wrong water injection method is used, which ultimately leads to problems such as low production efficiency. By consulting a large number of literature, this paper summarizes various methods and calculation formulas in oil field water injection production, classifies water injection methods according to different situations in actual oil field production, and optimizes reasonable injection methods. Finally, a knowledge document on injection well allocation and production regulation are formed, providing solutions and program designs for various situations that may arise in water injection development.

2. Current Status of Research on Injection Well Allocation

2.1. Current Status of Foreign Research

From the 1930s to the 1950s, water flooding technology began to appear in major oil fields[1], as water flooding technology matures, it is widely used in various oil fields. From the 1960s to the 1980s, with the in-depth study of water injection technology, high-efficiency water flooding technology has been widely used. These technologies include improving the layout of water injection wells and improving the operation of water injection wells. These technologies have significantly improved the water injection effect and oil field recovery rate.

In 1981, Chu [2] studied the effects of reservoir parameters including permeability, porosity, thickness and compressibility on the pressure of observation wells in layered reservoirs. The study found that pressure would lead to the occurrence of interlayer interference phenomena. Based on this study, reasonable technical policy boundaries for layer subdivision were established.

In 2010, E.J. McKay et al.[3] studied the selection of injection water based on the redevelopment of the Froy oil field and ultimately chose seawater as injection water, thus saving a lot of operating expenses. In 2015, Espinola combined water injection, oil field development and artificial lift analysis through surface and underground coupling models to determine the best production strategy. In October of the same year, Osod published a paper titled Research on Injection Water Compatibility and Scale Prediction Analysis for Optimization of Low Permeability Carbonate Reservoir Development at the SPE Kuwait and Natural Gas Exhibition Conference[4], which deeply evaluated the risk of inorganic scale deposition during water injection in undeveloped carbonate reservoirs with high-salinity brine (TDS-205g/L).

In 2021, Fitri Ramli[5] proposed an alternative method for evaluating the optimal number of injection wells and filling wells in oil field development plans. He selected the optimal number of filling wells and injection wells through a numerical method of incremental recovery and multi-objective optimization using auxiliary history matching and uncertainty tools. This method reduced the number of numerical simulations and improved the efficiency of oil field exploitation.

In 2023, Ranjit Singh conducted two short-term injection tests and one long-term injection test on the ABH oil field. The results showed that injection pressure, well design and mode selection are crucial for designing water flooding in low permeability reservoirs of hydraulic fracturing wells[6], because injection pressure, well design and mode selection affect the effective permeability of the reservoir.

2.2. Research State in China

The development of domestic water injection development technology has undergone a process of continuous progress and innovation. First of all, at the technical level, water injection development technology has been significantly improved and improved in China. With the improvement of oil field recovery rate, the initial water injection effect gradually weakened, so improving the water injection effect has become the focus of current water injection technology research. Domestic research institutions and enterprises have invested their efforts and vigorously carried out research on the optimization of water injection effects, aiming to improve the water injection effect of oil wells. For example, the types of water injection agents are becoming diversified to meet the needs of different reservoir conditions, achieve better profile adjustment effects, and inhibit the diffusion of water areas. In 1980, Hu Futang et al. [7] proposed a one-dimensional two-phase estimation method for areal water injection in order to improve the level of oilfield development. In 1985, Zhang Rui[8]proposed the idea of using dimensionless production curves to calculate the final development index of oil fields. In 1990, Yu Hongwen[9] proposed a method to calculate the stratified liquid production of oil wells by the stratified water injection volume of water injection wells based on the principle of injection-production balance, reservoir geology, oil displacement and production conditions. In 2000, Yu Qitai et al. proposed a feasibility evaluation formula for cyclic water injection based on the cross-permeability theory of intra-layer elasticity and capillary force of cyclic water injection[10]. In 2005, Liu Yujuan[11] gave the impact of different water injection methods on oil field development. In 2008, Xiu Nailing[12] et al. proposed the relationship between the effective time of unstable seepage water injection in low permeability reservoirs and the well spacing. In 2012, Tan Songtao [13] proposed a method to improve the efficiency of oil field water injection system. In 2018, Liu Honglan[14] proposed a new technology for integrated measurement and adjustment of stratified water injection wells. In 2022, Ren Zhilong et al. [15] proposed an innovative new water injection technology based on the oil layer blockage mechanism of water injection wells. In 2024, Zhu Chengtao designed the oil field injection intelligent control software[16] to monitor and control each injection layer in real time and achieve fine injection.

