Study on the influencing factors of productivity under pressure drive development in low permeability reservoir

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Abstract: The productivity of low-permeability reservoirs is affected by multiple factors. After the development of water injection by pressure drive, it will also be affected by factors such as construction, resulting in large differences in the productivity of different oil wells. According to reservoir engineering knowledge, the factors affecting the productivity of pressure drive water injection development are preliminarily determined. The conceptual model of pressure drive water injection development of low permeability reservoir is established by numerical simulation method. Combined with orthogonal design, the main control factors of pressure drive water injection development productivity are determined. The main control factors include injection production well spacing, water injection volume of pressure drive measures, water content before pressure drive, porosity, and quantitative analysis of the main control factors. Through correct analysis and evaluation of these factors, it provides guiding significance for the productivity prediction of pressure drive water injection development in low permeability reservoirs and the optimization of pressure drive water injection scheme.

Keywords: Low permeability reservoir; Pressure drive; Numerical simulation; Influencing factor

1. Introduction

The development technology of pressure drive water injection is a technology to realize the combination of 'fracturing-infiltration-flooding' to improve the recovery rate. The main principle is to form cracks through fracturing and quickly send the oil displacement agent to the enrichment site of remaining oil through cracks. The oil displacement agent is quickly filled into the pores, reducing the contact time and contact distance between the chemical agent and the formation and improving the oil displacement efficiency. At the same time, by injecting a large amount of oil displacement fluid, the formation energy can be replenished in a short time, the effect of energy storage before pressure can be achieved, the formation pressure can be improved and maintained, and the stable production period can be prolonged.

At present, pressure drive water injection development technology has been applied on a large scale in low permeability reservoirs. With respect to the pressure drive water injection development technology, current scholars' research directions mainly focus on the design optimization of pressure drive water injection volume and the dynamic propagation of fractures. Xu [1] used reservoir engineering methods to analyze the pressure distribution characteristics of the injection end and production end and defined the pressure drive development mechanism of low permeability reservoirs. A water injection design method for a pressure drive well is presented. Huang [2] optimized the pressure drive mechanism, the pressure drive well selection, pressure drive injection volume, injection displacement, and filling time based on field practice. Wu [3] studied the fracture propagation law of pressure drive water injection technology and optimized the water injection volume and water injection pressure difference combined with numerical simulation. Considering that the productivity of oil wells after the pressure drive is very different, and the productivity after the pressure drive is affected by multiple factors such as fluid, reservoir, well pattern, and construction [4-5], there is no mature productivity prediction method at present. There is a lack of research on the influencing factors of productivity under pressure drive development in low permeability reservoirs. Based on the productivity formula of vertically fractured wells in low permeability reservoirs and from the perspective of the integration of injection well and production well, the influencing factors related to pressure drive development are screened comprehensively. The conceptual model of pressure drive for low permeability reservoir development is established based on the actual model of pressure drive development provided by the field and the field data. The influencing factors of productivity under pressure drive development are considered in various aspects [6]. An orthogonal test determined the main controlling factors of productivity under pressure drive, and then the main controlling factors were quantitatively analyzed.

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2. Screening of productivity factors in pressure drive development

As a new type of enhanced oil recovery technology, there is currently no relatively accurate oil well productivity formula. Through consulting the data and according to the productivity formula (1) of vertical fracturing well in low permeability reservoirs [7]:

$$Q = \frac{2\pi K h\left(p_e - p_w\right)}{\mu B\left[\xi_e + \frac{\pi h_d}{2x_f}\left(\frac{K}{K_d} - 1\right)\right]} \times \left[1 - \frac{2\lambda x_f \sinh \xi_e + \pi h_d\left(\lambda_d - \lambda\right)}{\pi\left(p_e - p_w\right)}\right] \quad (1)$$

