International Journal of Science, Environment and Technology, Vol. 6, No 5, 2017, 3095 – 3104

ISSN 2278-3687 (O)
2277-663X (P)

INFLUENCE FACTORS OF FRACTURED HORIZONTAL WELL PRODUCTIVITY IN HESHUI CHANG 6 TIGHT OIL RESERVOIR

Meng Zhan, Yang Shenglai and Wang Lu, Qian Kun, Ma Quanzheng
CMOE Key Laboratory of Petroleum Engineering in China University of Petroleum,
Beijing 102249, P.R. China

Abstract: Volume fracturing has become an effective technology in tight sandstone reservoir stimulation, however, only the correlation between individual parameters and productivity were considered when doing sensitivity analysis, rarely took a full account of the degree of influence of each parameter on the horizontal well productivity. This paper considered the formation parameters, fracturing operation parameters and the well spacing, which contained the porosity, permeability, horizontal well length, fracturing stages, fracture length, fracture conductivity and the well spacing. Then, the information amount theory and gray correlative method were used to calculate the productivity parameters of fractured horizontal wells, and checked the results by numerical simulation. The results revealed that fracture length, horizontal well length and fracturing stages as primary parameters, and permeability, porosity, fracture conductivity and well spacing as secondary parameters. Therefore, the accurate fracturing design and operation is expected to significantly improve the productivity of Heshui Chang 6 tight sandstone reservoir.
Keywords: Tight sandstone reservoir, multistage volume fracturing, productivity influencing parameters, numerical simulation, orthogonal experiment

Introduction

With the depletion of conventional oil and gas energy and the continuous development of petroleum technology, dense reservoir gradually become the darling of Petroleum Exploration and Development. Dense oil and gas resources are widely distributed in China, including Ordos Basin tight oil zone, where has already put into commercial development [1]. Ordos Basin tight oil is mainly developed in the original lake center, such as Chang (4+5), Chang 6, Chang 7, Chang 8, Chang 9 oil groups, which has an area of about $(8\sim10)\times10^4 km^2$, and the predicting geological resources is $(35\sim40)\times10^8 t$. In this paper, Heshui Chang 6 tight sandstone reservoir is chosen as the research object, the results have reference value for the other tight reservoirs.

Heshui Chang 6 tight oil reservoir possesses "low permeability, low pressure, low abundance" features, horizontal well completions and multistage volume fracturing [3] process has become the key technology in the successful development of tight reservoirs. But the

*Received Sep 7, 2017 * Published Oct 2, 2017 * www.ijset.net*

influential factors of Heshui Chang 6 fractured horizontal well productivity is not only the length of horizontal wells, fracture half-length, fracturing stages, conductivity, but also the geological and reservoir condition and well network parameters. In the actual fracturing design, it is necessary to pick out the main factors in order to guide fracturing design more effectively.

Analysis of information amount calculation

According to information amount theory [4], horizontal well length, fracture half-length, fracturing stages, conductivity, porosity, permeability, well spacing, row spacing these eight factors are respectively calculated, which associate with the fractured horizontal well initial productivity. The size of various factors information displays the impact on the fractured horizontal well initial productivity. The greater the total amount of information, the greater impact on the fractured horizontal well initial productivity. By using the basic practice information amount analysis, the initial production capacity which is less than 10.5t/d is divided into group A, more than 10.5t/d is divided into Group B. Every factor will respectively counted in different range and the frequency of group A and group B will also be worked out. The distribution of the difference between A and B will be obtained by further calculation. The larger difference degree means the larger amount of information. The calculation steps are as follows:

①Calculate the probability frequency of group A and group B in every interval, namely $y_{A\delta}$ and $y_{B\delta}$, δ is the interval number;

②Calculated the average probability frequency $\overline{y_{\delta}}$ of each interval, the formula is $\overline{y_{\delta}}=0.1(y_{\delta-2}+2y_{\delta-1}+4y_{\delta}+2y_{\delta+1}+y_{\delta+2})$;