3. Injection Well Matching and Regulated Production Scheme

3.1. Calculate Recoverable Reserves

Recoverable reserves are calculated to determine how much oil and gas can be produced in an oil and gas field. This helps engineers and managers evaluate the value of the oilfield, formulate a production plan, allocate resources reasonably, improve efficiency, reduce costs, and ensure long-term stable production of the oilfield. The methods for calculating recoverable reserves in the initial stage of development include: empirical formula method and analogy method.

1. Empirical formula method:

(1) Formula 1 (applicable to water-flooded sandstone reservoirs):

$$E_R = 0.274 - 0.1116\, lg\, \mu_R + 0.09746\, lg\, K - 0.0001802 h_{oe} f - 0.06741 V_k + 0.0001675 T \tag{1}$$

In the formula: K is the average permeability, 10^{-3}μm^2; f is the coefficient of variation, VK; T is the oil layer temperature, °C; μ_R is the oil-water viscosity ratio; h is the average effective thickness, m.

(2) Formula 2 (applicable to water-flooded sandstone reservoirs):

$$E_R = 0.05842 + 0.08461\, lg\left(\frac{k_a}{\mu_0}\right) + 0.3464\phi + 0.003871 f \tag{2}$$

Where: K is permeability, 10^{-3}μm^2; μ_0 is the viscosity of the formation crude oil, mPa·s; ϕ is the effective porosity, f.

(3) Formula 3 (applicable to bottom water carbonate reservoirs):

$$E_R = 0.2326\left(\frac{\varphi S_{oi}}{B_{oi}}\right)^{0.969}\left(\frac{k_e \mu_w}{\mu_0}\right)^{0.4863}(S_{wi})^{-0.5326} \tag{3}$$

In the formula: μ_o is the viscosity of underground crude oil, $mPa \cdot s$; k_e is the effective permeability, μm^2; ϕ is the total porosity, f; S_{oi} is the original oil saturation, f; S_{wi} is the original water saturation, f; B_{oi} is the original oil saturation, dimensionless; μ_w is the groundwater viscosity, $mPa \cdot s$.

(4) Formula 4 (applicable to water-flooded conglomerate reservoirs)

$$E_R = 0.9356 - 0.1089\, lg\, \mu_o - 0.0059 p_i + 0.0637\left(\frac{k_e}{\mu_o}\right) + 0.001696 f + 0.003288 L - 0.9087 V_k - 0.00183 h_{ow} \tag{4}$$

Where: $\mu_o$is the viscosity of the formation crude oil under saturation pressure, $mPa \cdot s$; k_o is the effective permeability, μm2; P_i is the original formation pressure, MPa; f is the permeability variation coefficient; L is the ratio of injection and production wells; h_{ow} is the geological reserves of the transition zone; V_k is the oil layer connectivity, μm^2.

(5) Formula 5 (applicable to solution gas drive reservoirs)

$$E_R = 0.2126\left[\frac{\varphi(1-S_{wi})}{B_{ob}}\right]^{0.1611}\left(\frac{k}{\mu_{ob}}\right)^{0.0979}(S_{wi})^{0.3722}\left(\frac{P_b}{P_a}\right)^{0.1741} \tag{5}$$

Where: $\mu_{ob}$is the viscosity of the formation crude oil at saturation pressure, $mPa \cdot s$; B_{ob} is the volume coefficient of the original crude oil at saturation pressure; P_b is the saturation pressure, MPa; P_a is the abandonment pressure, MPa.

2. Analogy

The analogy method is a method of evaluating recoverable reserves based on analogy oil fields or oil field data under similar geological conditions to infer the reserves of the target oil field. By comparing the similarities between the target oil field and the known oil field, the data and experience of the known oil field are used to estimate the reserves of the target oil field.