In the Formula: x_f ——Fracture half-length, m

h_d ——Thickness of contamination zone around the fracture, m

K ——Permeability of reservoir before contamination, μm^2

K_d ——Contaminant zone permeability, μm^2

λ——Start-up pressure gradient of the reservoir before pollution, MPa/m

λ_d ——Contaminant zone starting pressure gradient, MPa/m

h——Thickness of reservoir, m

μ ——Fluid viscosity, mPa·s

B ——Volumetric factor

p_e ——Formation pressure, MPa

p_w ——Bottom hole pressure, MPa

According to the productivity formula of vertically fractured wells in low permeability reservoirs, the productivity after pressure drive is related to fracture properties[8], permeability, fluid viscosity, reservoir thickness, porosity, and bottom hole pressure. The pressure drive water injection, well spacing, and pressure drive timing (water cut before pressure drive) under pressure drive development also greatly influence the productivity after the pressure drive. Finally, the influencing factors related to pressure drive water development are as follows: water cut before pressure drive, well spacing, water injection, permeability, oil viscosity, effective thickness, and porosity. Through field data observation, due to the mutual interference among various influencing factors, there is no strong correlation with productivity after pressure drive, and there is no obvious linear relationship or functional relationship. Numerical simulation software will be used for specific analysis later.

3. Numerical simulation analysis of Influencing factors of pressure drive productivity

3.1 Conceptual model of pressure drive development

According to the actual model of Block A provided by the mine and the corresponding actual production data, a pressure drive well group in the model is selected, and the water injection well is subjected to 20 days of pressure drive water injection. The total water injection volume is 8000 m^3 (after pressure drive water injection, the production well is effective, and the production is improved). Due to the short-term high-pressure water injection, the pressure near the water injection well is high, and the fracture is generated and gradually expanded. In the actual block model, the pressure drive characteristics are characterized by adding cracks between the injection well and the production well[9] (the pressure drive water injection time is 20 days, which is divided into 10-time steps, and the software restart function is used to simulate the gradual expansion of cracks). Finally, the crack area with a length of 200 m, a width of 30 m, and a height throughout the whole model is gradually formed. As shown in Figure 1, different pressure drive water injection forms different cracks, and different cracks correspond to different conductivity. The conductivity of the crack is affected by changing the permeability of the crack, which corresponds to different pressure drive water injection.

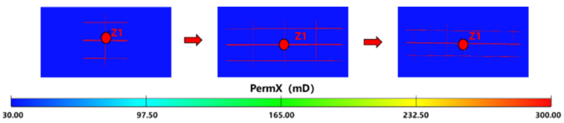

Fig 1. Gradual extension of fractures around the injection well

After the pressure drive measures are taken, a period of soaking is carried out, and constant pressure development is carried out. The production data of the model and the actual data of the block are fitted by line (changing the permeability of the added cracks). After the fitting is completed (the error between the actual production data and the model production data is within 5 %), it is obtained in the actual block model: when the pressure drive water injection is 8000 m^3, the fracture permeability is 300 mD. If the injection volume increases or decreases, the fracture permeability will also increase or decrease proportionally[10]. This result is applied to the following conceptual model of pressure drive water injection development.

Based on the actual model of Block A, a conceptual model of pressure drive development is established. The same reservoir depth, initial formation pressure, initial oil saturation, PVT parameters, and relative permeability curves are used. The number of model grids is 41 * 41 * 10. The size of a single grid in the X and Y directions is 10 m, the size of the grid in the Z direction is 4 m, the buried depth of the reservoir top surface is 2900 m, the initial pressure is 29 Mpa, and the initial oil saturation is 0.6. The model is a homogeneous model with four production wells (W1, W2, W3, W4) and one injection well (Z1), which is arranged in a five-point well pattern. The model is shown in Figure 2.

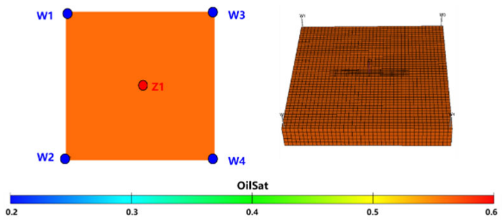

Fig 2. Initial oil saturation of model

3.2 A multi-factor study on influencing factors of pressure drive water injection development productivity

After the model is established, the injection-production balance production is carried out first. When the water cut reaches the specified size, the pressure drive is carried out, the production well is closed, the water injection well is formed by short-term high-pressure water injection, the water injection well is closed after the water injection, and the 40-day soaking is carried out. Then the production well is subjected to constant pressure production. The average daily oil production within one month after the pressure drive and the average daily oil production within three months are used as evaluation indexes.

