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Research on Determination of the Main Factors Influencing the Gas Well Post-Frac Productivity Prediction for Tight Sandstone Reservoirs Based on Factors Analysis

Bi-Ci Jiang[1*], Bao-Zhi Pan[1], Hai-Tao Zhang[2], Xiao-Ming Yang[2], Gang Chen[3], Wen-Bin Liu[4]

[1]Jilin University, Changchun, China
[2]Research Institute of Exploration and Development, Petro Changqing Oilfield Company, Xi'an, China
[3]China Coal Research Institute Xi'an Science and Industry Group, Xi'an, China
[4]China University of Petroleum (East China), Qingdao, China
Email: [*]jiangbici@163.com

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Abstract

With the characteristics such as low porosity, low permeability and low gas saturation, tight sandstone reservoirs almost have no natural capacity and need to be fractured (or fracturing) for productivity. Therefore, fracturing capacity prediction is very necessary. However there were so many factors, and the relations between the factor and the post-frac productivity are complex. In this study, first of all factors are concluded from the gas well stable productivity formula, then I used factor analysis to look for the main factors from the logging parameters and fracturing parameters in SULIGE area. This study could provide basal references for the gas post-frac productivity prediction in tight sandstone reservoirs.

Keywords

Factor Analysis, Tight Sandstone, SULIGE Region, Post-Frac Productivity

1. Introduction

The fracturing is needed for tight reservoirs' productivity, and the factors influencing the gas productivity prediction became complicated after fracturing. At present, there are two methods for tight sandstone gas post-frac productivity prediction that are formula method (Chen, 1998) and mathematical statistical method (Zhang, 2011; Zhang, 2007; Zhang, 2013; Zhang, 2008). For formula method, the accurately determined parameters involved in the equation are needed. However, for mathematical statistical method, the main factors were needed. The main factors come from the logging parameters and fracturing parameters. Zhang Jing (2011) used linear regression analysis and Zhang Song-yang (2007) used method of trial and error to look for the relationship between

[*]Corresponding author.

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the log parameters and the open-flow potential. Zhuang Hua (2013) used gray correlation method to search for the main factors in post-frac capacity in SULIGE region. Huang, He and Zhang (2010) integrated gray correlation, stepwise analysis, principal component analysis to analyze the main factors which had influence on ultra-low permeability reservoir oil production capacity. Factor analysis puts all of the information involved in original variables together, by exploring the internal structure of the correlation matrix and makes multivariate integrated into a small number of factors, which can reproduce the original relationship between the variables (Luo et al., 2005). Factor analysis is a good application in lithology identification (Luo et al., 2013). In this study, first it concluded the total factors from the gas well stable productivity formula, then it used factor analysis to analyze the main factors of tight sandstone gas Post-frac capacity forecast. This study could provide basal references for mathematical statistical method in the gas post-frac productivity.

2. Theoretical Formulas of Gas Reservoir Fracturing Capacity

In the literature (Chen, 1998), gas well stable binomial deliverability equation is

$$P_i^2 - P_{wf}^2 = AQ_g + BQ_g^2 \quad (1)$$

Where P_i is reservoir static pressure, (MPa); P_{wf} is the bottom hole flowing pressure (MPa); A and B is binomial coefficients.

$$A = (8.484\times10^4 \mu_g ZTp_{sc} / KhT_{sc})[\ln(r_e / r_w) + 0.434S_a] \quad (2)$$

$$B = (1.966\times10^{-8} \beta\gamma_g ZTp_{sc}^2 / h^2T_{sc}^2R)\left(1/r_w - 1/r_e\right) \quad (3)$$

when $p_{wf} = 0.101MPa$, the gas well absolute open flow is

$$Q_{AOF} = (\sqrt{A^2 + 4B(p_R^2 - 0.101^2)} - A) / 2B \quad (4)$$

where h is effective thickness(m); p_{sc} is terrestrial standard pressure (MPa); K is permeability (mD); T_{sc} is terrestrial standard temperature (K); Z is gas deviation factor; S_a is apparent skin factor; β is inertial resistance coefficient caused turbulence; γ_g is gas gravity; μ_g is gas viscosity(mPa·s); r_e is gas control radius, m; r_w bottom radius, m; R is universal gas constant ($KMPa\cdot m^3/(Kmol\cdot K)$); T formation temperature(K).