In the middle and late stages of oil field development, the comprehensive water content of the water-driven oil field will reach more than 40%. At this time, we usually use the water drive curve method.

1. Water Drive Curve Method

(1)Type A water drive curve method

The mathematical expression of type A water drive curve is:

$$lg\,W_P = BN_P + A \tag{6}$$

(2)Type B water drive curve method

The mathematical expression of type B water drive curve is:

$$lg\,L_P = A + BN_P \tag{7}$$

(3)Type C water drive curve method

The mathematical expression of type C water drive curve is:

$$\frac{L_P}{N_P} = A^* + B^* L_P \tag{8}$$

(4)T-type water drive curve

The mathematical expression for the D-shaped water displacement curve is:

$$L_p/N_p = A + BW_P \tag{9}$$

Where: Wp is the cumulative water production, 10,000 tons; Np is the cumulative oil production, 10,000 tons; Lp is the cumulative liquid production, 10,000 tons; A is the intercept and B is the slope.

2. Tong Xianzhang Plate Method

The relationship between fw and R in water-driven oil fields is as follows:

$$\lg\frac{f_w}{1-f_w} = 7.5(R - E_R) + 1.69 \tag{10}$$

Where: According to the plate, use R and the corresponding $f_w$to find the corresponding E_R. The recoverable reserves can be calculated based on E_R.

3. H-C-Z Model

The ratio of oil and gas field production to cumulative production and the corresponding development time show a relationship similar to that of formula (11). After calculation by linear regression algorithm, the values of C and D can be obtained.

$$\ln\frac{q}{N_P} = C - Dt \tag{11}$$

Let a=e^c,b=D, and find e^{-bt}. The recoverable reserves are:

$$\ln N_P = \ln N_R - \frac{a}{b}e^{-bt} \tag{12}$$

In the formula: N_R is recoverable reserves, 10^4t; q is the general annual production, 10^4t; Np is the cumulative oil production, 10^4t.

4. Wang-li model

In the double logarithmic coordinate system, according to the changing law of the cumulative production growth rate, formula (13) is obtained, which is a mathematical expression describing the relationship between the cumulative production growth rate and the exploitation stage. The recoverable reserves value NR and the coefficient value C are assigned values, which are determined according to the geological characteristics and production data of the specific oil field. By substituting the known recoverable reserves value NR and the coefficient value C into formula (13), a linear regression analysis is performed to obtain the estimated value of the recoverable reserves.

$$\ln\left(\frac{N_R}{N_p} - 1\right) = C + D\ln(C + t) \tag{13}$$

In the formula: C and D are coefficients; Np is the cumulative output.

5. Kapitov decay curve analysis method

Generalized Kapitov decreasing type relation:

$$Np = a_1 + b_1(t - t_0 + C)^{1-\frac{1}{n}} \tag{14}$$

Where: Np is the cumulative output from the start of oil field production; a1, b1, and C are coefficients.

3.2. Formulate a Reasonable Well Pattern

Formulating a reasonable well pattern is of great significance to oilfield development and production. A reasonable well pattern can ensure that the oil and gas resources inside the oilfield are effectively exploited, maximize development efficiency, and increase production. By determining a reasonable well pattern, the layout of injection wells can be optimized, ensuring that the injected liquid is evenly distributed throughout the oilfield, improving the recovery rate of the reservoir, and reducing the cost of exploitation, reducing unnecessary well construction and maintenance costs, improving exploitation efficiency, and reducing production costs. There are two types of methods to formulate a reasonable well pattern, namely, the empirical formula method and the numerical simulation method.