③Calculate the average frequency ratio $\overline{y_{A\delta}}/\overline{y_{B\delta}}$;

④ Calculate the diagnosis coefficient Z_{δ}: $Z_{\delta}=10l_g(\overline{y_{A\delta}}/\overline{y_{B\delta}})$;

⑤ Calculate the amount of information on each parameter change interval I_{δ}: $I_{\delta}=1/2Z_{\delta}(\overline{y_{A\delta}}-\overline{y_{B\delta}})$;

⑥ Calculate the total amount of information I: $I=\Sigma I_{\delta}$。

Selecting 10 fractured horizontal wells XY24-22, XY25-17, XY26-18, XY26-19, XY32-27, XY33-26, XY34-23, XY34-24, XY34-25, XY7 in Heshui Chang 6 tight oil reservoir as examples to calculate the impact of various parameters on fractured horizontal well productivity, and parameters of horizontal wells of Chang 6 formation in Heshui Area are shown in Table 1. The amount of information of horizontal well length, fracture half-length, fracturing stages, conductivity, porosity, permeability, well spacing, row spacing these eight factors are respectively calculated.

Table 1: Parameters for horizontal wells of Chang 6 formation in Heshui Area

Well	initial productivity/(t/d)	horizontal well length /m	fracturing stages	fracture half-length/m	conductivity/($\mu m^2 \cdot cm$)	porosity /%	permeability/$10^{-3}\mu m^2$	well spacing/m	row spacing/m
XY24-22	10.48	667	8	121	31	10.2	0.169	650	60
XY25-17	11.04	695	8	172	31	11.2	0.221	400	130
XY26-18	9.86	911	8	160	31	10.0	0.159	520	140
XY26-19	10.6	876	9	135	31	9.8	0.137	650	210
XY32-27	11.95	1034	12	208	20	10.7	0.22	700	219
XY33-26	12.3	1120	14	234	27	10.9	0.256	800	183
XY34-23	10.8	855	8	186	25	10.3	0.156	420	102
XY34-24	10.9	909	12	172	25	9.6	0.175	550	138
XY34-25	10.02	836	11	152	25	8.5	0.301	650	180
XY7	9.16	500	7	122	19	9.9	0.114	620	265

In this paper, the information amount of horizontal well length is calculated as example, the calculation process will be described and the results in Table 2, then total information amount of other parameters are calculated in the same way, the result shown in Figure 1. As can be seen from the results of the analysis, the fracture half-length, horizontal well length, fracturing stages these three parameters are major factors that affect Heshui Chang 6 tight sandstone reservoirs fractured horizontal well productivity.

Table 2: Information amount calculation of horizontal well length

sequence number	interval of length/m	quantity		probability frequency		average frequency		average frequency ratio	Z_δ	I_δ
		A	B	$y_{A\delta}$	$y_{B\delta}$	$\bar{y}_{A\delta}$	$\bar{y}_{B\delta}$	$\bar{y}_{A\delta}/\bar{y}_{B\delta}$		
1	0-590	1	0	25	0	15	1.67	9	9.542	63.616
2	590-670	1	0	25	0	15	3.33	4.5	6.532	38.104
3	670-750	0	1	0	16.67	10	11.67	0.86	-0.67	0.558
4	750-830	0	0	0	0	10	13.33	0.75	-1.249	2.082
5	830-910	1	3	25	50	15	20	0.75	-1.249	3.123
6	910-990	1	0	25	0	15	15	1	0	0
7	990-1070	0	1	0	16.67	7.5	15	0.5	-3.01	11.289
8	1070-1150	0	1	0	16.67	2.5	10	0.25	-6.021	22.577
Sum		4	6	100	100	90	90	17.61	3.88	141.35

