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Evaluation of Development Effect of Tight Oil in Daqing Oilfield

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Abstract

Tight oil reserves are very rich in China, which has become a hot spot and focus in the field of unconventional oil and gas resources in recent years. The unused reserves in the periphery of Daqing are mainly the tight reservoirs in Fuyu oil layer. How to carry out the commercial development of tight oil and obtain economic benefits is the top priority at present. In recent years, the application of large-scale fracturing technology has achieved good production effect in tight oil mining. Through field test, the rapid construction and effective utilization of tight oil have been accelerated, and the technical breakthrough has been realized. Finally, numerical simulation technology is used to further demonstrate the feasibility of large-scale fracturing technology for tight oil mining.

Keywords

Fuyu Oil Layer; Tight Reservoir; Large Scale Fracturing Technology; Development Effect Evaluation.

1. Introduction

The main difficult-to-produce reserves in the periphery of Daqing Oilfield are tight reservoirs in Fuyu oil layer. In order to realize the economic and effective utilization of such reservoirs, 15 field tests of tight oil have been carried out from 2013 to 2018. According to the characteristics of different reservoirs, new technologies are used to increase production and new mechanisms are used to promote production. Two development models, 'vertical well+fracture network fracturing' and 'horizontal well+volume fracturing', have been established and solidified. Among them, single-layer single sweet spot and multi-layer superimposed concentrated sweet spot are developed by large-scale horizontal well fracturing, and large-scale sweet spot area is developed by vertical well fracture network fracturing. The cumulative production is 3.6 million tons and the cumulative oil production is 5.54 million tons. Good development results have been achieved and breakthroughs have been achieved in technology (Table 1). However, since the development of tight oil is accompanied by a substantial increase in engineering investment (large-scale fracturing investment or long horizontal well), the investment of single well is usually 2-3 times that of conventional oil in the development scheme, which is mainly reflected in two aspects of drilling investment and fracturing investment. Therefore, under the condition of low oil price, economic factors have become a key factor restricting the effective use of tight oil. A new mechanism and new system have been developed for the development of tight oil to achieve the goal of reducing investment and cost, thus promoting the progress of tight oil development from single well to test area to development area [1–5].

In order to effectively improve the development effect of Fuyu oil layer and make economic and effective use of this kind of oil layer, three key production experiments were carried out, namely, the production improvement experiment of single well fracture network fracturing in vertical wells, the production improvement experiment of fracture network fracturing in experimental area, and the production improvement experiment of horizontal well volume fracturing [7]. The

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three tests have achieved good results, which can be widely applied to ensure the effective and economic use of Fuyu oil layer.

Table 1. Overview of tight oil test area

serial number	block	horizon	Area (km^2)	Reserves (10^4t)	Number of wells (wells)			Build capacity (10^4t)	Accumulated oil (10^4t)	Development Model
					Design	Finishing drilling	Go into operation			
1	Yuanping 1	F	11.8	305	9	9	9	3.77	10.21	Horizontal well volume fracturing
2	Qiping 2	G	12.8	239	11	11	11	1.23	3.10	
3	Long 26	G	21.6	345	12	12	10	6.34	14.03	
4	Long 26 Outward expansion	G	129.8	2124	42	35	18	1.84	4.33	
5	Pu 34	F	14.5	297	14	10	10	1.88	3.50	
6	Fang 38	F	19.3	299	15	9	9	1.10	2.05	
7	Yuan 151	F	4.3	203	9	6	6	1.15	1.84	
8	Yuan 211	F	16.4	349	9	9	2	0.18	0.18	
9	Fang 198-133	F	6.38	239	9	8	/	/	/	
10	Pu 42-5	F	6.6	139	6	4	4	0.14	0.14	
Subtotal			243.5	4539	136	113	79	17.63	39.38	
11	Zhou 602-4	F	2.1	84	19	19	15	0.57	1.70	Vertical well fracture network fracturing
12	Ta 9	F	7.3	263	17	15	11	0.54	0.91	
13	Pu 483	F	4.5	321	57	7	2	0.11	0.11	
14	Shu 9-2	F	2.7	194.2	33	33	23	1.06	1.06	
15	Ta 21-4	F	45.6	2317	290	86	/	/	/	
Subtotal			62.2	3179	416	160	51	2.39	3.78	
Total			305.7	7718	552	273	130	30.67	55.4	

