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Study on Productivity Numerical Simulation of Highly Deviated and Fractured Wells in Deep Oil and Gas Reservoirs

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Abstract. This paper establishes the model of sandstone, porosity and permeability on single well in allusion to 10 highly deviated and fractured wells in deep oil and gas reservoirs of Jidong Oilfield, which forms a numerical simulation method of highly deviated and fractured wells in deep oil and gas reservoirs of Jidong Oilfield. The numerical simulation results of highly deviated and fractured wells productivity in deep oil and gas reservoirs are given out under different layers (layer ES1, layer ES3, layer ED2,and layer ED3), different deviation angles(60°and 75°), different fracture parameters and producing pressure drops. Through the comparison with testing data getting from exploration wells, we know that the calculation results of numerical simulation are consistent with practical testing results.

1 Introduction

Large-scale hydraulic fracturing of highly deviated and horizontal wells is the most effective method to develop low permeability sandstone and carbonate reservoir, tight oil and gas reservoir, unconventional oil and gas reservoir [1-3]. The productivity simulation and influencing factor analysis of highly deviated and fractured wells are the scientific basis of fracturing design and productivity prediction [4-5]. The computational difficulties of numerical simulation of highly deviated and fractured wells are mainly reflected in deviation angle, long-term flow conductivity, the processing of natural fracture, etc [6-8]. At present, the researches on highly deviated fracturing issues mainly focus on the mechanism of fracture initiation and propagation, deviated well fracturing, indoor simulation experiments, field tests and so on [9-11]. There are few researches on the productivity numerical simulation of highly deviated and fractured wells [12-14]. This paper forms a deviated and fractured wells productivity numerical simulation method of natural fracture development formation in deep oil and gas reservoirs, which provides a basis for the optimization design of the fracturing construction parameters and the evaluation of fracturing effect on highly deviated wells, so as to guide the actual field work for oilfield.

2 Establishment of representative well geological models

For 10 representative highly deviated wells of different layers in deep oil and gas reservoirs of Jidong Oilfield, on the basis of porosity and permeability deriving from single well logging interpretation, establish the geological models based on single well sandstonesection distribution, which provides the basis for numerical simulation.

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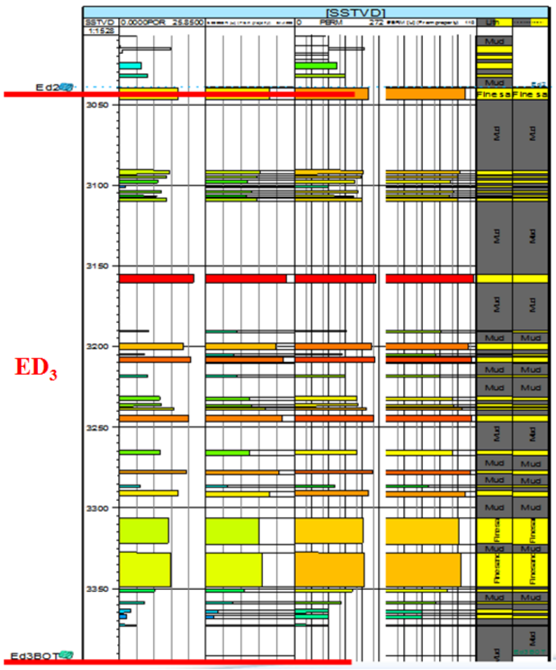

Figure 1. Log interpretation profile.

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The sample well is located in layer ED_3 of Jidong Oilfield deep reservoirs, and the log interpretation profile is shown in Figure 1. The plane grid number of the sample well is set to 54 *44, with a step length of 30m, and the number of vertical grid is set to 59. There is no interference between the sample well and the surrounding wells, so a rectangle boundary can approximatively be used as the boundary of a single well model. Figure 2 shows the plane grid graph of the sample well, and Figure 3-Figure 6 respectively represent for the structure model, porosity model, permeability model and sandstone model of the sample well.

The geological model shows that the single well model is faithful to the single well data, and the goodness of fit is more than 95%.

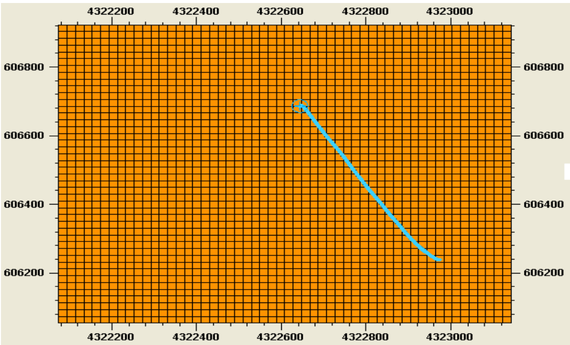

Figure 2. Plane grid.

