Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(12):635-639

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Analysis on influencing factors of well productivity in tight oil reservoir with gray correlative method

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ABSTRACT

The objective of this study is to find out the key factors of well productivity in tight oil reservoir. According to the analysis of influence factors, eight factors are selected by taking the Chang 7 reservoir in Ordos basin for example. Gray correlative method is used to calculate the eight parameters correlation and check the influences on well productivity. The result shows that: sand volume, initial oil saturation, resistivity, interval transit time, porosity, perforation thickness, permeability and thickness effects on well production are smaller and smaller. The enrichment zones of Chang 7 reservoir are selected by using the results. Average well production in enrichment zones is 11.88m^3/d, which is significantly higher than 6.43m^3/d of the other regions. Gray correlative method is effective and convenient to analyze well productivity parameters in tight oil reservoirs.

Keywords: Tight oil, gray correlative method, well productivity, influencing factors

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INTRODUCTION

Tight oil is the oil that gathers in the tight reservoir without long distance migration[1,2]. While the staged fracturing technology of horizontal well becomes more and more mature, exploration and development of tight oil reservoirs have achieved great breakthrough in USA. In China, tight oil is the most realistic reservoir at unconventional oil-gas resources and will be an important breakthrough in oil exploration[3].Well productivity is the key factor that restricting the development of tight reservoir. There is an important significance to ascertain main factors of productivity for the development of tight oil reservoirs. Many factors affect the well productivity and there is a complex relationship between them. What's more, each factor has different degree of influence on the single well productivity. Gray correlative analysis method quantitatively characterizes the degree of association between factors according to the acquaintance of the trend factors and reveals the various impact on performance index[4,5]. This paper determines the correlation between parameters and well productivity by selecting parameters affecting well productivity according to the theory of grey correlative analysis method. Then, some factors that influence well productivity were sorted by using gray correlative analysis method, there are 11 wells that are used as research subjects at Chang 7 reservoir of Ordos Basin region. The results provide way to select enrichment zones of well in the tight reservoirs.

INFLUENCE FACTORS OF PRODUCTIVITY

Fracturing is needed to obtain industrial productivity in tight reservoir, which is of poor physical property, strong heterogeneity and complicated pore structure[6,7]. There are many factors to influence the well productivity in tight sandstone reservoirs. They can be divided into three categories: Geological factors, fluid properties and engineering parameters[8,9]. Geologic factors include reservoir thickness, permeability, initial oil saturation and so on. Fluid properties contain viscosity, density, etc. Engineering factor mainly refers to perforation length, fracturing parameters and well completion method. Fluid properties are always the same in the same reservoir. The paper screens a number of factors from the geological factors and engineering factors by using statistical methods, which control well productivity at Chang 7 reservoir of Ordos Basin region.

Geological Factors

The geological factors mainly include porosity, permeability and thickness of the reservoir. The reservoir pore space is the set of crude oil. Porosity and oil productivity are generally a positive correlation. The large the permeability, the higher the production may be. The reservoir thickness is thick with abundant reserve and the production is likely to be higher.

Hydrocarbon-bearing Property

Hydrocarbon-bearing property mainly refers to the oil saturation. Oil flowing though the tiny capillary does not satisfy Darcy's law. Tight sandstone reservoir is hydrophilic. Oil saturation is higher, elastic expansion and wicking effect is stronger, so well production is higher.

Engineering Factors

Engineering parameters contain perforation length, fracturing parameters etc. Perforation length relating to the extent of reservoir in contact with the wellbore affects the rate of oil flow into the wellbore. Fracturing manner and fracturing scale have a great influence on the morphology and length of fracture. The amount of pre-fluid and proppant are parameters to evaluate the fracturing scale in this paper.

GREY CORRELATIVE ANALYSIS PRINCIPLES

The basic idea of grey correlative analysis is based on the sequence similarity of the curve geometry to determine whether it is closely related. The closer the curves of corresponding sequence are, the greater the correlation is[4]. The purpose of gray correlative analysis is the quantitative characterization of correlation between factors. The theory of grey correlative method are described below.