Using orthogonal test design[11], water cut before pressure drive, injection-production well spacing, water injection volume, permeability, crude oil viscosity, effective thickness, and porosity were selected as influencing factors. According to the variation range and data concentration of the influencing factors of the field data, the reasonable range of each factor is determined, and three horizontal values are taken within the reasonable range. The selected orthogonal table is L18 (3^7). The orthogonal test factor level table is shown in Table 1 , a total of 18 tests must be done, and the test plan is prepared. The test is carried out according to the plan, and the test results (average daily oil production within one month after the pressure drive and the average daily oil production within three months) are recorded. The orthogonal test software is used for variance analysis of the test results.

Table 1. Orthogonal test factor level table

	Water cut before pressure drive (%)	Injection-production well spacing (m)	Water injection volume (m^3)	Permeability (md)	Crude oil viscosity (cp)	Effective thickness (m)	Porosity (%)
Level 1	20	150	4000	15	1	5	5
Level 2	40	300	8000	30	2	10	10
Level 3	60	450	12000	45	3	15	15

Analysis of variance shows[12] that F is more significant than that, and the larger the F-ratio is, the more significant it is. If the F-ratio is greater than the F critical value, that item is significant. The test variance table is shown in Table 2 and Table 3.

Table 2. Daily oil production test variance table within one month after pressure drive

	Water cut before pressure drive (%)	Injection-production well spacing (m)	Water injection volume (m^3)	Permeability (md)	Crude oil viscosity (cp)	Effective thickness (m)	Porosity (%)
F-ratio	271.95	494.47	261.67	33.23	1.00	48.07	187.49
F critical value	19	19	19	19	19	19	19
Significance	2	1	3	6	7	5	4

The daily oil production within one month after the pressure drive is taken as the evaluation index of the test scheme, as shown in Table 2. According to the F ratio, the influence on the development capacity of the pressure drive is ranked as follows: injection-production well spacing > water content before pressure drive > water injection volume of pressure drive measures > porosity > effective thickness > permeability > crude oil viscosity. The comparison of the F-ratio and F critical value shows that the injection-production well spacing, water content before pressure drive, water injection volume of pressure drive measures, porosity, effective thickness, and permeability have a significant influence on the productivity of pressure drive development.

Table 3. Daily oil production test variance table within three months after pressure drive

	Water cut before pressure drive (%)	Injection-production well spacing (m)	Water injection volume (m^3)	Permeability (md)	Crude oil viscosity (cp)	Effective thickness (m)	Porosity (%)
F-ratio	29.84	50.25	43.68	1.00	1.24	7.32	19.99
F critical value	19	19	19	19	19	19	19
Significance	3	1	2	7	6	5	4

The daily oil production within three months after the pressure drive is taken as the evaluation index of the test scheme, as shown in Table 3. According to the F ratio, the influence on the productivity of pressure drive development is ranked as follows: injection-production well spacing > water injection volume of pressure drive measures > water content before pressure drive > porosity > effective thickness > crude oil viscosity > permeability. The comparison of the F-ratio and F critical value shows that the injection-production well spacing, water injection volume of pressure drive measures, water content before pressure drive, and porosity significantly influence the productivity of pressure drive development.

3.3 Single factor study on influencing factors of pressure drive water injection development productivity

Through the previous multi-factor analysis, the main controlling factors of pressure drive water injection development capacity are injection-production well spacing, water injection volume of pressure drive measures, water content before pressure drive, and porosity. According to the design of the pressure drive scheme, based on the data given by the mine site, within a reasonable range, the injection-production well spacing, water injection volume of pressure drive measures, water content before pressure drive, and porosity take 10 horizontal values each. The influencing factors are input into the conceptual model of pressure drive water injection development. The daily oil production within three months after the pressure drive is analyzed as the evaluation index. The pressure drive capacity results corresponding to different influencing factors are recorded to generate scatter plot analysis, the scatter plot results are shown in Figure 3.