In the formula (4), it's very difficult to accurately determine the various parameters. For these parameters h p_{sc}, T_{sc}, R, T, r_w, it is easy to obtain obtained. However, for the others, exact values are difficult to be obtained. K suffered many influential factors, so it is usually established by the relationship of porosity. S_a is affected by many factors (Chen & Yan, 2004), so it is difficult to get an accurate value. β is related to S_a. Z is the function of formation temperature and formation pressure (Gao & Hao, 2001), so there were some discrepancies; μ_g is got based on the empirical formula proposed by Lee and Gonzalez (Gao & Hao, 2001), and there will be some deviation; r_e is affected by permeability, reservoir pressure and other factors, there is some deviation too. Therefore, there is a big difficulty and a certain deviation when using the formula method to calculate gas well fracturing capacity, it's necessary to predict gas well fracturing capacity by using statistical mathematical methods. However there are too many parameters to response reservoir conditions and fracturing conditions. We need to filter out the main influencing parameters.

In the formula (4) we could see that factors influencing gas well fracturing capacity besides the gas's property, the thickness and the reservoir's conditions, gas well fracturing capacity is also closely related to reservoir's properties (permeability K),fracturing parameters (mainly effect S_a, r_e and reservoir properties). In order to avoid the impact of reservoir thickness and the various parameters referred come from unit thickness.

2. Selecting Factors Influencing the Gas Well Post-Frac Productivity for Tight Sandstone Reservoir

Nowadays, the forecast of productivity is building a model with an indicator which can reflect the gas productivity. The indicator is built by the well deliver ability testing, the porosity, the absolute permeability and so on (Zhang, 2011; Zhang, 2007; Zhang, 2013; Zhang, 2008). Compared with conventional reservoir, tight gas reservoir has tight lithology, poor physical property, strong aeolotropism, low trap amplitude and low natural deliverability. In the actual production process, fracturing has a great impact on tight gas productivity. So it is needed to consider the reservoir property and the fracturing parameters in the post-frac productivity predicting.

The formation P_{1-2}sh in SULIGE area is a typical representative of tight sand stone reservoirs with the permeability (0.1 - 1) * 10^{-3}·μm^2. In this study, the data came from 52 wells in west of SULIGE region, ten parameters from logging and fracturing parameters were picked up: natural gamma (GR, API), acoustic travel time (AC, us/m), resistance (RT, Ω·m), density (DEN, g/cm^3), neutron(CNL,%), the amount of sand per meter (SD, m^3), the sand ratio (SR,%), the sand concentration (SC, kg/m^3), delivery capacity per meter(VOE, m^3/min) and total amount of fluid into the well per meter (FV, m^3/min).

3. Analyzing the Impact of Various Factors on Fracturing Capacity by Factor Analysis Method

Factor analysis method put all relevant information of the original variables together. It reduces the number of factors by exploring the internal structure of the correlation matrix, which can reflect the relationship among the original variables, and looks for the reason of the correlation additionally (Zhu et al., 2014). Factor analysis method that can determine the main factors for tight sandstone post-frac predicting, it could search out the internal correlation among all of the factors, and afford a few general factors to explain the varieties of post-frac productivities in the tight sandstone. Then we could select the main effect factors of tight sand stone fracturing capacity forecast based on the contribution made by each factor in the common factors.

The step of factor analysis method is just as following:

First: importing the raw data X_{n*p}, then calculating the average values and variance of the sample, and standardizing the data. Second: evaluating the sample's correlation matrix R = (r_{ij}) p * p. Third: finding the eigen value of correlation coefficient matrix λi (λ1, λ2, ..., λp > 0) and the corresponding standard orthonormal eigen vectors (li). Forth: determining the number of common factors; Fifth: calculating the common variance of common factors h_i^2. Last: calculating the score of the common factors component and then explaining the practical application.

