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Optimization Research of Effective Stimulation for Carbonate Reservoir and its Application

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Abstract

Based on the characteristics of carbonate reservoirs, staged-fracturing technology for horizontal wells was adopted to effectively drain the reservior. Fracture parameters including orientation, number, length, fracture conductivity and distribution were optimized, and accordingly a hydraulic fracturing design was developed. Applied in oilfield, this method was proved to be effective in oil production. Therefore, it can provide theoretical guidance for the design of the stage-fractured horizontal wells.

Keywords: *Carbonate reservoir formation, multi-stage fractured horizontal well, fracture parameters, fractures distribution, optimization design*

1. Introduction

DS Low permeability reserves block locates in the southern zone peripheral of Z oilfield, Kazakhstan. It has nearly large reserves, but distribute in a widespread area. Also this block is consisted by many separated thin layers, each one is from 4.5 meters to 16.2meters.Poor physical properties and low pressure, pressure coefficient 0.6-0.8, are its representative characteristics. Because of the limited well control area, it is difficult for conventional vertical well to achieve effective development. Besides, considering the complex reservoir types and strong heterogeneity, horizontal well fracturing technology research must be carried out to improve lateral reservoir extent and increase final productivity [1-4]. Horizontal well fractures simulation and fracture distribution pattern optimization are the foundation of horizontal well design [5-6]. This study aimed to form a horizontal well fractures optimization program and design method in reconstruction, which can guide site staged fracturing of horizontal wells directly.

2. The Objective Function and Simulation Method

Horizontal well productivity is not only the key parameter of economic evaluation, but also the optimization foundation of hydraulic fracturing treating parameters. Analytic and numerical simulations are the two main productivity prediction methods [7-9]. Based on numerical simulation, this study established reservoir, wellbore and fracture model through professional simulation software Eclipse. The black-oil modules can flexibly handle multiple species grid, many reservoir types (homogeneous, heterogeneous, double porosity ,double permeability media, *etc.*,), all kinds of wellbore conditions (vertical wells, deviated, horizontal well).What's more, fracturing time point and corresponding fracturing parameters

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can be set based on the concept of conductivity. During simulation, the entire simulating area grid was built by Eclipse software Grid modules. Near fracture grids were refined and their conductivities were determined according to "equivalent conductivity" principle.

3. Fracture Parameters Optimization

Productivity of staged fractured horizontal wells is correlated with fracture parameters. For low permeability reservoir, fracture characteristics including azimuth, number, length and conductivity are the key factors influencing horizontal well productivity. With simulation software, the number of segments, fracture length and conductivity were optimized. For certain single well, the best fracture parameters were selected according to the specific formation conditions to provide theoretical guidance for fracturing design.

3.1. Fracture Azimuth Optimization

In order to study the effects of different fracture azimuth of horizontal well productivity, artificial fractures were defined as 35 degree and 90 degree with horizontal wellbore (see Figure 1 and Figure 2),and productivities of both cases were simulated.

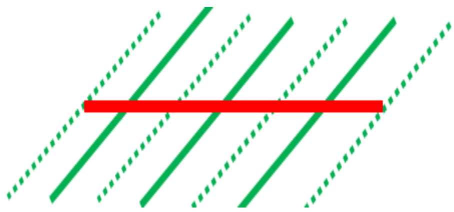

Figure 1. Model of 35°between Artificial Fractures and Horizontal Wellbore

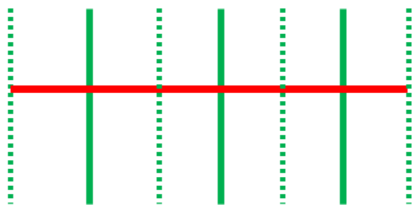

Figure 2. Model of 90°between Artificial Fractures and Horizontal Wellbore

By comparing the cumulative oil production in 3 years under both situation (see Figure 3), it can be concluded that the cumulative oil production of 90 degree is higher. Therefore, we should try to keep drilling the horizontal section extending along the direction of the minimum horizontal stress, to generate transverse fractures.