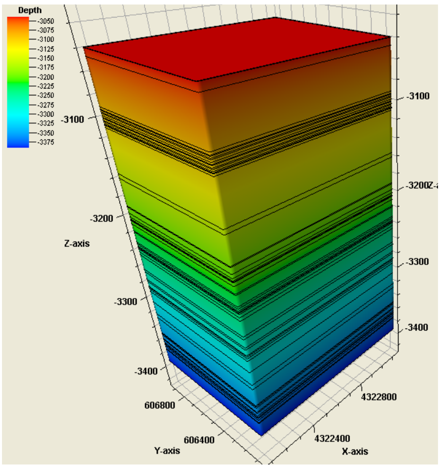

Figure 3. Structure model.

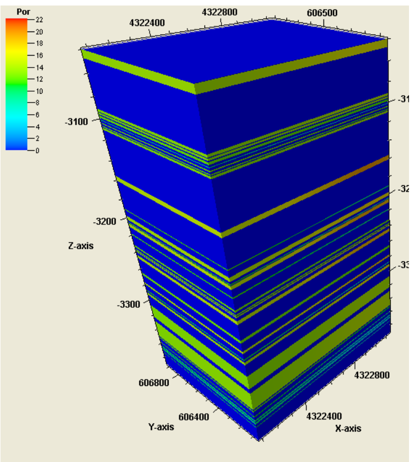

Figure 4. Porosity model.

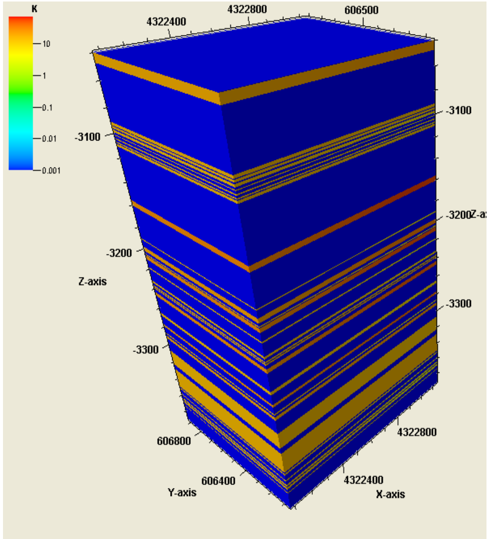

Figure 5. Permeability model.

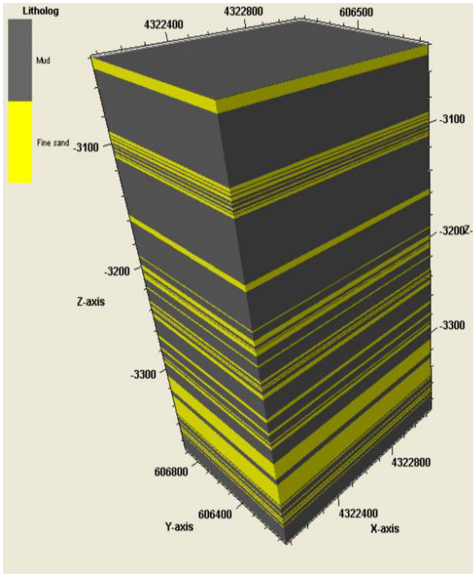

Figure 6. Sandstone model.

3 Numerical Simulation of Highly Deviated and Fractured Wells

3.1 Simulated horizons and the treatment of natural fracture development

Table 1 shows the testing and log interpretation results, natural fracture development and some others of the target layer section of 10 representative wells, and we can get the following conclusions from Table 1: layer ES_3 of deep oil and gas reservoirs in Jidong Oilfield is natural fracture development, while the fractures of layer ES_1, layer ED_2 and layer ED_3 do not develop. Through practical experience and the analysis of calculation results, for the intervals of natural fracture development, the goodness of fit is higher when the effective permeability is dealt with logging permeability, and for the intervals that do not develop, when the effective permeability is calculated according to 1/8 of the logging permeability, the result is more reliable.

Table 1. Simulation horizons and natural fracture development situation.