1. Empirical for Fig.1 Empirical formula fracturing development technology

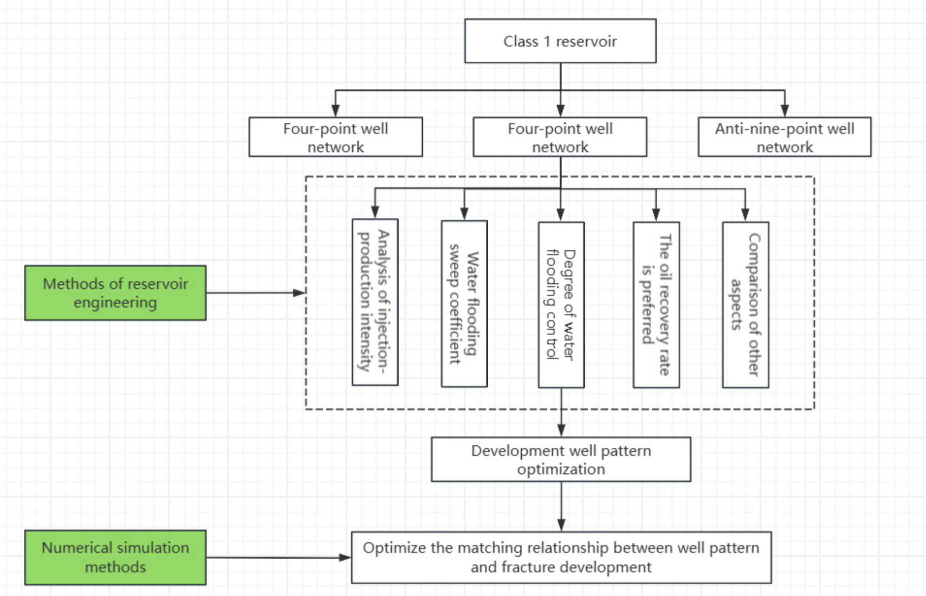

Fig 1. Empirical formula fracturing development technology flow

2. Numerical simulation method

There are three types of well pattern that can be used to optimize the well pattern by numerical simulation method, which are the reverse seven-point well pattern, the staggered row well pattern and the diamond-shaped reverse nine-point well pattern. The actual geological model of the block is imported to set up the well pattern, and three main factors need to be considered in this part: well pattern density, well pattern control area and production system. The well pattern density can be determined according to the economic limit well pattern density. The control area of the well pattern can be determined according to the economic limit control reserve template of a single well under different oil prices. After the simulation, a reasonable well pattern was determined by comparing the recovery degree, daily oil production and decline rate of different schemes. The process of digital and analog optimization and reasonable well pattern form is as follows:

1) According to the digital model optimization process, numerical simulation software (Eclipse or CMG) is used to import geological data, fluid data, rock data, and initialization data in turn.

2) On the premise of ensuring the consistency of well pattern density and control area, different well pattern forms (staggered row well pattern, diamond-shaped anti-nine-point well pattern and anti-seven-point well pattern) are set in the production data module.

3) the simulated fractures, and the half-length of the fractures can be set according to the understanding of fracturing and fracture-making, and the half-length of the fractures is usually set in the range of 60-120m. When setting the crack direction, the in-situ stress direction should be considered, and the crack direction is consistent with the in-situ stress direction. On the basis of the completed well pattern setting, the oil and water well grid infill

4) Based on the actual production data of the block, the model is set up for liquid production, the liquid volume is determined according to the actual liquid production of the block, the injection-production ratio is set to 1:1, the water injection is synchronized, the water injection well is injected with a fixed liquid volume, the injection pressure does not exceed the formation rupture pressure, and the simulation time is generally set for 10 or 15 years.

5) After the simulation is completed, the drawings of liquid production, oil production, water cut, recovery degree, formation pressure, water cut and recovery degree are output, and the scheme with high recovery degree, low decline rate and slow water cut rise is selected as the optimal well pattern scheme through comparative analysis

3.3. Calculation of the amount of Betting

Injection volume usually refers to the amount of water that needs to be injected into the formation in order to maintain formation pressure balance and enhance oil recovery during oilfield water injection development. In this paper, the calculation methods of the allotment amount are classified into two forms: the calculation method of the allotment amount according to the different water injection methods, including two forms: stratified water injection and general water injection; Another option is to classify the dispensing methods according to the conditions that apply to different reservoirs.