3.2. Number of Fracture Segment Optimization

For common 500m length horizontal wells, number of fracture segment was optimized for different formation permeability (see Figure 4 and Figure 5). Assumption: every single fracture length: 70 meters, conductivity: 20 D.cm, formation thickness: 14.5 meters. The simulation results show that, for a lower permeability reservoirs (the effective permeability is less than 0.1 ~ 0.3mD), single well productivity increase gradually with the increase of segment number, and substantially with linear tendency. As can be seen from the graph, with the effective permeability gradually increased, more and more well productivity can be gotten. But a turning point appeared with the change of segment number. For 0.5mD reservoirs, the turning point was about 5~6. For higher permeability reservoirs, the number of fractures needed was less and less (see Figure 5).When reservoir permeability is 1mD, the preferred number of fractures is 4-5. But if reservoir permeability is 3mD, this optimized number is 3-4. For even greater permeability reservoir, well productivity increased as the number of fractures. But for these high permeability reservoirs, compared with its higher natural production, one more fracture only contributes less than 1% production. Meanwhile, for optimized area, this production increase can reach 5%.We can conclude that for these good property wells and layers, stimulation aims to relieve pollution and put more effective interval into use, or to increase the connectivity between wellbore and formation natural fractures.

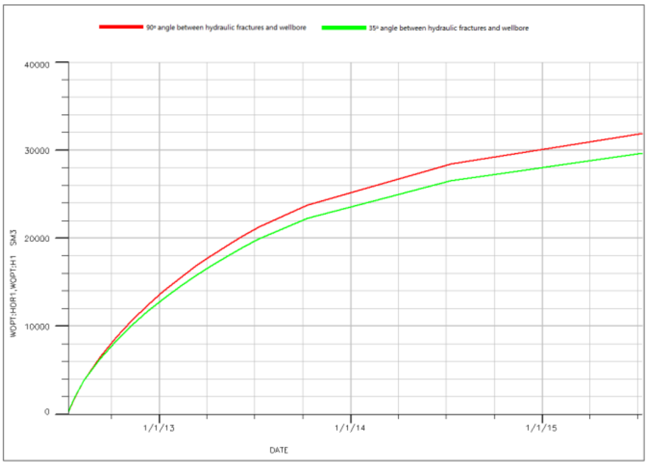

Figure 3. Accumulative Oil Production with Angle 35°and 90°

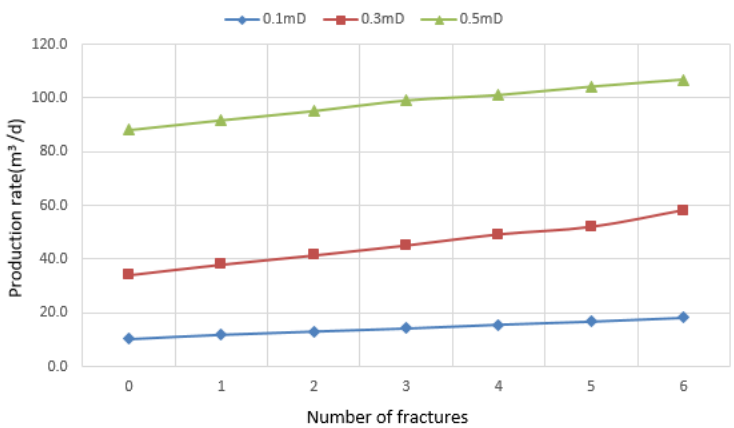

Figure 4. Productivity Changed with Fracture Number Under 0.1mD, 0.3mD and 0.5Md

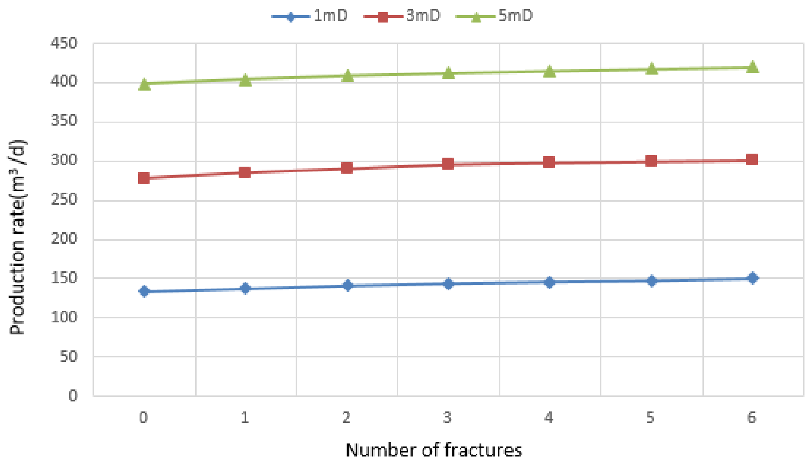

Figure 5. Productivity Changed with Fracture Number under 1mD, 3mD and 5mD

In addition, with the increase of permeability, reservoir connectivity improves, the pressure near wellbore transmit quickly, all these make the impact of fractures on single well production gradually decreases. Figure 6-7 shows that for 0.1mD reservoir, there is a new connected area once a fracture added. Figure 8-9 shows that for 5mD reservoir, oil drainage area almost doesn't change when fracture number increases. But for the good property reservoirs, the main purpose should be removing pollution and connecting natural fractures. Therefore, the optimized fracture number depends on physical properties and single well analysis results.