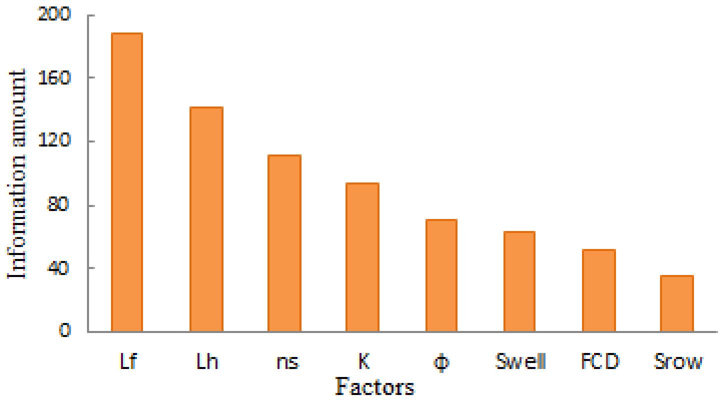

Fig.1: Information amount comparison of different parameters

Analysis of Grey relational calculation

Grey relational analysis[6-9] can handle random factors, identify their relevance and the main factors. Considering the practicality of this method, grey relational analysis is applied to analysis Chang 6 tight sandstone reservoir fractured horizontal well productivity factors in this paper. Set $X_0=\{X_0(k)|k=1,2,\cdots,n\}$ as the reference column (also known as the major column), $X_i=\{X_i(k)|k=1,2,\cdots,n\}$ $(i=1,2,\cdots,m)$ as the comparison columns (also known as sub-series or factors columns) where n is the number of values (number of wells) for each parameter, m is the number of comparison columns (the number of parameters). The Xi (k) and X_0 (k) of the correlation coefficient ξ is: $\xi_i(k)=\dfrac{\underset{i}{Min}\,\underset{k}{Min}\,\Delta_i(k)+\rho\,\underset{i}{Max}\,\underset{k}{Max}\,\Delta_i(k)}{\Delta_i(k)+\rho\,\underset{i}{Max}\,\underset{k}{Max}\,\Delta_i(k)}$

Where ρ is distinguished coefficient, $\rho\in(0,+\infty)$. The smaller ofρ , the stronger the ability to distinguish. The specific value of ρ usually takes 0.5 while the general value of the interval is (0,1). The absolute difference of X_i and X_0 at the k time (index or spatial) is $\Delta_i(k)=|X_0(k)-X_i(k)|$, and then the correlation coefficient of X_i and X_0 can be obtained, $\xi_i=\{\xi_i(k)|k=1,2,\cdots,n\}$. Correlation can be obtained by the average method: $\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$.

According to the data in Table 1, take the initial production data as a reference sequence and the remaining eight parameters as comparison columns. The parameters of the normalized results are shown in Table 3. According to Table 3, correlation degree can be obtained by further correlation and the results are shown in Figure 2. The results show consistent with the information amount analysis.

Table 3: Normalized results of productivity-influencing factors

Well	Initialproductivity	horizontal well length	fracturing stages	fracture half-length	conductivity	porosity	permeability	well spacing	row spacing
XY24-22	0.42	0.269	0.143	0	1	0.637	0.294	0.625	0
XY25-17	0.599	0.315	0.143	0.451	1	1.006	0.572	0	0.341
XY26-18	0.223	0.663	0.143	0.345	1	0.539	0.241	0.3	0.39
XY26-19	0.459	0.606	0.286	0.124	1	0.48	0.123	0.625	0.732
XY32-27	0.889	0.861	0.714	0.770	0.083	0.815	0.567	0.75	0.776
XY33-26	1	1	1	1	0.667	0.889	0.759	1	0.6
XY34-23	0.522	0.573	0.143	0.575	0.5	0.654	0.225	0.05	0.205
XY34-24	0.554	0.66	0.714	0.451	0.5	0.396	0.326	0.375	0.38
XY34-25	0.274	0.542	0.571	0.274	0.5	0.01	1	0.625	0.585
XY7	0	0	0	0.009	0	0.52	0	0.55	1