3.3.1. A Dispensing Method Classified by Water Injection

1. General water injection

Calculate the amount of injection per well:

(1) Correction coefficient method

The correction factor method is a method used to determine the density of well patterns in oilfield development. It comprehensively considers a variety of factors, such as injection-production balance, water cut rise rate, well fluid supply capacity, water displacement reservoir liquid production ratio, etc., in order to comprehensively and exhaustively reflect the actual underground demand, so as to derive a reasonable formula for calculating well pattern density.

$$Q_{iw} = \left(Q_o \frac{B_o}{\rho_o} + Q_w\right) abfcg \tag{15}$$

where: Q_o is the daily oil production of the water injection well connected to the production well, t/d; B_o is the volume coefficient of crude oil; Q_w is the daily water production of the water injection well connected to the production well, $\frac{m^3}{d}$; Q_{iw} is the amount of single well allocation, $\frac{m^3}{d}$; ρ_o is the density of crude oil.

(1) Connected thickness ratio method

The connected thickness ratio method takes into account the differences in petrophysical properties, permeability, porosity and other parameters in different regions or sections of the reservoir. These characteristics further affect the flow and distribution of oil and water during the water flooding process, thereby affecting the exploitation effect and recovery rate of the oilfield.

$$Q_{iw} = \frac{H_{oc}}{H_o} \times L_{oc} \tag{16}$$

where: Q_{iw} is the calculated single well allocation, $\frac{m^3}{d}$; H_oc is the sum of the effective thickness of the part shot by the production well and the water injection well, m; H_{oc} is the sum of the effective thicknesses of the total parts of the production well, m; L_{oc} is the sum of the liquid production of each production well connected with the water injection well, $\frac{m^3}{d}$.

Calculation of field or block allocation:

(1) Logistic model[17][18]

Logistic model, also known as logistic regression model, is a statistical learning method widely used in classification problems. It is by mapping the output of the linear regression model through a nonlinear function, and converting the continuous output into probability value, and the logistic model method is based on the oil field or block as the research object, and establishes a mathematical model between the comprehensive water cut and the cumulative water consumption, the comprehensive water content and the cumulative water-oil ratio. The mathematical model of Logistic cycle is calculated as follows:

$$X = \frac{D}{1 + Ae^{Bt}} \tag{17}$$

where: t is the development time or process of the system; D is the empirical constant of the life process; X is the system; A and B are the fitting coefficients. When B<0, the cyclic model represents the development of the system from its rise to the development of X as$\lim_{t\to\infty} X \to D$

$$Q_i = \left[\frac{\ln A1 - \ln A2}{B_1} + \frac{B2}{B_1}\frac{fw}{1-fw}\right] Qo \tag{18}$$

where: Q_0 is the annual oil production of the unit or block, 104t; Q_w is the annual water yield of a unit or block, 10^4m^3; Q_i is the annual water injection of a unit or block, 10^4m^3.

2. Layered water injection

(1) Residual oil method [19]

The residual oil method is a method used to estimate unexploited recoverable reserves in an oil field or reservoir.

The distribution ratio of the remaining recoverable reserves in each sublayer is as follows:

$$\eta_j = \frac{N_j'}{\sum_{j=1}^{m} N_j'} \tag{19}$$

The formula for calculating the reasonable amount of each small layer:

$$Q_j = Q\eta_j = Q\frac{N_j\left(1-\frac{1}{1+ce^{-\frac{aQ_j'}{V_{\phi j}}}}\right)}{\sum_{j=1}^{m} N_j\left(1-\frac{1}{1+ce^{-\frac{aQ_j'}{V_{\phi j}}}}\right)} \tag{20}$$

where N_j' is the remaining recoverable reserves of the j-th sublayer, and 10^4m^3;m is the total number of production layers of the well. Q_j is the dosage of layer J based on the distribution of residual oil, m^3/d; η_j is the proportion of the remaining recoverable reserves of the J small layer to the remaining recoverable reserves of the well group, decimal; Q is the daily allotment of the well group, m^3/d; N_j is the recoverable reserves of small layer J, 10^4m^3 ;a is the coefficient related to the development parameters such as reservoir physical properties and well pattern, and there is no dimension. Q_j' is the cumulative water injection of the J sublayer, 10^4m^3; $V_{\phi j}$ is the pore volume of the J sublayer, 10^4m^3;b is the recoverable reserve recovery degree when the water flooding oilfield is developed to the limit, decimal; R_0 is the degree of recoverable reserves at the initial moment of water flooding development of the oilfield.

