A Research of Perforation Plan-decision Based on Grey Cluster Relation

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***Abstract*—Perforation completion in oil and gas wells is the most important way of completion engineering, the optimization of perforation completion's designing is influenced by a variety of factors. In order to get the ideal effect of perforation operation, in this paper, a Perforation plan-decision based on Grey Cluster Relation is putted forward. It aims to provide a scientific guidance for the Perforation. The simulation experimental results show that new models are effective, which offer one kind of science decision-making foundation for petroleum Perforation.**

Keywords-Perforating Operation; Grey Cluster Relation; Perforation Plan-decision

I. INTRODUCTION

Perforated well completion As the most extensive and major method of the well's completion, the reasonable selection of parameters for the program has great meaning of improving efficiency and reducing costs[1][2]. By establishing a quantitative regression model to study the relationship between the parameters of the perforation and the production ratio, this algorithm can also analysis how different factors (perforation elasticity, perforation penetration, shot density, perforation diameter, perforation phase angle) act on the production ratio and casing strength coefficient. It provides a reliable theoretical basis for the perforation parameter optimization, and gives different perforation completion optimization schemes [3].

Due to the mutual restriction of different parameters, the current subjective decision-making for perforation program can't make all the factors to achieve the best at the same time. In order to solve the above problems and reduce the subjective influence of the decision maker, maximize the productivity ratio[4], a Perforation Plan-decision Based on Grey Cluster Relations proposed[5-7].

II. PERFORATION PLAN-DECISION BASED ON GREY CLUSTER RELATION

Perforation optimization needs to confirm a solution to maximize the production capacity. This solution depends on many factors and the main influencing factors are hole depth, pore size, pore density, phase angle, formation heterogeneity, drilling pollution degree and depth, perforation compaction thickness and degree. All these factors are acting on the decision-making of the solution on the same time.

Perforation Plan-decision based on Grey Cluster has made the model of perforation parameters and the oil well productivity. Gray parameters are clustered in the parameters of the perforation scheme, and the evaluation function is established to design the optimal scheme [8-10].

A. Building of model

First simulating and calculating the productivity ratio of oil and gas, then making a non-linear regression analysis, According to whether perforation penetration penetrate the drilling zone or not, an equation can be established, it indicates the relationship between perforating parameters and capacity.

1) *The regression equation when the perforation penetration does not penetrate the drilling zone:*

$$\begin{aligned} PR=&0.000156Y_h^2-0.000452W_h+0.000000205W_h^2+0.319K_{zr}-0.103K_{zr}^2-0.0009512r_w+0.000002378r_w^2 \\ &-0.25+0.00148K_s-0.00000123K_s^2+0.00958K_m-0.0000998K_m^2-0.00467X_w\lg(K_{zr})+0.0178K_j-0.000296K_j^2 \\ &+0.00195X_w-0.00001X_w^2-2*0.000828X_w*\lg(K_{zr})+0.4\lg(K_{zr})+0.3488Y_c-0.1745Y_c^2+0.69W_c-0.35W_c^2 \\ &-0.00778Y_h \end{aligned} \tag{1}$$

2) The regression equation that perforation penetration has penetrated the contaminated zone of drilling:

$$\begin{aligned} PR=&-0.25+0.00191K_s-0.00000136K_s^2+0.01665K_m-0.000173K_m^2-0.00856K_m\lg(K_{zr})+0.0201K_j \\ &-0.000335K_j^2+0.00211X_w-0.0000108X_w^2-0.001774X_w\lg(K_{zr})+0.5\lg(K_{zr})+0.512Y_c-0.253Y_c^2 \\ &+0.3315W_c-0.168W_c^2-0.00963Y_h+0.000193Y_h^2-0.000841W_h+0.000000714W_h^2+0.406K_{zr}-0.135K_{zr}^2 \\ &-0.0009736r_w+0.00000243r_w^2 \end{aligned} \tag{2}$$

The quantitative relationships between parameters (perforation penetration KS, perforation aperture Kj, perforation phase Xw, perforation compaction degree Yc, perforation compaction thickness Yh, drilling damage thickness Wh, drilling pollution degree Wc, shot density Km, borehole radius rw, formation permeability Kzr) and the oil production ratio PR is the basis for the optimization of perforating parameters.

B. Perforation program base on Grey Cluster Relation

The main factors in the decision-making of the perforation plan are six factors: perforation ratio, perforation phase angle, shot density, perforation penetration, perforation diameter and casing strength decreasing coefficient, which are expressed by attributes x_1, x_2, x_3, x_4, x_5, x_6 respectively. Initial feature object matrix D is made like this:

$$D=\begin{pmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ x_{41} & x_{42} & x_{43} & \cdots & x_{4n} \\ x_{51} & x_{52} & x_{53} & \cdots & x_{5n} \\ x_{61} & x_{62} & x_{63} & \cdots & x_{6n} \end{pmatrix} \tag{3}$$

In the formula, x_{ij} represents j th attribute of the ith scheme; in the j scheme x_{1j} represents the productivity ratio, x_{2j} is the phase angle, x_{3j} is the perforation diameter, x_{4j} is the hole depth, x_{5j} is the aperture, and x_{6j} is the casing strength reduction coefficient. There are n scheme and 6 attributes.