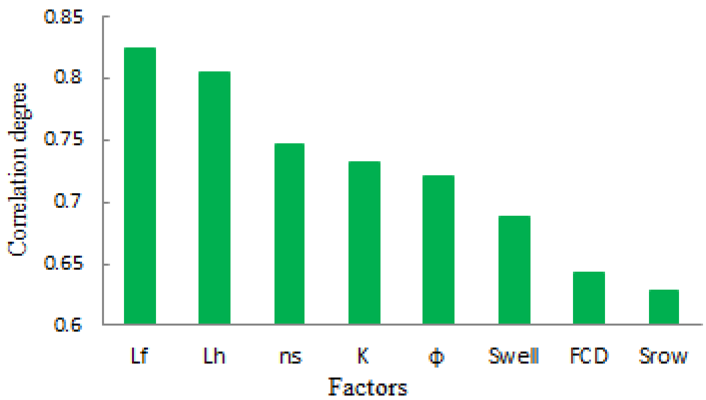

Fig. 2: Grey correlation degree sorting of different parameters

Numerical simulation of Orthogonal experiment

Since most of the Heshui Chang 6 tight oil reservoir horizontal wells take multistage volume fracturing process, numerical simulation of this article takes LS-LGR (logarithmic spacing - local grid refinement) modeling method [10-11] to reflect this characteristic. The Heshui Chang 6 tight oil reservoir simulation parameters are as follows: original formation pressure 14.7MPa, average reservoir thickness 20m, the original oil saturation 54.6%, formation oil viscosity 0.807mPa • s, ground oil density 0.84g / cm^3. Take net grid step dx = dy = 10m, only one lay in the vertical. Artificial hydraulic fracture is calculated by the equivalent conductivity. The modeling grid is shown in Figure 3.

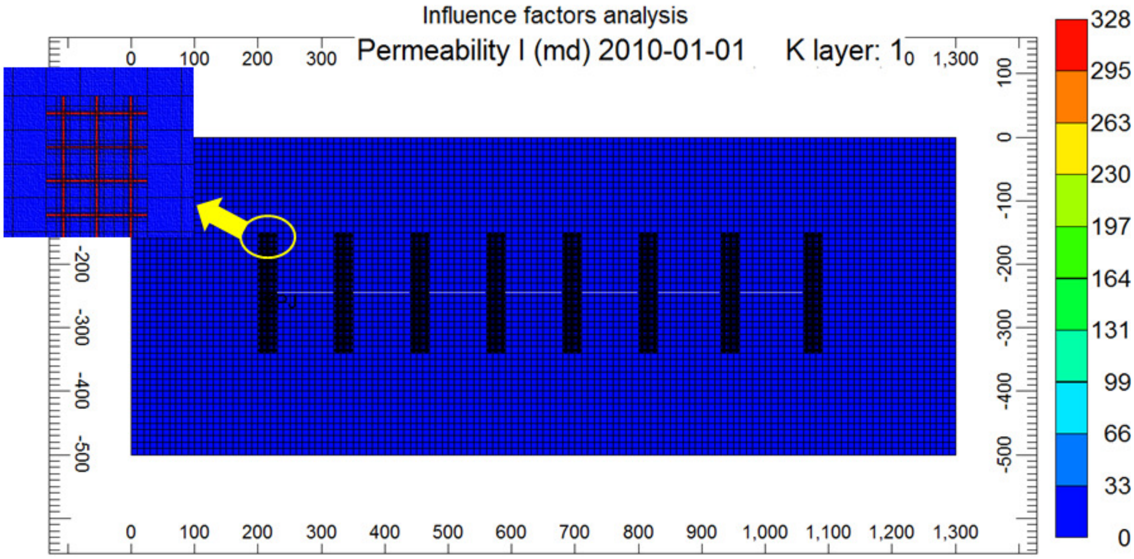

Fig.3 Schematic diagram for volume fracturing network of a horizontal well

An orthogonal 3100 experiment is designed to verify the results of the analysis of statistical data. Table L32 (4^9) is selected for the experiment. Select the length of horizontal wells, fracturing stages, fracture half-length, conductivity, porosity, permeability, well spacing, row spacing eight parameters and four levels of value, as is shown in table 4. By designing orthogonal experiment, analyze the impact of various primary and secondary factors. The specific programs and three-year cumulative oil production are shown in Table 5.