Table 2. Statistical table of production improvement effect of fracture network fracturing in Fuyu oil layer

Blocks	Mining horizon	Permeability (mD)	Fracturing time (Years and months)	Number of fractured wells (wells)	Number of fracturing segments (number)	Fracturing thickness (m)	Construction scale (m^3)		Before measures			Early after measures			Daily incremental oil (t/d)
							Sand content	Liquid measure	Producing liquid (t/d)	Oil production (t/d)	Water rate (%)	Producing liquid (t/d)	Oil production (t/d)	Water rate (%)	
Pu 333 guide	Fuyu	1.35	2011~2012	5	6.6	19.2	129	3039	1.7	0.6	62.7	14.9	7.8	47.8	7.2
Pu 333	Fuyu	1.35	201304	17	4.5	13.7	105	6582	1.1	0.4	64.3	11.0	3.6	67.1	3.2
Shu 2	Fuyu	1.0	201306	4	3.3	12.2	89	5827	1.0	0.7	25.6	22.3	10.3	53.8	9.6
Zhou 6	Fuyu	1.2	201308	9	3.9	8.8	100	4880	0.5	0.3	40.0	21.1	3.9	81.6	3.6
Mao 503	Fuyu	0.8	201309	2	5	16.5	120	7411	1.8	1.2	33.3	43.1	14.7	65.9	13.5
Yuan 121-3	Fuyu	1.0	201310	4	4.5	14.2	104	6709	0.3	0.3	5.0	24.6	4.7	80.9	4.4
Total				41	4.6	14.1	108	5741	1.07	0.58	45.8	22.8	7.5	67.1	6.9

2. Fracturing effect evaluation of vertical well fracture network

2.1. Fracturing productivity evaluation of vertical well fracture network

2.1.1. Single well fracturing test in vertical wells

In order to seek the effective production mode of Fuyu oil layer, the fracture network fracturing production test has been carried out since 2011. According to the statistics of six blocks, the effect of fracture network fracturing on increasing oil is significant. Before the test, it is the

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conventional fracturing water injection development, and the mining effect is poor. The fracture network fracturing technology is used to transform the reservoirs that cannot be economically and effectively used. The stimulation effect of fracture network fracturing in 41 wells in 6 blocks of Fuyu oil layer is counted. After the measures, the average daily oil increase is 6.9 t. The initial production of fracture network fracturing is 1.8-5.6 times of the stable production of conventional fracturing, and the average is 2.4 times (Table 2).

2.1.2. Fracture network fracturing production test in test area

After good results have been achieved in the single well fracture network fracturing test of the old vertical wells, Ta 9 and Shu 9-2 fracture network fracturing test areas have been opened in 16 and 17 years, respectively, and good results have been achieved. The initial stable oil production intensity is 0.25t/d.m–0.30t/d. m, which is about two times higher than that of conventional fracturing. The median porosity is 13.2% and the median permeability is 0.52 mD in Ta 9 test area. The fractured water injection development of 600m×240m well pattern and fracture network is used, and 9 wells are put into production. The average effective thickness of single well is 6.9 m, and the initial stable oil recovery strength is 0.26t/d.m (Table 3). The porosity of Shu 9-2 test area is 11.6%, and the permeability is 0.61 mD. The 450m×150m well pattern and fracture network fracturing water injection development are adopted. 33 wells are deployed, and 20 wells are put into production. The average effective thickness of single well is 12.7 m, and the initial stable oil recovery strength is 0.29t/d.m.