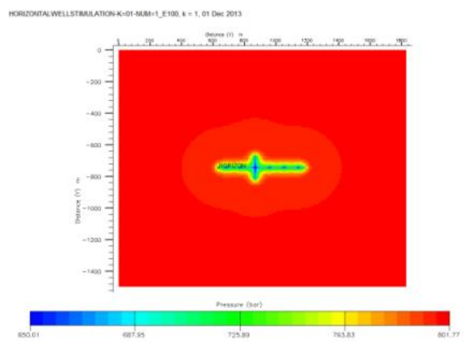

Figure 6. Drainage Area of 0.1mD and 1 Fracture

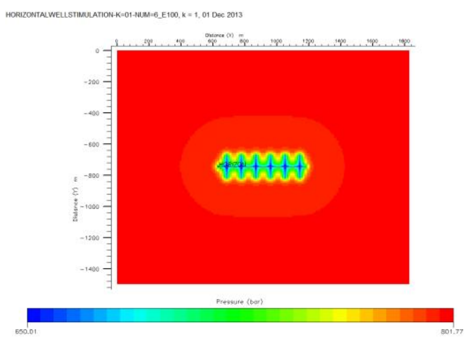

Figure 7. Drainage Area of 0.1mD and 6 Fractures

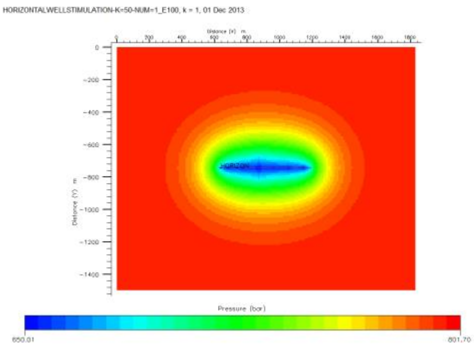

Figure 8. Drainage Area of 5mD and 1 Fracture

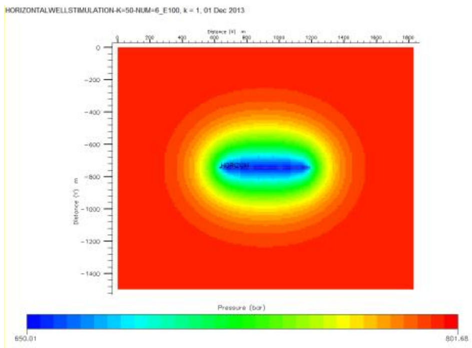

Figure 9. Drainage Area of 5mD and 6 Fractures

3.3. Optimization of Fracture Length

From above conclusions, we knew that the higher the reservoir permeability, the faster pressure propagates in the reservoir and thus the less fracture segments demanded. But on the opposite, for lower permeability reservoirs, too short fracture length can't keep stable production. Figure 10 shows when the reservoir of 0.1mD is divided into 5 sections and each fracture length reaches 110m, single well production increases 100%. Besides, Figure 10 shows when the reservoir of 5mD is fractured in the same way, single well production increases less than 5%.

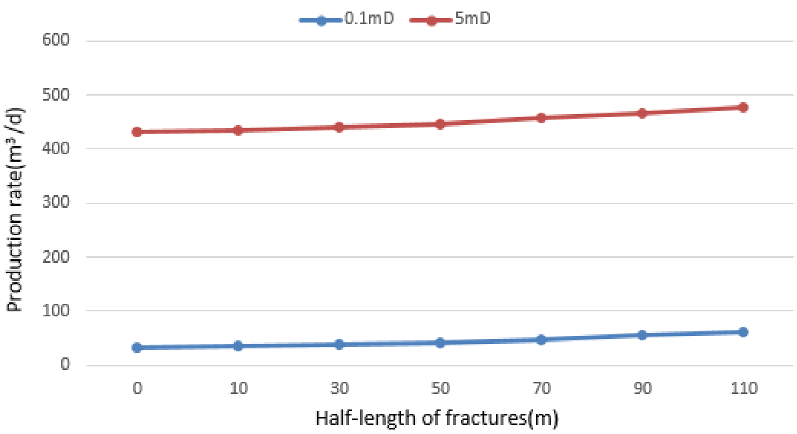

Figure 10. Production Increase with Different Fracture Length under 0.1mD, 0.5mD

Thus, for low permeability tight carbonate reservoirs, longer fracture length means more single well controlling area and productivity. While for high permeability reservoirs, due to the faster pressure transmission speed and good formation connectivity, fracture length plays a less impact on productivity.