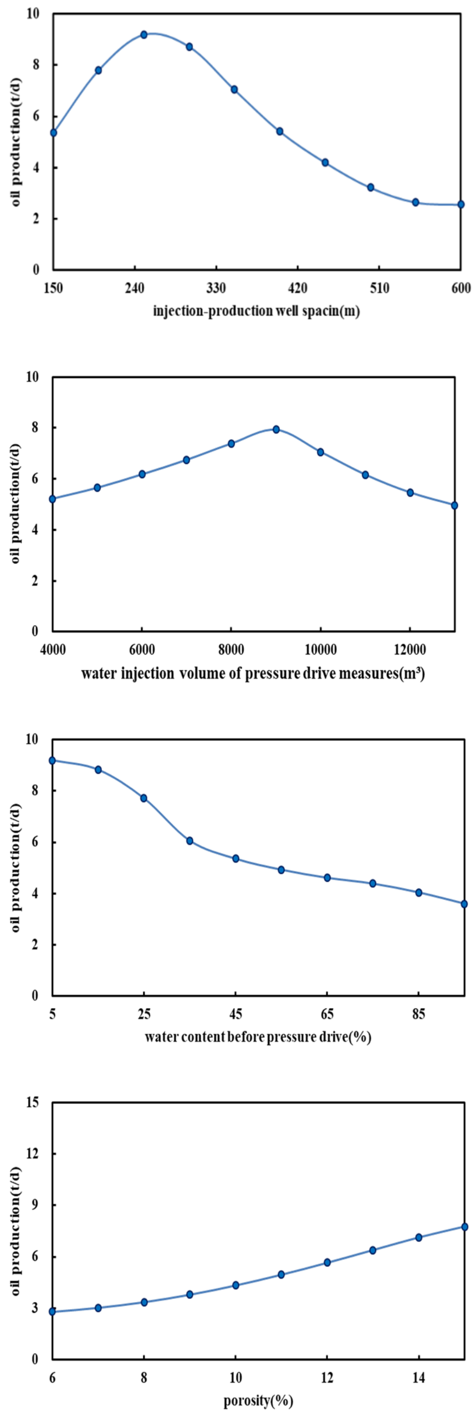

Fig 3. Quantitative analysis chart of main control factors

Injection-production well spacing: when the injection-production well spacing is less than 240 m, and the productivity after the pressure drive increases with the increase of injection-production well spacing. When the injection-production well spacing is greater than 240 m, the productivity after the pressure drive decreases with the increase of injection-production well spacing.

The water injection volume of the pressure drive measures when the water injection volume is less than 9000 m^3, and the productivity after the pressure drive increases with the increase of water injection volume. When the water injection is greater than 9000 m^3, the production capacity after the pressure drive decreases with the increase of water injection.

Water content before pressure drive: with the increase of water content before the pressure drive, the relative permeability of crude oil decreases, and the relative permeability of water increases, resulting in a gradual decrease in productivity after the pressure drive.

Porosity: As the porosity increases, the reserves between the well groups increase, and the productivity after the pressure drive gradually increases.

4. Conclusion

The productivity formula of a vertically fractured well in a low permeability reservoir is used to screen out the influencing factors related to pressure drive, including water cut before pressure drive, injection-production well spacing, water injection rate, permeability, crude oil viscosity, effective thickness, and porosity. Numerical simulation is used to establish a conceptual model of pressure drive water injection development in line with the actual block. The main controlling factors of productivity after a low permeability pressure drive are determined by orthogonal design, including injection-production well spacing, water injection volume of pressure drive measures, water content before pressure drive, and porosity.

Through quantitative analysis of the main control factors, it is concluded that too low injection-production well spacing will increase the water content of the production well after the pressure drive and decrease productivity after the pressure drive. Too high will lead to a decrease in the effect after pressure drive, inability to effectively displace, and reducing productivity. Therefore, the injection-production well spacing should be set between 200-300 m; the low water injection rate of pressure drive measures will lead to poor pressure drive effect, and the formation energy will not be effectively supplemented. If it is too high, water channeling will occur, resulting in an increase in water cuts in production wells. Both of them will reduce productivity after the pressure drive. The appropriate injection volume should be set according to different well groups, and the injection volume should be between 8000-10000 m^3. The higher the water cut before the pressure drive, the lower the recoverable reserves of the well group. The pressure drive water injection development should be carried out in the low permeability reservoir as soon as possible. The larger the porosity, the larger the reserves between the well groups, and the higher the productivity after the pressure drive. Through the analysis of the main control factors, this paper can provide the basis for the optimization of the field pressure drive scheme and the basis for the prediction of the production capacity after the subsequent pressure drive.

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