(2)Under-injection method [20]

The under-injection method is a method used to determine the amount of water injected in oilfield development. By analyzing the geological characteristics, reservoir properties and exploitation conditions of the oilfield, combined with mathematical models and engineering experience, the amount of water that needs to be injected into each oil well is determined to maintain the injection-production balance of the oilfield, improve the recovery rate and prolong the production cycle of the oilfield.

$$Q_i = Q\frac{W_{zi} - W_i}{\sum_{i=1}^{m}(W_{zi} - W_i)} \tag{21}$$

where: W_{zi} is the cumulative injection volume of the ith section of the ultimate water subwater, 10^4m^3; W_i is the cumulative injection volume of the ith layer at the current moment, which is 10^4m^3

(3)Injection-to-ratio method

The injection-production ratio method is a method used in oilfield development to determine the proportional relationship between water injection and oil production. By analyzing the geological conditions, reservoir characteristics and exploitation conditions of the oilfield, the optimal ratio between the water injection and the oil production volume is determined to maintain the injection-production balance of the oilfield, improve the recovery rate and prolong the production cycle of the oilfield.

Layered section water allocation:

$$Q_{wj} = (Q_{o1}B_o/\rho_o)Z + q_w \tag{22}$$

where: Q_{o1} is the oil production of the well group summarized by the stratified section, t/d; Q_{wj} is the water distribution of the layered section of the water injection well, m^3/d; Z is the injection-production ratio of the layer, dimensionless; q_w is the additional water volume of the interval, m^3/d; B_o is the volume compressibility coefficient of crude oil, MPa^{-1}; ρ_o is the density of crude oil.

3.3.2. The Dispensing Method is Classified by the Physical Properties of Reservoirs

(1) Conventional reservoirs

Conventional reservoirs refer to those oil and gas reservoirs that are formed and eventually accumulated in specific geological structures or formations after a certain migration distance. This type of reservoir usually has good reservoir performance, high permeability and high natural productivity, and is an important exploitation object in the petroleum industry.

(2) Reservoirs with good connectivity

A reservoir with good connectivity usually refers to the reservoir with excellent connectivity between reservoirs, that is, the reservoir sand bodies have a high degree of connectivity and the fluid can flow smoothly in the reservoir. Such reservoirs have high natural productivity and production efficiency in oil development. Among them, the connection thickness method is suitable for the calculation of the injection volume of reservoirs with good connectivity.

(3) Reservoirs where water is injected into a declining phase

Reservoirs in which water injection enters the decreasing period refer to reservoirs in which the water injection effect of the reservoir gradually weakens with the extension of the exploitation time and the water injection begins to show a decreasing trend in the process of water injection development. This decreasing trend may be characterized by a gradual decrease in the amount of water injection, a steady or rising pressure in the water injection, and a gradual decline in well production.

(4)Low permeability reservoirs

Low permeability reservoirs are reservoirs with low reservoir permeability, resulting in poor fluid flow capacity in the reservoir. The development of this type of reservoir is relatively difficult, because of the complex pore structure and uneven pore distribution, which greatly restricts fluid migration.

(5) Reservoirs with multi-layer co-production and large inter-layer differences

The development of this type of reservoir has its own unique technical challenges and management requirements, as it refers to the existence of multiple reservoirs in a reservoir, and there are large differences in physical properties, oil content and productivity between these reservoirs, and the method of combined layer exploitation is adopted in the production process.

3.4. Regulatory Measures

3.4.1. Research on Key Issues in Water Injection Development

Key issues include ineffective water injection, weak water absorption capacity of wells, uneven water absorption due to dynamic fractures, reduced production, and water channeling and flooding. Solutions to these problems include optimizing water injection strategies, enhancing reservoir protection, controlling water quality, improving the water injection process, and choosing the right timing for water injection, so as to improve development efficiency and ensure long-term production of the oilfield.