Serial Number	Horizon	Interval (m)	Testing/Logging	Natural Fracture	Treatment of Effective Permeability
1	ES_3	4340.8-4379.4	oil layer	development	effective permeability = logging permeability
	ES_3	4676-4691.8	oil layer	development	effective permeability = logging permeability
	ES_3	4834.4-4852.2	oil layer	development	effective permeability = logging permeability
	ES_3	4890.8-4902	hydrocarbon zone	development	effective permeability = logging permeability
2	ES_1	4078-4124	second type reservoir	undevelopment	effective permeability = 1/8 of logging permeability
	ES_1	4337-4393	second type reservoir	undevelopment	effective permeability = 1/8 of logging permeability
3	ES_{2+3}	4744.6-4801.6	second type reservoir	development	effective permeability = logging permeability
4	ES_{2+3}	4077.8-4138	gas layer	development	effective permeability = logging permeability
	ES_{2+3}	4284-4305.4	poor gas layer	development	effective permeability = logging permeability
	ES_{2+3}	4317-4373.8	poor gas layer	development	effective permeability = logging permeability
5	ES_3	4309.8-4318.8	oil layer	development	effective permeability = logging permeability
	ES_3	4663.8-4741	oil layer	development	effective permeability = logging permeability
6	ED_2	3405.8-3415.6	poor oil layer	undevelopment	effective permeability = 1/8 of logging permeability
7	ED_2	4661.6-4673.6	oil layer	undevelopment	effective permeability = 1/8 of logging permeability
Serial Number	Horizon	Interval (m)	Testing/Logging	Natural Fracture	Treatment of Effective Permeability
7	ED_2	4700.8-4718.4	hydrocarbon zone	undevelopment	effective permeability = 1/8 of logging permeability
8	ES_1	4272.2-4280.8	poor oil layer	undevelopment	effective permeability = 1/8 of logging permeability
9	ED_3	4533.6-4544.6	oil layer	undevelopment	effective permeability = 1/8 of logging permeability
10	ED_3	3404.6-3447.4	oil layer	undevelopment	effective permeability = 1/8 of logging permeability

3.2 Experiment of long-term flow conductivity

The experiment of long-term flow conductivity can reflect the true flow conductivity of the fracture under the condition of oil and gas reservoir, and provide reliable reference for fracturing design and construction. The Fracturing Center of PetroChina Research Institute of Petroleum Exploration gives the experimental result of long-term flow conductivity (20-40 mesh ceramic), which is shown in Figure 7.

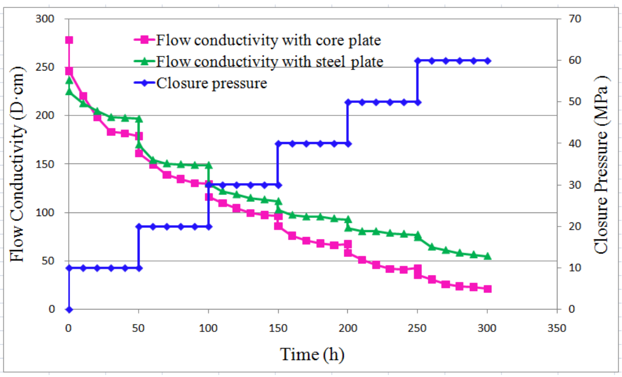

Figure 7. Experimental result of long-term flow conductivity.

The long-term flow conductivity fitting model of core plate is shown as following according to the experimental results:

$$w_f \cdot k_f = 258.69 / e^{0.0078t} \qquad (1)$$

where w_f is fracture closure width (cm), k_f is fracture permeability (D), t is time (d).

According to the model, the flow conductivity is about 5.0 D.cm at 22 - 20 days (Table 2).

Table 2. Predicting results of long-term flow conductivity.

Time (d)	Flow Conductivity(D.cm)
2	177.90
4	122.34
6	84.14
8	57.86
10	39.79
12	27.36
14	18.82
16	12.94
18	8.90
20	6.12
22	4.21
24	2.89
26	1.99
28	1.37
30	0.94

3.3 Skin factor caused by well deviation

The highly deviated well is different from vertical and horizontal wells. In the process of production, the well deviation will cause formation fluid disturbance and generate additional pressure drop, which can be represented by the skin factor. Figure 8 is a schematic diagram of partially perforated deviation well. Where θ is deviation angle (°), r_w is well diameter (m), z_w is the central coordinate of deviation well (m), h_w is the perforation length (m), h is reservoir thickness (m).