(1) Determining the reference numbers. Evaluation system is decided according to the evaluation purpose. On the base of the collecting evaluation data, the parent sequence and child sequences is determined. The parent sequence denotes as:

$$X_0 = (x_0(1), x_0(2), x_0(3), \cdots, x_0(m))$$

Whre,X_0——parent sequence; x——elements; m——the number of samples.

(2) Data dimensionless. Due to different dimensions and magnitude, it generally requires to turn the original data into dimensionless one. There are many dimensionless methods, such as mean transformation, initial transformation, standardization transformation and so on. Growth sequence uses the initial transformation. Mean transformation is used to turn the general comparative sequence into dimensionless one.

(3) Calculated the absolute difference between child sequences and parent sequence. It is expressed below:

$$\Delta_i = \left| x_0^{'}(k) - x_i^{'}(k) \right| \qquad k=1,\ldots,n;\ i=1,\ldots,m$$

(4) Taking the maximum and minimum values from the absolute difference.

$$mm = \min_{i=1}^{n} \min_{k=1}^{m} \left| x_0^{'}(k) - x_i^{'}(k) \right|$$

and $$MM = \max_{i=1}^{n} \max_{k=1}^{m} \left| x_0^{'}(k) - x_i^{'}(k) \right|$$

(5) Calculating the correlative coefficients $\xi_i(k)$ between child sequences and parent sequence.

$$\xi_i(k) = \frac{mm + \rho \cdot MM}{x_i^{'}(k) + \rho \cdot MM}$$

Where, ρ is resolution factor, the value is between 0 and 1, which reflects the distinguishing ability. The higher the value is, the stronger the distinguishing ability is. In general, ρ＝0.5.

(6) Calculating correlative coefficients.

$$\gamma(X_0, X_i) = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

(7) Ranking correlative coefficients. Correlative coefficients are sorted to obtain comprehensive evaluation factors.

GREY CORRELATIVE ANALYSIS IN THE INFLUENCE FACTORS OF PRODUCTIVITY

Chang 7 layer in Ordos Basin is typical of tight sandstone reservoir, which is closely linked to shale layer. Its permeability is generally $0.2\times10^{-3}um^2$[10-12]. Diameter of pore-throat is nano-scale, generally 10～1000nm, with average scale of about 100um[10,12]. Due to dense formation and complex migration law, well productivity is affected by many factors in tight reservoir. In this paper, eight parameters are used for gray correlative analysis. These eight parameters include physical properties, oil saturation and engineering factors in Chang 7 formation. The original data is shown in table 1.

Table 1 Original Data of 11 wells

Well Name	Qo /(m^3/d)	φ /%	Rs /Ω·m	AC/(um/s)	H /m	K /mD	Soi /%	L /m	M /m^3
An231-40	12.3	12.12	80.91	229.88	6.9	0.25	46.42	4	35
An235-50	7.5	11.27	29.25	224.13	8.5	0.23	45.36	5	35
An240-27	19.9	10.16	61.06	217.24	8.5	0.163	54.49	2	40
An350-103	3.6	8.97	49.76	207.49	12	0.11	58.98	8	50
An83-7	25.4	11.39	50.22	224.63	17.2	0.293	51.38	6	45
An238-47	15.4	10.36	46.57	218.58	23.3	0.177	46.47	9	65
An234-35	7.9	10.16	31.92	217.15	27.5	0.175	51.8	4	40
An230-42	6.2	9.92	33.8	215.94	33.2	0.163	54.17	12	75
An501-102	27.8	10.15	42.82	217.23	37.1	0.169	54.55	11	93.4
An238-23	20.4	8.74	97.58	216.61	43.1	0.56	66.64	14	55
An344-42	19.9	12.05	35.8	229.1	40.7	1.34	55.55	12.5	70

Where, Q_o——oil production, φ——porosity, Rs——resistivity, AC——interval transit time, H——formation thickness, K——permeability, S_{oi}——initial oil saturation, L——perforation length, M——sand volume.