Depending on the method factor analysis, we analyze the data with SPSS software. The detail procedure is as below:

Step one: Judging the parameters selected whether are suitable for factor analysis

The precondition of using factor analysis method is that there is a linear relationship between the variables. Then the factors could be reduced and the purpose could be achieved. The result of analyzing of correlation matrix shows that the correlation coefficients were greater than 0.3. So there is a strong correlation between the factors which has an impact on tight sand gas reservoir fracturing capacity forecast. The correlation matrix of various factors was below (**Table 1**):

Meanwhile calculating KMO and BaetlettSphere degree of the above table, results were as follows (**Table 2**):

Table 2 shows: the statistic observation of BaetlettSphericity testing was 477.417, and the corresponding probabilities P (Sig) was close to zero. If the significance level was 0.05, due to the probability P was less than the significance level 0.05, you could pull off the null hypothesis. So obviously there were differences between correlation matrix and unit matrix, meanwhile KMO value was 0.715, that fit the criteria well. In short the method of factor analysis was available in this study.

Step two: Extracting factors

According to the correlation coefficient matrix of the original variants, eigen values over1were selected by PCA. Then calculating the explained variance of each parameters. The initial common factor variance is estimators of eachvariant's explained variance. It is always equal to 1 in PCA. Because the number of components equals to the original parameters' number, the common value is equal to 1. The common factor variance extracted was used to predict factors' multiple correlation square value. The low value shows that the variant is not suitable as a factor, so it will be abandoned in the analysis. Now calculate the communality of the chosen factors. The results are as following in **Table 3**:

The third column in table 3(extracted) is the final solution of common variable degree according to the factor analysis. What can be obtained is that most of the information has been analyzed with factor analysis, just a few information was lost. The overall effect of factor extraction is well.

The number of the analyzed factors is ten, so there are ten ingredients. Now calculating characteristic values for each component (the total characteristic values). The proportion of each component's explained variance in the total variance is just the proportion of the factors' characteristic value in the total eigen value. Now calculat-

Table 1. Correlation coefficient matrix.

Factors	SD	SR	SC	VOE	FV	RT	GR	AC	CNL	DEN
SD	1	0.623	0.612	0.652	0.641	0.02	−0.04	0.107	0.074	0.104
SR	0.623	1	0.991	0.879	0.706	−0.2	0.24	0.079	0.063	0.14
SC	0.612	0.991	1	0.883	0.7	−0.1	0.246	0.075	0.083	0.135
VOE	0.652	0.879	0.883	1	0.764	−0	0.187	0.093	0.09	0.22
FV	0.641	0.706	0.7	0.764	1	0.19	−0.08	−0.08	−0.13	0.129
RT	0.022	−0.154	−0.145	−0.03	0.189	1	−0.37	−0.53	−0.44	0.249
GR	−0.039	0.24	0.246	0.187	−0.076	−0.4	1	−0.08	0.339	0.472
AC	0.107	0.079	0.075	0.093	−0.08	−0.5	−0.08	1	0.557	−0.62
CNL	0.074	0.063	0.083	0.09	−0.126	−0.4	0.339	0.557	1	−0.26
DEN	0.104	0.14	0.135	0.22	0.129	0.25	0.472	−0.62	−0.26	1

Table 2. KMO and Bartlett's test results.

Kaiser-Meyer-Olkin(KMO)		0.715
	Similar chisquare	477.417
Sphericity test of Bartlett	**df**	45
	Sig.	0

Table 3. Common factor variance table.

	Initial	Extracted		**Initial**	Extracted
SD	1	0.731	**RT**	1	0.861
SR	1	0.949	**GR**	1	0.908
SC	1	0.94	**AC**	1	0.849
VOE	1	0.893	**CNL**	1	0.922
FV	1	0.813	**DEN**	1	0.872

ing the summation percentage of the proportion of each component's explained variance in the total variance. Then extract the components whose total variance is greater than 0.5. The results are shown in **Table 4**.