3.4. Optimization of Fracture Conductivity

Fracture conductivity was also simulated. It can be seen that the optimized fracture conductivity of 0.1mD and 0.3mD formations is 15~20D.cm; 25D.cm for 1mD formation, 35D.cm for 3mD formation and 40D.cm for 5mD formation. It shows that the higher conductivity the more productivity. Detailed results are shown in Table 1.

Table 1. Optimized Conductivity under Different Formation Permeability

Reservoir permeability, mD	0.1	0.3	1	3	5
Recommended fracture conductivity, D·cm	15	20	25	35	40

Based on above simulation results, optimized fracturing treatment under different physical properties, formation thickness and horizontal section length were listed in Table 2.

Table 2. Optimized Parameters under Different Formation Properties and Horizontal Section Length

Effective thickness, m	Horizontal section length, m	Permeability, mD	Recommended segment number	Recommended fracture length, m	Recommended conductivity, D.cm
<10	800-1500	<0.1	10	100	20
		0.1-1	8	70	25
		>1	6	50	>30
10-20	600-800	<0.1	8	100	25
		0.1-1	6	70	30
		>1	4	50	>35
>20	400-600	<0.1	6	100	30
		0.1-1	4	70	35
		>1	3	50	>40

4. Optimization of Fracture Distribution

The distribution patterns of fracure directly affect the productivity of the horizontal well. As for. Staged fracturing of horizontal wells, it's important to determine a reasonable manner of distributing fracture. We studied the daily and accumulative productivity of fractured horizontal wells of different fractue distributon, and optimized the best fracture distribution model , on which the field performance could be theoretically guided.

4.1. Effect of Fracture Interval

Take eight artificial fractures for example. There are three different cases of fractures distribution: case I, eight cracks evenly distributed along the horizontal axis; case II, "sparse outer and dense inner", that is two stages fractures in the center, each stage have four clusters; Option III, "dense outer and sparse inner", that is two stages fractures in the center, each stage have four clusters; shown as Figure 11.

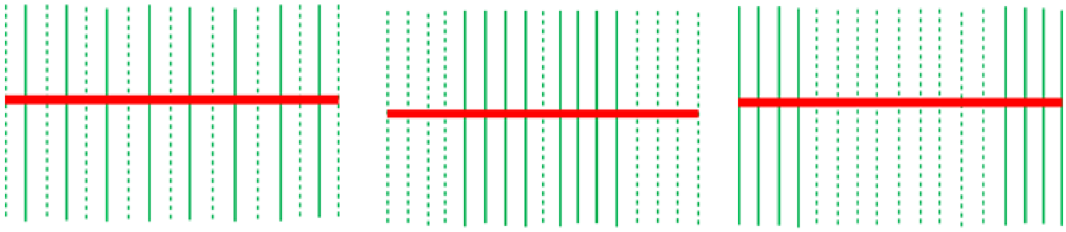

Figure 11. Sketch Map of Different Fractures Distribution

Simulation result show in Figure 12, it's shown that the accumulative production of case I is more than case III and the accumulative production of case III is more than case II. That means the fractures should be evenly distributed along the horizontal axis under acceptable technology.