Define the dimensionless quantity:

$$z_{\mathrm{wD}} = z_{\mathrm{w}} / r_{\mathrm{w}},\ \ h_{\mathrm{wD}} = h_{\mathrm{w}} / r_{\mathrm{w}},\ \ h_{\mathrm{D}} = h / r_{\mathrm{w}} \tag{2}$$

When all the intervals are perforated:

$$z_{\mathrm{wD}} / h_{\mathrm{D}} = 0.5,\ \ h_{\mathrm{wD}} \cos\theta_{\mathrm{w}} / h_{\mathrm{D}} = 1.0 \tag{3}$$

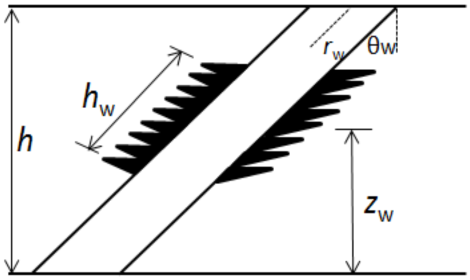

Figure 8. Schematic diagram of partially perforated deviation well.

At this point, the skin factors of different deviation angles are shown in Table 3. Where $s_{\theta+p}$ is the skin factor caused by well deviation and perforation, s_p is the skin factor caused by perforation, and s_θ is the skin factor caused by well deviation.

Table 3 shows that when all the intervals are perforated, the skin factor caused by perforation is 0, that is to say, the skin factor is only related with the deviation angle. In this paper, the skin factor caused by well deviation is integrated into the grid computing of numerical simulation.

Table 3. Skin factors of different deviation angles (Cinco-Ley)

θ_w	$S_{\theta+P}$	S_P	S_θ
15	-0.128	0	-0.128
30	-0.517	0	-0.517
45	-1.178	0	-1.178
60	-2.149	0	-2.149
75	-3.577	0	-3.577

4 Analysis of Calculation Results

The numerical simulation results of highly deviated and fractured wells productivity in deep oil and gas reservoirs is given out under different layers, different deviation angles, different fracture parameters and producing pressure drops. When the producing pressure drop is 24MPa, the production estimation ranges of different layers are shown in Table 4.

Table 4. Production estimation ranges of different simulation schemes

Simulation Scheme	Permeability (mD)	Reservoir Thickness	Porosity	Initial Production (m^3/d)	Production after1 Year (m^3/d)
Oil well of layer ES_1	2.6	7	9.7%	3-4.5	0.8-1.4
Gas well of layer ES_1	0.26	56	5.46%	1.5×10^4-3×10^4	0.5×10^4-1×10^4
	4.8	46	12%	15×10^4-25×10^4	6×10^4-10×10^4
Oil well of layer ES_3	0.5	15-39	6.8%	5-25	0.5-9
	7	78	12%	150-225	40-70
Gas well of layer ES_3	0.5	11	6.8%	5×10^4-10×10^4	2×10^4-4×10^4
	7	9	12%	25×10^4-45×10^4	10×10^4-18×10^4
Oil well of layer ED_2	0.68-1.5	12-17.6	13%-15%	1-4	0.25-1.25
	18	9.8	16%	7.5-11	2-3.5
Oil well of layer ED_3	6.2-13.2	11-42	12.7%-15.1%	8-12	2-4

5 Summary

The numerical simulation results of highly deviated and fractured wells productivity in deep oil and gas reservoirs are given out under different layers, different deviation angles, different fracture parameters and producing pressure drops.

When the producing pressure drop is 24MPa, the production estimation ranges of different layers and production parameters are obtained through the statistical results of numerical simulation: for the oil wells in layer ES_1, when the permeability is about 2.6 mD, the initial production is between 3 and 4.5 m^3/d, and for the gas wells in layer ES_1, when the permeability is about 0.26 mD, the initial production is between 1.5×10^4 and 3×10^4 m^3/d. For the oil wells in layer ES_3, when the permeability is about 0.5 mD, the initial production is between 5 and 25 m^3/d, and for the gas wells, the initial production is between 5×10^4 and 10^5 m^3/d. For the oil wells in layer ED_2, when the permeability is about 0.68 to 1.5 mD, the initial production is between 1 and 4 m^3/d. For the oil wells in layer ED_3, when the permeability is about 6.2 to 13.2 mD, the initial production is between 8 and 12 m^3/d. The results of this research have an important significance for the optimization design of the fracturing construction parameters and the evaluation of fracturing effect on highly deviated wells.

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