Table 4: Level values of different parameters in orthogonal experiments

the level of value	horizontal well length /m	fracturing stages	fracture half-length /m	conductivity /($\mu m^2 \cdot cm$)	porosity /%	permeability /$10^{-3}\mu m^2$	well spacing /m	row spacing /m
1	500	8	50	10	8	0.1	400	100
2	700	10	90	15	9	0.2	500	150
3	900	12	130	20	10	0.3	600	200
4	1100	14	170	25	11	0.4	700	250

Table 5: Orthogonal experiments scenarios

number	horizontal well length /m	fracturing stages	fracture half-length /m	conductivity /(D•cm)	porosity /%	permeability /mD	well spacing /m	row spacing /m	three-year cumulative oil production/t
1	500	8	50	10	8	0.1	400	100	2430.46
2	500	10	90	15	9	0.2	500	150	3676.88
3	500	12	130	20	10	0.3	600	200	5034.28
4	500	14	170	25	11	0.4	700	250	6333.83
5	700	8	50	15	9	0.3	600	250	3050.37
6	700	10	90	10	8	0.4	700	200	4632.75
7	700	12	130	25	11	0.1	400	150	6537.16
8	700	14	170	20	10	0.2	500	100	8148.12

9	900	8	90	20	11	0.1	500	200	4757.19
10	900	10	50	25	10	0.2	400	250	3770.64
11	900	12	170	10	9	0.3	700	100	8761.78
12	900	14	130	15	8	0.4	600	150	7924.92
13	1100	8	90	25	10	0.3	700	150	4159.49
14	1100	10	50	20	11	0.4	600	100	4020.39
15	1100	12	170	15	8	0.1	500	250	9849.06
16	1100	14	130	10	9	0.2	400	200	8543.24
17	500	8	170	10	11	0.2	600	150	5486.31
18	500	10	130	15	10	0.1	700	100	4931.18
19	500	12	90	20	9	0.4	400	250	3911.44
20	500	14	50	25	8	0.3	500	200	2641.91
21	700	8	170	15	10	0.4	400	200	6495.49
22	700	10	130	10	11	0.3	500	250	4947.16
23	700	12	90	25	8	0.2	600	100	4977.6
24	700	14	50	20	9	0.1	700	150	3560.93
25	900	8	130	20	10	0.2	700	250	6163.07
26	900	10	170	25	11	0.1	600	200	8755.77
27	900	12	50	10	10	0.4	500	150	3910.54
28	900	14	90	15	11	0.3	400	100	5987.01
29	1100	8	130	25	9	0.4	500	100	6344.35
30	1100	10	170	20	8	0.3	400	150	8747.52
31	1100	12	50	15	11	0.2	700	200	4505.22
32	1100	14	90	10	10	0.1	600	250	6913

Range analysis method and variance analysis method is used to deal with orthogonal test results. The results are shown in Figure 4 and Figure 5. The range analysis results are shown in Table 6. The result shows that fracture half-length, horizontal well length, fracturing stages are the major factors that affect Heshui Chang 6 fractured horizontal well productivity.

To analysis various factors rankings through information amount analysis, gray relational analysis, numerical simulation orthogonal test range analysis and variance analysis are used, as is shown in Figure 6. The fracture half-length, horizontal well length and fracturing stageshave the stronger impact. While conductivity, one of the fracturing treatment parameters, affect weakly, which consistent with the geological features of Heshui Chang 6. Without transformation, economic output is difficult to obtain. The purpose of reservoir stimulation is also different from the previous conventional fracturing. High fracture conductivity is no longer the aim, while to obtain greater volume of reservoir stimulation is more important.