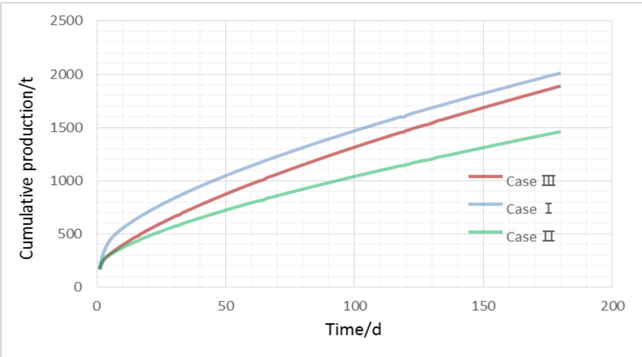

Figure 12. Accumulative Production Curves of Different Fracture Distribution

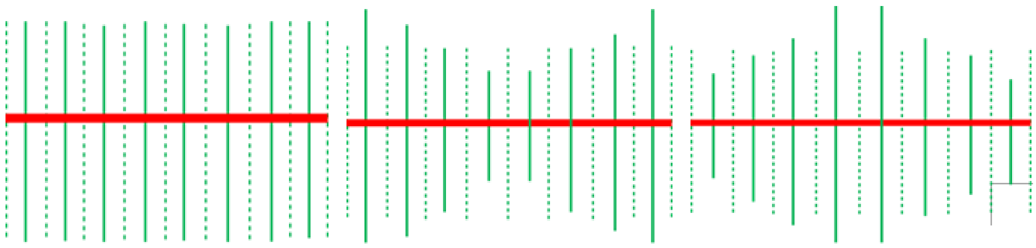

Figure 13. Sketch Map of Different Fractures Length

4.2. Effect of Fracture Length

In order to study the effect of fracture length on the accumulative production, take the eight fractures for example. Designed three cases, the total length of three cases is the same, which eliminated the effect of spread rang on production. Case I, equal length fracture, each length is 120m; case II, "dumbbell-shaped fracture" the lengths of fracture from left to right are180, 140, 100, 60, 60, 100, 140, 180m; case III, "spindle-shaped fracture", the lengths of fracture from left to right are 60, 100, 140, 180, 180, 140, 100, 60m. The sketch map of different fractures length shown as Figure 13.

Simulation result show in Figure 4, it's shown that the accumulative production of case I is more than case II and the accumulative production of case II is more than case III. That means the fractures in both ends should be longer, formed dumbbell-shaped fracture under acceptable technology.

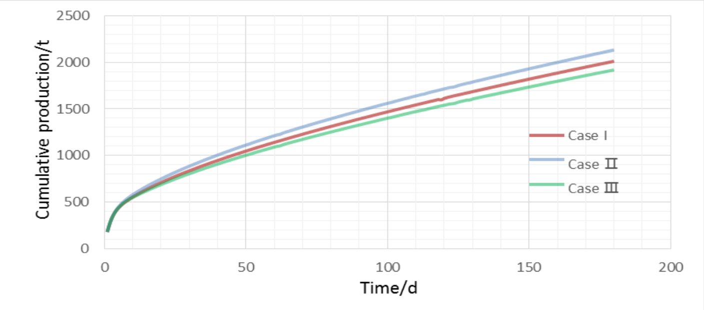

Figure 14. Accumulative Production Curves of Different Fracture Length

Table 3. Statistics of Horizontal Wells Staged Fracturing in D Block

No.	Horizontal Sectionm	Permmd	Staged number	Production After Acid t/d	Validityd	Accum Production
1	400	0.1-0.3	4	90	735	7742
2	401	0.3-1.0	4	94	735	30636
3	394	0.4-2.1	4	55	540	10851
4	398	0.2-0.8	5	71	499	6815
5	401	0.1-0.4	4	35	484	7915
6	455.5	0.3-1.4	5	26	443	8561
7	450	0.6-2.7	5	26	426	4599
8	600	0.2-0.3	5	51	276	4672
9	451	0.2-1.5	5	21	277	2666
10	601	0.2-0.5	5	29	210	1129
11	600	0.05-0.4	5	43	165	3477
12	601	0.3-0.6	5	31	158	2451
13	598.5	0.1-0.3	5	32	100	1677
14	450	0.1-1.5	5	34.00	86.00	2207.00
Sum	6801			638	5134	95398
Ave	485.79			45.57	366.7	6814.14

5. Field Application

The high efficient staged fracturing technology have been applied in 14 horizontal wells in DS low permeability reserves block. The reservoir property, horizontal section length, thickness and the reservoir distribution had been taken into consideration when doing the treatment design, open hole packers were used to stage. The treatment were conducted under the guidance of "even distribution, longer outer and shorter inner", the result shown in Table 3, the average daily production was 45.57t/d, the average accumulative production in validity was 6814t.

The total effect of these horizontal wells was 3.1 times of the vertical wells in the same block.

6. Conclusion

The direction of fractrues effect the poductivity of horizontal wells. The horizotal wells production of transverse fractures is higger than of non-transveres. The strike of horizontal should be along with the minimum principal stress, so the transverse fractures should be got, the production would be higher.

The production has relarionship with the fracture parameters. The simulation result shown that, with the increase of fracture length, conductivity, the production of horizontal well could increase and there would be "viscous" increase. So as for specific reservoir, when the permeability is less than 0.1mD, the thickness is less than 15m, the well should be placed carefully. To realied the best develop, the optimal fracture parameters should be matched with reservoir.

The fracture distribution effect the production. So the fractures should be uniformly placed along the horizontal axis under the acceptable technology, the length of outer fractures would be longer. The “even placement, outer longer and inner shorter” pattern is conducive to improve the production of staged fracturing horizontal wells

The formulated high efficient stimulation simulation technology of horizontal wells had been applied in Z oil field, and yield favorable effect. This technology would provide theoretical guidance for the development of low permeable carbonate reservoir.

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