Table 3. Table 9 Production Situation of Test Area

Serial number	Well number	Oil test/reflow stage				Initial stability (1 year)			
		Fluid production (t)	Oil production (t)	Oil production intensity (t/d.m)	Water rate (%)	Fluid production (t)	Oil production (t)	Oil production intensity (t/d.m)	Water rate (%)
1	Ta 24-120-Xie 121	16.5	2.5	0.29	84.8	4.3	2.1	0.24	31.6
2	Ta 24-120-Xie 123	3	1.9	0.70	36.7	0.2	0.2	0.06	9.1
3	Ta 24-124-Xie 121	5.9	2.4	0.30	59.3	3.0	1.7	0.22	36.2
4	Ta 24-124-Xie 123	9.6	2.7	0.69	71.9	2.8	1.6	0.41	27.8
5	Ta 24-124-Xie 125	9	2.9	0.74	67.8	2.7	1.8	0.46	21.5
6	Ta 24-128-Xie 121	9.6	5.8	1.61	39.6	2.8	2.3	0.64	11.6
7	Ta 24-128-123	5.4	3.9	0.53	27.8	3.2	2.3	0.31	26.9
8	Ta 24-132-Xie 123	5.5	4.2	0.25	23.6	2.9	2.5	0.15	14.9
9	Ta 24-132-Xie 125	8.5	3.1	0.47	63.5	2.5	1.7	0.26	16.1
Average		8.1	3.3	0.47	59.3	2.7	1.8	0.26	33.3

2.1.3. Scale application of vertical well fracture network fracturing

Ta 21-4 well area is developed by vertical well fracture network fracturing elastic mining mode. Two sets of development well patterns of 500m×300m and 600m×300m are used. A total of 290 vertical wells (including 31 substitute wells) are designed. The daily oil production of single well in the early stage is predicted to be 2.61~3.81t/ d, the construction capacity is 26.89×10^4t, and the geological reserves are 2317.44×10^4t.

At present, 60 wells have been fractured and put into production in Ta 21-4 well area. The average thickness of single well fractured sandstone is 16.6m, and the effective thickness is 8.8m. The fracturing fluid is injected into 5951 square wells, sand is added into 262 square

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wells, 39 pumping wells, and 21 self-injection wells are produced. The average daily oil production of single well is 3.7 t/d, the comprehensive water cut is 69.3%, and the cumulative oil production of the whole region is 12,561t, which meets the design index.