Table 6: Range analysis of orthogonal experiments

Factor	Horizontal well length /m	fracturing stages	fracture half-length /m	conductivity /(D•cm)	porosity /%	permeability /mD	well spacing /m	row spacing /m
mean result of level Ⅰ	4305.79	4860.84	3486.31	5703.16	5920.91	5966.84	5802.87	5700.11
mean result of level Ⅱ	5293.70	5435.29	4876.92	5802.52	5825.60	5658.89	5534.40	5500.47

mean result of level Ⅲ	6253.87	5935.89	6303.17	5542.87	5420.34	5416.19	5770.33	5670.73
mean result of level Ⅳ	6635.28	6256.62	7822.24	5440.09	5321.78	5446.71	5381.03	5617.32
range	2329.5	1395.78	4335.93	362.42	599.13	550.65	421.84	199.64

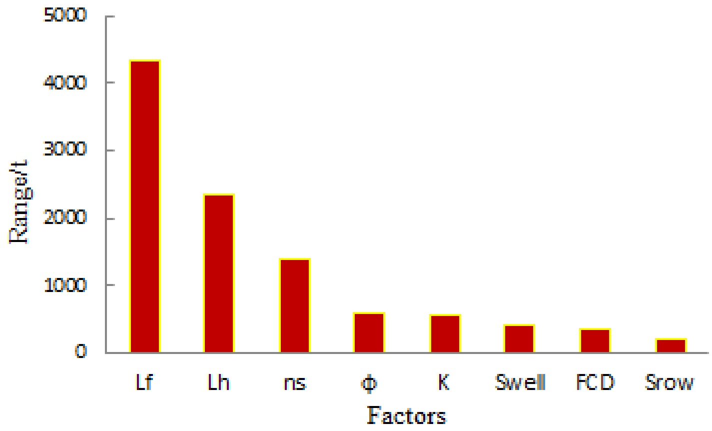

Fig.4: Range comparison of different parameters

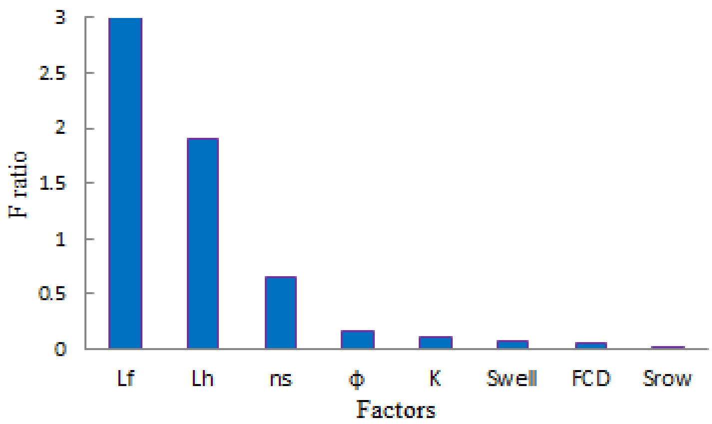

Fig.5: F ratios of different parameters

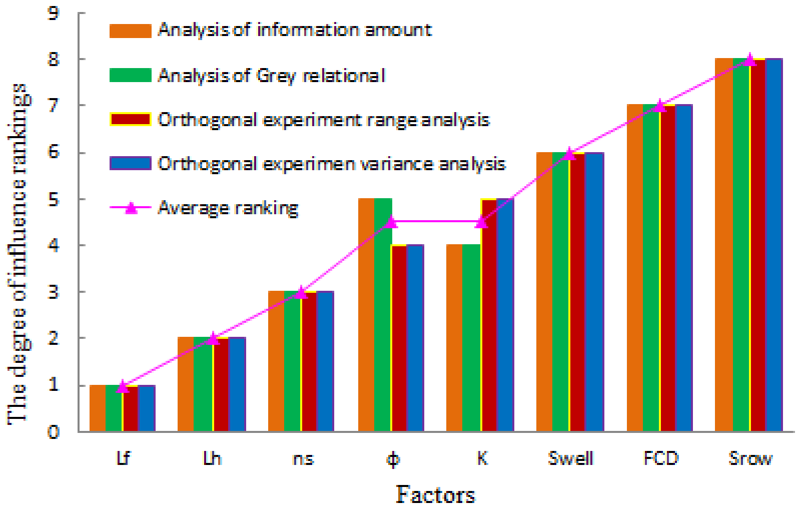

Fig.6: Influence degree comprehensive ranking of different parameters

Conclusions

1. In this paper, the information amount theory and gray correlative method are used to calculate the productivity influence parameters of fractured horizontal wells, and the results is checked by numerical simulation. The results revealed that fracture length, horizontal well length and fracturing stages are main parameters.

2. Three kinds of methods used show that the influence of conductivity is weak, so during the stimulation of tight oil reservoirs, it is no need to spend high cost in pursuing the high conductivity.

3. For Heshui Chang 6 tight sandstone reservoirs, primary parameters affecting the fractured horizontal well productivity are all belong to fracturing treatment factors, rational optimization of fracturing treatment is expected to significantly improve the tight sandstone reservoirs fractured horizontal well productivity.

Acknowledgement

The authors acknowledge a fund from the National Basic Research Program of China (973 Program)(No.51574257) and supports from the CMOE Key Laboratory of Petroleum Engineering.

References