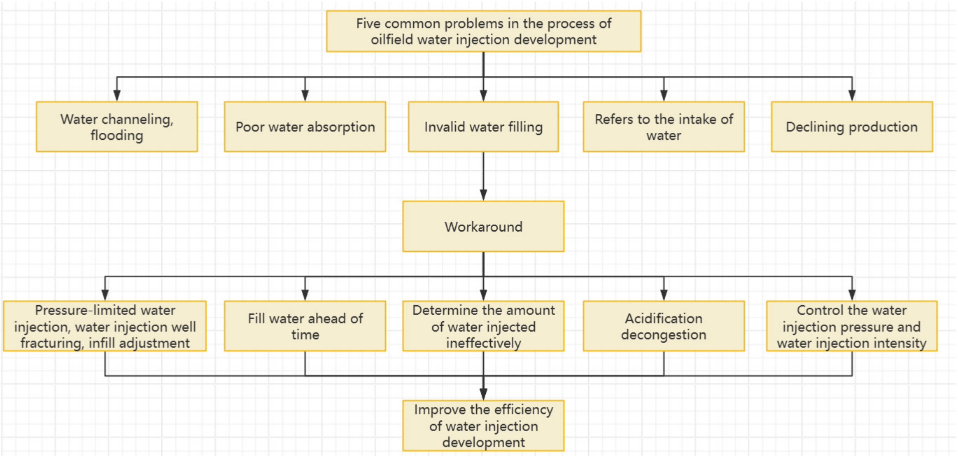

Fig 2. The research process for the key issues of water injection development

3.4.2. Detailed Solutions

(1)Addressing the problem of ineffective water injection

In view of the contradiction between the high injection-production ratio and the decline of formation pressure in ultra-low permeability reservoirs, the invalid water injection was determined by the principle of mass balance on the basis of analyzing the causes of ineffective water injection.

For elastic water flooding reservoirs, according to the mass balance method, the injection and recovery of the block should meet:

$$N_p B_o + W_p B_w = N B_{oi} C_t (P_i - P) + W_{ie} B_w \tag{23}$$

The cumulative effective water injection is:

$$W_{ie} = \frac{\left[N_p B_o + W_p B_w - N B_{oi} C_t (P_i - P)\right]}{B_w} \tag{24}$$

The cumulative invalid water injection is the difference between the cumulative water injection and the cumulative effective water injection of the block, and the mathematical expression is:

$$W_{iw} = W_i - W_{ie} \tag{25}$$

where: Np is the cumulative oil production, 10^4m^3; Wp is the cumulative water production, 10^4m^3; W_{ie} is the cumulative effective water injection, 10^4m^3; N is the geological reserve of the block or reservoir, 10^4m^3; $P_i$is the original formation pressure, MPa:P is the current formation pressure, MPa: B_{oi} is the volume coefficient of the original crude oil, f, and B_o is the volume coefficient of the current original oil, f; B_w is the volume coefficient of formation water, f; W_i is the cumulative water injection of 10^4m^3; B_iw is the cumulative ineffective water injection, 10^4m^3.

(2) The problem of poor water absorption capacity of water injection wells

The most effective way to reduce the water absorption capacity of the injection well due to reservoir damage is to carry out reservoir acidification and decongestion. Acidification and blockage of oil reservoirs is a common oilfield stimulation technology, which is mainly used to deal with the problem of permeability decline and production capacity reduction caused by sediments, calcium and magnesium scaling, gum and other blockages in oil layers.

(3) Dynamic seams lead to finger absorption problems

The problem of finger water intake caused by dynamic fractures [21] is a complex and important issue in oil extraction and water conservancy engineering. The presence of dynamic fractures complicates the flow of fluid in the formation, which may lead to the occurrence of finger intake and water absorption. Finger water absorption problems are usually caused by the dynamic development of cracks. These fractures may expand or change in response to changes in formation pressure, fluid flow, or other geological factors.

To solve this problem, the dynamic seam can be blocked by injecting a plugging agent or plugging material to block the entry of water. Then, the water injection amount and water injection pressure should be reasonably adjusted to control the speed and direction of water injection, so as to avoid water entering the dynamic seam and reduce the occurrence of finger water absorption. Then the position of the injection well needs to be optimized to avoid being too close to the dynamic seam position to reduce the possibility of water entering the dynamic seam. Finally, by adjusting the reservoir development plan, the reservoir adjustment is strengthened, the stability of the reservoir is improved, and the influence of dynamic fractures on the finger intake and water absorption problem is reduced.