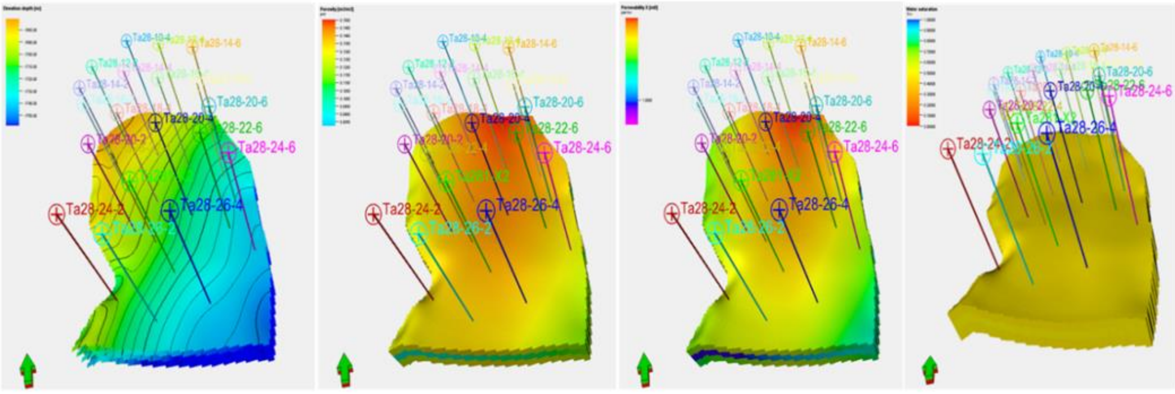

Fig. 1 Vertical well fracture network fracturing test area geological modeling

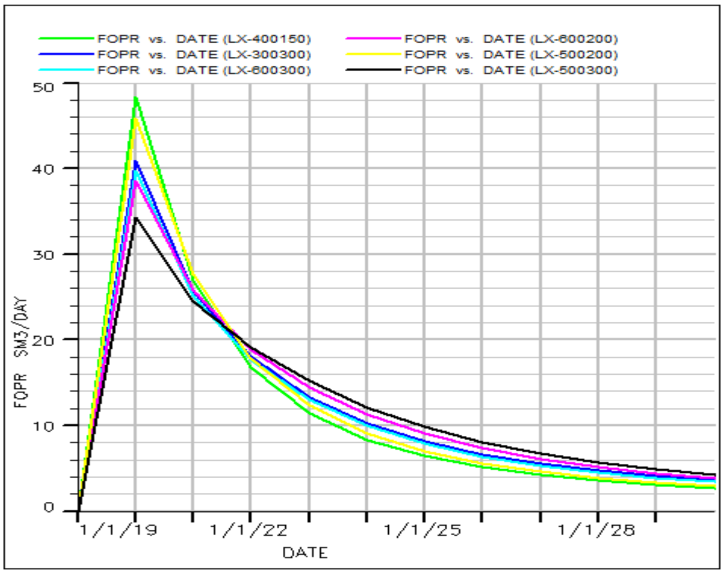

Fig. 2 Daily oil production curve of vertical well fracturing with different well pattern vertical

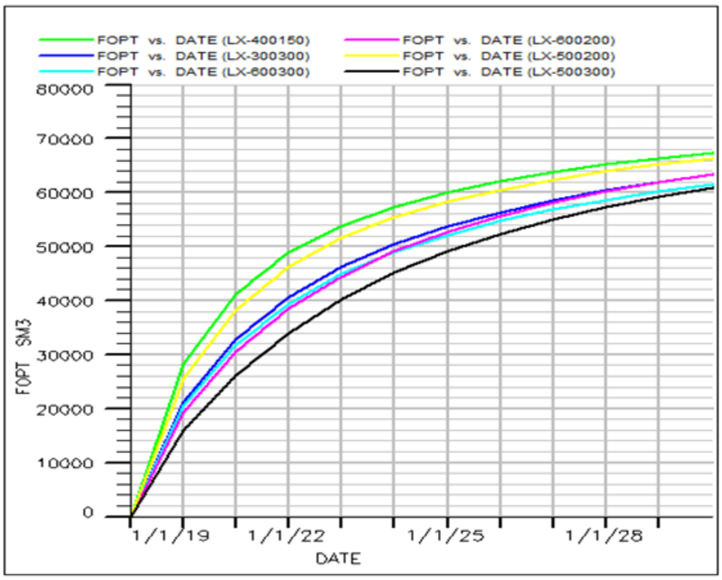

Fig. 3 The cumulative oil production curve of well fracturing with different well pattern

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Through the single well production test, the development effect of the test area and the development zone, the fracture network fracturing technology has a significant effect on the production of tight reservoirs, which can greatly improve the initial oil recovery rate and well control reserves, and realize the purpose of low well production and effective use. The initial stable oil recovery intensity can reach 0.25t/d.m~0.30t/d.m.

2.2. Fracturing recovery prediction of vertical well fracture network

According to the geological and logging data, the Petrel software is used to model, and the sand body size, reservoir continuity, fracturing scale and other factors are considered. The numerical simulation is carried out to predict the production law of vertical well fracture network fracturing in Ta21-4 fracture network fracturing test area. The predicted recovery rate is between 6.2% and 10.5% [8–9]. The decline law is in line with the hyperbolic decline model. The initial annual comprehensive decline rate is 0.30–0.35, and the decline index is 0.4.

Table 4. Relationship Table of Fracturing Recovery of Vertical Wells with Different Well Patterns

Well pattern	Well pattern density (well/km^2)	Controlled reserve (10^4/well)	Average initial daily oil production per well (t/d)	Single well limit cumulative oil production (10^4t)	Technical recovery factor (%)
600*300	6	9.08	0.37	0.7448	6.2
500*300	7	7.78	0.35	0.7396	7.5
600*200	8	6.81	0.33	0.7221	8.6
500*200	10	5.45	0.31	0.6812	10.5