The section 2 (total) of **Table 4**, there are four values greater than 0.5 in the variant correlation matrix as 4.079, 2.402, 1.625, 0.63. These four factors integrated 87.368 percentage information of the ten variants. In other words, the four factors which are in front reflect most information of the original data. Therefore extracting four common factors is appropriate, and it can also represent a comprehensive condition.

Step three: According to the common factor component scores, finding the main influencing factors of tight sand gas deliverability

Now we build equations for four general factors according to calculated scores coefficient of general factor. Then we select the previous two of the absolute values of the coefficient as the main factors of the impact of tight sandstone gas reservoir fracturing capacity. Coefficient matrix of component score is shown in **Table 5**:

$$F1=0.198SD+0.233SR+0.232SC+0.229VOE+0.229FV+0.009RT-0.039GR +0.031AC-0.029CNL-0.009DEN \tag{5}$$

$$F2=-0.026SD-0.011SR-0.005SC+0.029VOE-0.079FV+0.053RT+0.484GR -0.289AC+0.134CNL+0.503DEN \tag{6}$$

$$F3=0.335SD-0.182SR-0.161SC+0.035VOE-0.028FV+0.216RT+0.171GR +0.263AC+0.836CNL+0.067DEN \tag{7}$$

$$F4=-0.378SD+0.242SR+0.227SC-0.009VOE-0.166FV-0.716RT+0.24GR +0.115AC-0.311CNL-0.159DEN \tag{8}$$

In **Table 5**, each of the largest two of absolute value of the coefficient expressions of various common factors

Table 4. The total explained variance.

Ingredient	Initialeigenvalue			Squareextracted and loading		
	Total	**Variance's percentage**	**Summation percentage**	**Total**	**Variance's percentage**	**Summation percentage**
1	4.079	40.794	40.794	4.079	40.794	40.794
2	2.402	24.017	64.811	2.402	24.017	64.811
3	1.625	16.254	81.065	1.625	16.254	81.065
4	0.63	6.303	87.368	0.63	6.303	87.368
5	0.446	4.458	91.826			
6	0.268	2.678	94.504			
7	0.255	2.548	97.052			
8	0.194	1.939	98.991			
9	0.092	0.924	99.915			
10	0.008	0.085	100			

Table 5. Component score coefficient matrix.

Factors	Components			
	1	2	3	4
SD	0.198	−0.026	0.335	−0.378
SR	0.233	−0.011	−0.182	0.242
SC	0.232	−0.005	−0.161	0.227
VOE	0.229	0.029	0.035	−0.009
FV	0.229	−0.079	−0.028	−0.166
RT	0.009	0.053	0.216	−0.716
GR	−0.039	0.484	0.171	0.24
AC	0.031	−0.289	0.263	0.115
CNL	−0.029	0.134	0.836	−0.311
DEN	−0.009	0.503	0.067	−0.159

is: the first common factor (F1) is the sand ratio(SR), sand concentration (SC); the second common factor (F2) is the natural gamma ray (GR), density (DEN); the third common factor (F3) is the neutron (CNL), the amount of sand per meter(SD); the fourth common factors (F4) resistivity (RT), the amount of sand per meter(SD). In the first common factor (F1) (**Table 4** that, F1 information reflects 40.794%) expression, the five parameter coefficients represent fracturing construction accounted for a large proportion than the five logging parameters, so we can see that fracturing construction parameter have a great impact on tight sand gas fracturing capacity.

4. Conclusions and Understanding

For tight sand reservoirs, the relationship between individual factors and gas reservoir fracturing production is complicated, so we cannot determine the impact factors of tight sandstone gas fracturing capacity by a simple linear correlation analysis.

In factor analysis, correlation of each factor which has an impact on tight sand gas fracturing capacity is greater than 0.3. There must be a certain relationship among the various factors.

From factor analysis we can see that fracturing parameters is important in tight gas reservoir post-fract productivity prediction, therefore we must consider fracturing parameter into tight sand gas fracturing capacity forecast.

The main factors determined by factor analysis are sand ratio (SR), sand concentration (SC), natural gamma ray (GR), density (DEN), neutron (CNL), the amount of sand per meter (SD), resistivity (RT).

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