[1] Jia Chengzao, Zou Caineng, Li Jianzhong, et al. Assessment criteria,main type,basic features and resource prospects of the tight oil in China. Acta petrolei Sinica, 2012, 03: 343-350.

[2] HAO Pengpeng, LIU Hongjun, YANG Youyun, et al. The reservoir characterization and porosity evolution in tight sand reservoir in Chang 63 and Chang 73 sub-member in Ordos

basin. Inner Mongolia Petrochemical Industry,2013,21:138-141.

[3] Mayerhofer M, Lolon E, Warpinski N, et al. What is stimulated reservoir volume? Production & Operations, 2010, 25(1): 89-98

[4] Yu Qitai, Zhao Ming, Lin Zhifang. Research on Oil Displacement Efficiency and Sweep Efficiency in Water Drive Sandstone Oilfield (I). Oil Exploration and Development,1989,163: 48～52

[5] Liang Tao, Chang Yuwen, Guo Xiaofei, et al. Influence factors of single well's productivity in the Bakken tight oil reservoir. Oil Exploration and Development, 2013, 03:357-362.

[6] Fu Li. Gray system theory and application. Beijing: Science & Technology Press, 1992:185－211.

[7] Liang Chengbo, Zhong Jianhua, Cai Fulong, et al. Influence factors analysis of oil field output based on grey correlation analytical method. Natural gas geoscience, 2006, 17(6):851－853.

[8] Deng Julong. Gray theoretical basis. Wuhan: Huazhong University of Science and Technology Press, 2002:122－209.

[9] Liu Sifeng, Guo Tianbang, Dang Yaoguo, et al. Grey System Theory and Application. Beijing: Science Press, 1999:40－77.

[10]Li Xianwen, Fan Fengling, Li Xiaohui, et al. Fracture network system simulation and morphology optimization. Journal of Xi'an Shiyou University (Natural Science Edition), 2014, 29(1):71-75.

[11]Barry Rubin. Accurate Simulation of Non-Darcy Flow in Stimulated Fractured Shale Reservoirs. SPE 132093, 2010.

Nomenclature

Lf	Fracture half-length (m)	FCD	Fracture conductivity (D·cm)
Lh	Horizontal well length (m)	ns	Fracturing stages
φ	Porosity	LS-LR	Logarithmically Spaced - Locally Refined
K	Permeability (mD)	SRV	Stimulated Reservoir Volume
Swell	Well spacing (m)		
Srow	Row spacing (m)		