Table 5. Statistical Table of Production in Yuanping 1 Experimental Area

Serial number	Well number	Length (m)			Fracturing situation				Controlled reserve (10^4t)	First year output (t/d)	Production days	Total oil
		Horizontal zone	Sand stone	Oil sandstones	Method	Joint spacing	Fracturing fluid (m^3)	Sand-adding (m^3)				
1	Yuanping 1	2660	1484	1021	Cutting	30	9971	1079	27.9	21.1	2228	25414.7
2	Yuanping 1-1	1626	1485	1479	Cutting	60	14307	1430	28.4	20.5	1539	18336.8
3	Yuanping 1-2	805	378	332	Cutting	55	6787	680	11.3	9.9	1263	6170.8
4	Yuanping 1-3	1136	906	723	Cutting	50	7704	770	14.3	8.7	1444	6368.8
5	Yuanping 1-4	1468	1446	1434	Cutting	55	8600	820	16.6	11.8	1252	9964.1
6	Yuanping 1-5	990	961	840	Cutting	55	10837	1116	17.2	15.4	1592	13939.1
7	Yuanping 1-6	1109	849	679	Cutting	75	7616	770	16.6	6.4	1154	4894.1
8	Yuanping 1-7	1547	935	909	Cutting	50	9461	797	17.1	10.4	1292	8839.1
9	Yuanping 1-8	1027	281	213	Cutting	70	8031	690	10.7	9.1	1427	7005.3
Average		1374	969	848		56	9257	906	17.7	12.6	1466	100932.8

3. Effect Evaluation of Horizontal Well Volume Fracturing

3.1. Productivity evaluation of horizontal well volume fracturing

A total of 9 horizontal wells were drilled in Yuanping 1 test area. The length of drilled horizontal wells was 1374m, the length of drilled sandstone was 969m, the length of oil-bearing sandstone

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was 848m, the drilling rate of sandstone was 70.5%, the drilling rate of reservoir was 61.7%, the oil immersion was 229.0m, the oil spot was 478.6 m, and the oil trace was 120.5m.

Yuanping 1 test area completed a total of 9 wells volume fracturing, starting production in October 2013, the average single well fracturing 8.8,18.5 clusters, liquid addition 9257 m^3, sand addition 906 m^3, production decline rapidly in the early three months, production tends to be stable after nine months, the first year average single well daily oil production 12.6 t, basically reached the design level, the overall production effect is good. The average length of the test area in Yuanping 1 is 1374 m. The sandstone drilling rate is 70.5%, and the oil layer drilling rate is 61.7%. The stable production in the first year is 12.6t/d, and the cumulative oil production is 100932.8t (Table 5).

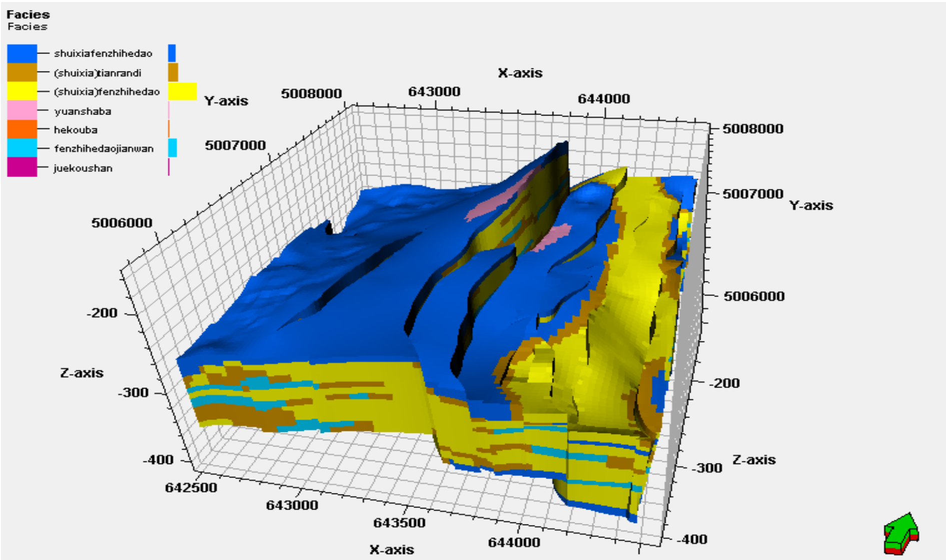

Fig. 4 Geological Model of Well Yuanping 1

According to the development effect of horizontal well large-scale fracturing test area, the application of horizontal well large-scale fracturing technology can achieve effective utilization for the tight reservoir with thin whole well thickness but prominent main layer. For horizontal wells with horizontal section length of 1000m~1500m, the initial stable production can reach 6~20 t/d.