Determine parent sequence and child sequences

Since the purpose of this study was to determine the effects of various factors on productivity, oil production of 11 well is chosen. Remaining factors are child sequences: porosity, resistivity, interval transit time, formation thickness, permeability, initial oil saturation, perforation length, sand volume (Table 2).

Table 2 Sample Data

Factor	φ /%	Rs /Ω·m	AC /(um/s)	H /m	K /mD	Soi /%	L /m	M /m^3	Qo /(m^3/d)
Symbol	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_0

Table 3 Correlative coefficient, correlation and correlative ranking results

Factor	Φ /%	Rs /Ω·m	AC /(um/s)	H /m	K /mD	Soi /%	L /m	M /m^3
	0.805	0.642	0.860	0.730	0.966	0.965	0.820	0.892
	0.707	0.951	0.728	0.916	0.877	0.799	0.917	0.911
	0.803	0.927	0.812	0.593	0.629	0.829	0.566	0.704
	0.693	0.653	0.664	0.838	0.940	0.616	0.645	0.675
	0.702	0.668	0.680	0.595	0.638	0.661	0.601	0.618
correlative coefficient	0.984	0.935	0.988	0.988	0.744	0.909	0.929	0.897
	0.759	0.934	0.751	0.682	1.000	0.757	0.992	0.874
	0.723	0.848	0.710	0.580	0.948	0.697	0.558	0.592
	0.615	0.582	0.621	0.847	0.511	0.631	0.755	0.915
	0.731	0.711	0.795	0.742	0.802	0.939	0.774	0.803
	0.897	0.695	0.838	0.770	0.335	0.839	0.847	0.977
correlation	0.765	0.777	0.768	0.753	0.763	0.786	0.764	0.805
correlative ranking	5	3	4	8	7	2	6	1

Calculating Correlative Coefficient

According to the dimensionless method, turn the original data to dimensionless one. Correlative analysis is done between child sequences and parent sequence. The results are shown in Table 3.

According to the results of gray correlation analysis, the primary and secondary factors that influence well productivity are shown in the Fig.1: sand volume, initial oil saturation, resistivity, interval transit time, porosity, perforation length, permeability and formation thickness.

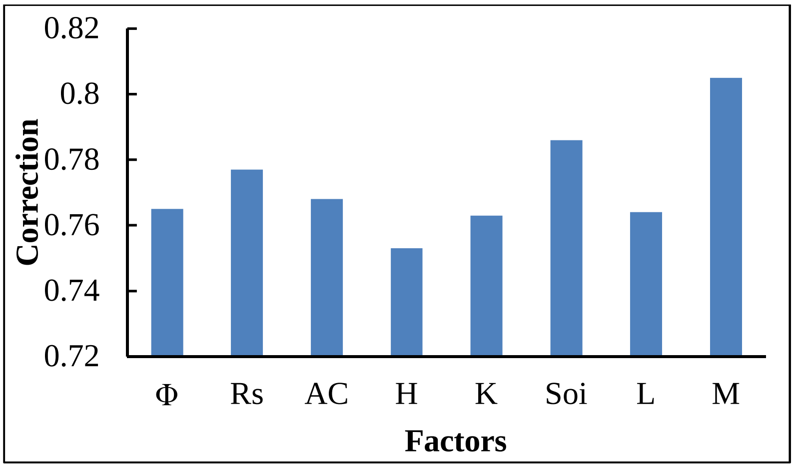

Fig.1 Results of gray correlative analysis

Example Applications

Well productivity is a key factor in the development of tight reservoir, it is of great significance to choose the enrichment zone. Because resistivity and interval transit time respectively reflect the characteristic of initial oil saturation and porosity, initial oil saturation and porosity are the two main factors of geology which influence well productivity. With the increase of initial oil saturation and porosity, well productivity increases. Fig.2 and Fig.3 are initial oil saturation distribution and porosity distribution in the main reservoir at a part of Chang 7 reservoir. From green to red, the darker the color is, the greater the value is.