(4)The problem of declining production

In view of the phenomenon of declining output in the development of water injection, the method of advanced water injection can be adopted. Advanced water injection is a technology for low permeability and ultra-low permeability reservoirs, which is proposed according to the non-Darcy seepage theory to improve the development effect of such reservoirs, taking into account the characteristics of starting pressure gradient and elastic-plastic deformation of the reservoir.

In the process of advanced water injection, a water injection well can be regarded as having a circular closed boundary, and its injection volume has a specific relationship with the formation pressure when it reaches the quasi-steady state.

$$V_1 = C_i V_f (P_i - \bar{P}), V_f = \pi(R_e^2 - R_w^2)h \tag{26}$$

where: $P_i$is the original formation pressure, Pa; V_f is the volume of the formation in the range of $(R_e - R_w)$, m^3; $R_w$is the effective well diameter, m; $\bar{P}$ is the average formation pressure, P_a; h is the thickness of the formation, m; C_t is the comprehensive compressibility coefficient, P_a; V$_1$ is the injected fluid area, m^3.

Substituting the boundary conditions, the integral yields:

$$P(r,t) = P_w(t) + \frac{Q\mu}{2\pi kh}\left(\ln\frac{r}{R} - \frac{1}{2}\frac{r^2}{R_e^2}\right) - R_e\lambda\ln r \quad (27)$$

According to the above formula, it can be concluded that the longer the advance water injection time, the higher the yield.

(5) The problem of water channeling and flooding

The development of water flooding in low permeability reservoirs is affected by water injection-induced fractures, and the multi-directional water occurrence of oil wells results in poor water flooding development. After the formation of water injection-induced fractures, the injected water flows rapidly along the fractures, and the scale continues to expand, which can easily lead to water channeling and flooding of oil wells, and the water flooding effect of oil wells on both sides is poor, and the degree of reserve production is low, which aggravates the heterogeneity and affects the development effect.

Effective Adjustment Strategy:

(1) Pressure-limited water injection. Due to the contradiction between the induced fractures of high conductivity and the low permeability of reservoir matrix pores, the development effect of low permeability reservoirs is reduced. In order to improve the overall development effect, measures need to be taken to prevent or delay the formation of cracks induced by high conductivity water injection. Controlling the water injection pressure to be lower than the opening pressure of natural cracks is the key to effectively prevent the formation of cracks, thereby improving the development effect.

(2) Volume fracturing of water injection wells. Due to the damage of the reservoir, the seepage of the water injection well is weakened, which leads to high pressure and difficult injection, increases the injection-production pressure difference, induces multiple fractures, hinders water circulation, and affects the effective displacement of the reservoir. Through volumetric fracturing water injection wells, obstacles are broken, pressure is reduced and seepage flow is directed, excess fractures are closed, water flooding paths are optimized, and the water cut of oil wells is reduced.

(3) Encryption adjustments. When the water injection pressure increases to the minimum horizontal stress, cracks are formed along the direction of the maximum horizontal stress, and the cracks in the direction of the injection-production line are gradually opened as the pressure rises. Water flooding in low permeability reservoirs is controlled by fracture opening. Multi-directional fractures lead to flooding, increased moisture content, and reduced yield. After changing the direction of water injection, the ineffective circulation still exists, the moisture content rises rapidly, and the output is difficult to stabilize.

4. Summery

(1) This paper comprehensively reviews the development process and current research status of oilfield water injection development technology, and systematically expounds the key technologies and methods of oilfield water injection development from the precise calculation of recoverable reserves, well pattern formulation, injection volume and control measures.

(2) Through an in-depth analysis of the principles and applications of various calculation methods, this paper not only provides a valuable reference for oilfield engineers, but also lays a theoretical foundation for the optimization and efficiency improvement of oilfield water injection development.

(3) The research and application of oilfield water injection development technology is a constantly developing field, with the progress of science and the change of oilfield development needs, new theories and technologies will continue to emerge, which will be explored and discovered by later generations.

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