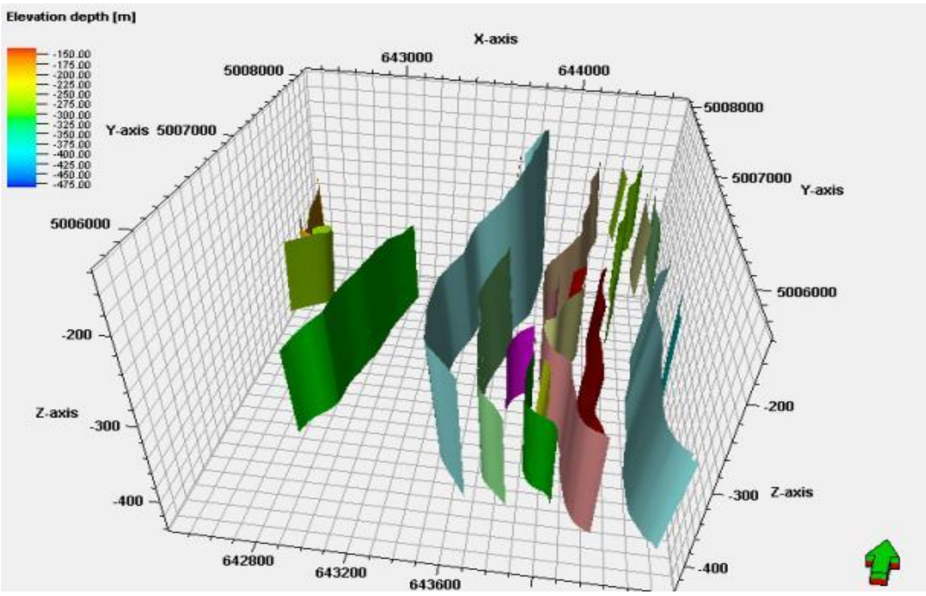

Fig. 5 Yuanping 1 Well Area Pressure Field Diagram

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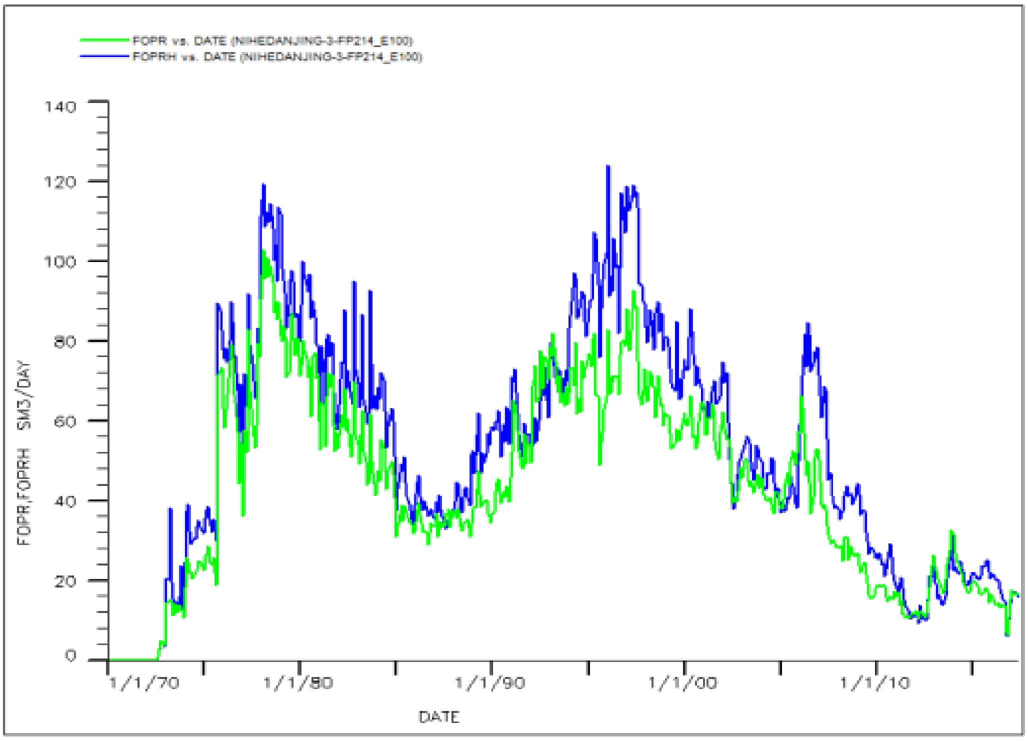