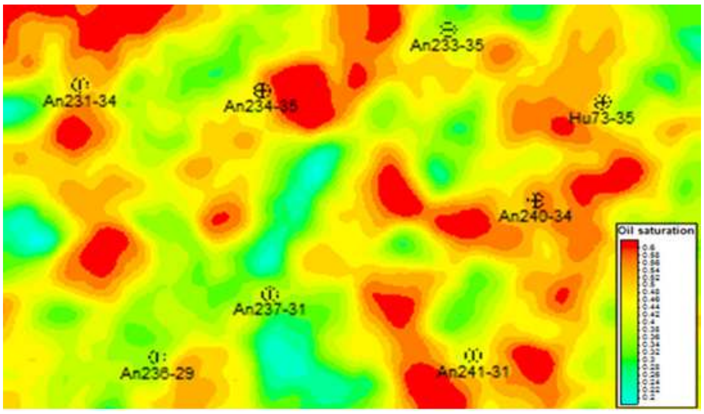

Fig.2 Distribution of initial oil saturation in the tight reservoir

The enrichment zone is the area of high oil saturation and high porosity. Based on Fig.2 and Fig.3, some enrichment zones have been selected. Production data of 4 wells in the enrichment zones and 3 wells outside the enrichment zones are compared (table 4). Result shows that average well production of 4 wells is 11.88m^3/d in enrichment zones, average production of the other 3 wells is 6.43m^3/d. Well production of enrichment zone is higher than that in the non-rich region, it shows that the method is accurate and feasible.

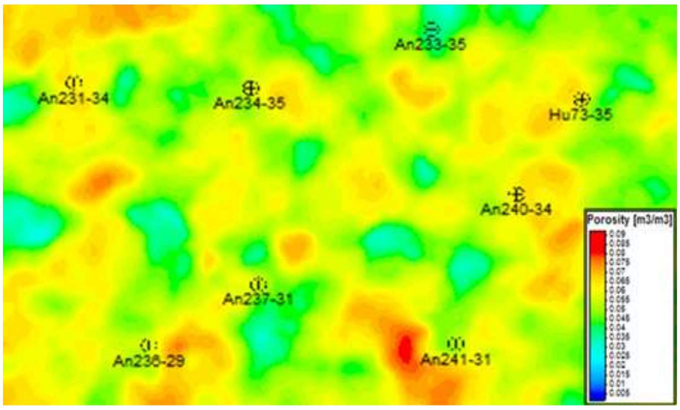

Figure 3 Distribution of porosity in the tight reservoir

Table 4 Comparison of enrichment zone and non-rich zone

Zone	Well Name	H /m	L /m	K /mD	Soi /%	M /m^3	Qo /m^3	Qava /m^3
enrichment zone	An231-34	43	8	0.183	62.13	60	7.9	11.88
	An234-37	12.9	10	0.177	44.13	54	14.4	
	An237-38	18.8	6	0.404	52	55	15.6	
	An241-30	39.1	10	0.237	59.57	60	9.6	
non-rich zone	An233-30	20	6	0.921	54.05	50	6.2	6.43
	An236-33	23.1	4	0.16	50.69	50	3.1	
	An237-30	22.4	9.9	0.15	53.01	60	10	

Where, Qava——average production.

CONCLUSION

(1) It analyses the influencing factors of well productivity by using gray correlative method. Results show that effects on well productivity from high to low are: sand volume, initial oil saturation, resistivity, interval transit time, porosity, perforation length, permeability and formation thickness. The massive fracturing and preferred region with high oil saturation will greatly improve well productivity in Chang 7 tight-oil reservoir in Ordos Basin.

(2) The enrichment zone is selected by using the result of gray correlative analysis at the part of Chang 7 reservoir. The average well production of 4 wells is 11.88m^3/d in enrichment zone, the average well production of the other 3 wells in non-rich region is 6.43m^3/d.

(3) It is convenient and requires less samples to use gray correlative method for analyzing factors of well productivity in tight reservoirs. The results can reflect the relationship between characteristic parameters and well productivity. It is of great significance to optimize development region and reduce the investment risk in tight reservoirs.

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