Fig. 6 Historical fitting curves of Yuanping 1 well area

3.2. Horizontal well volume fracturing recovery prediction

Through the historical matching of numerical simulation, the elastic recovery of nine development wells in Yuanping 1 test area is6.6–12.8%, with an average of 10.0% (Fig.4, Fig.5, Fig.6). Through the production prediction curve of 9 wells in Yuanping 1 test area, it is preliminarily judged that the elastic mining decline of large-scale fractured horizontal wells conforms to the hyperbolic decline law, the initial annual decline rate is 40%, and the decline index is 0.5 (Fig.7). The recovery factor is 9.85% calibrated by the decline curve method ; The decline curve method and numerical simulation method are used to comprehensively determine that the decline rate is 40% of the initial annual decline rate and the recovery rate is 10%[10–13].

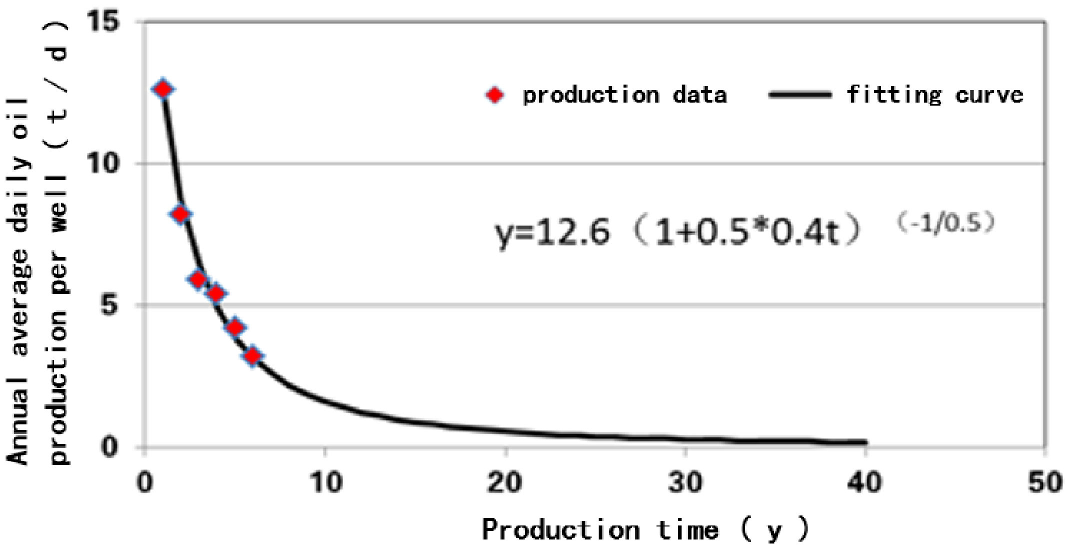

Fig. 7 Production prediction curve of Yuanping 1 well area

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4. Conclusion

(1) Through the recent field practice of tight oil development, it is determined that the stable oil recovery intensity in the initial stage of vertical well fracture network fracturing can reach 0.25–0.30 t/d.m, which is about two times higher than that of conventional fracturing, and the technical recovery rate is 6.2–10.5%. The initial stable production of horizontal well volume fracturing can reach 6.4–21.2t/d, and the average recovery is about 10%.

(2) The results of numerical simulation technology show that for tight oil, the use of large-scale fracturing technology has good application prospects, which can lay the foundation for the efficient development of tight oil and the increase of oil production.

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