As the different dimensions will have an impact on decision-making, so the formula (4) - (6) are used to D for normalization.

The normalization of attribute data based on the different effects caused by different attributes, the formula (4) shows the method to normalize production ratio, which called upper limit method. Inherent properties such perforation phase angle, shot density, perforation penetration, perforation diameter are concluded by extreme conversion method, shown as formula (5). Casing strength decreasing coefficient, as a cost-type attribute, calculated by the lower limit method, shown as formula (6).

$$r_{1j}=\frac{x_{1j}}{\max(x_{1j})} \tag{4}$$

$$r_{ij}=\frac{x_{ij}}{\max(x_{ij})-\min(x_{ij})} \tag{5}$$

$$r_{6j}=\frac{x_{6j}}{\min(x_{6j})} \tag{6}$$

In the formula, $2 \le i \le 5, j \le n$, the normalized decision matrix can be calculated: $R = (r_{ij})_{6\times n}$.

The Grey Clustering analysis is used to classify the attributes and the similar factors can be classified and simplified.

1) *Initialize processing:*

$$\begin{aligned} &r_{ij} = r_{ij} - r_{i1} \\ &2 \le i \le 5 \quad , \quad j \le n \end{aligned} \tag{7}$$

2) *Calculate the gray absolute correlation degree* ε_{ik} *of any two parameter index data Ri and Rk sequence* $(1 \le k, 1 \le i \le 6, j \le n)$*:*

$$\begin{cases} | S_i | = | \sum_{j=2}^{n-1} r_{ij} + 0.5 * r_{in} | \\ | S_k - S_i | = | \sum_{j=2}^{n-1} (r_{kj} - r_{ij}) r_{ij} + 0.5 * (r_{kn} - r_{in}) | \\ \varepsilon_{ik} = \dfrac{1 + | S_i | + | S_k |}{1 + | S_i | + | S_k | + | S_i - S_k |} \end{cases} \tag{8}$$

3) *Establishing attribute correlative sequence matrix according to the above gray absolute correlation degree:*

$$\varepsilon = \begin{bmatrix} 1 & \varepsilon_{12} & \varepsilon_{13} & \varepsilon_{14} & \varepsilon_{15} & \varepsilon_{16} \\ & 1 & \varepsilon_{23} & \varepsilon_{24} & \varepsilon_{25} & \varepsilon_{26} \\ & & 1 & \varepsilon_{34} & \varepsilon_{35} & \varepsilon_{36} \\ & & & 1 & \varepsilon_{45} & \varepsilon_{46} \\ & & & & 1 & \varepsilon_{56} \\ & & & & & 1 \end{bmatrix} \tag{9}$$

The critical value $r \in (0,1)$, in pursuit of accuracy the value of r is higher than 0.5, the higher the r value, the more accurate the classification is , and the accurate value of r is determined by actual data, the Ri and Rk classified as similar attributes; when $\varepsilon_{ij} \geqslant r$.

4) *Several attributes can be merged by the calculation above, and an attribute can be chosen to instead of other similar attributes.*

A new feature matrix D' and new normalization matrix $R' = (r'_{ij})_{m\times n}$ is established according to the Grey Clustering analysis, where m is the number of attributes and n is the number of schemes.

5) *Computing information entropy* E_i *and weight* ω_i $(1 \le i \le m, j \le n)$*:*

$$\begin{cases} E_i = -\dfrac{1}{\ln(n)} \sum_{j=1}^{n} r''_{ij} \ln(r''_{ij}) \\ r''_{ij} = \dfrac{r'_{ij}}{\sum_{j=1}^{m} r'_{ij}} \end{cases} \tag{10}$$

In particular, when $r''_{ij} = 0$, let $r''_{ij} \ln(r''_{ij}) = 0$.

$$\omega_i = \frac{1 - E_i}{\sum_{i=1}^{m} (1 - E_i)} \qquad 1 \le i \le m \tag{11}$$

And $0 \le \omega_i \le 1$, $\omega_1 + \omega_2 + \cdots + \omega_m = 1$, $1 \le m \le 6$.

Establish an evaluation function Z_k:

$$Z_k = \sum_{i=1}^{m} \omega_i r'_{ik} \quad , \quad 1 \le i \le m, \quad 1 \le k \le n \tag{12}$$

When the evaluation function value Z(Rk) is larger, the corresponding scheme is better. The program has the largest value of Z(k) is chosen as the final construction program.

III. SIMULATION EXPERIMENT

White XX well in Chang-qing Oilfield, the reservoir depth of middle layer is 1 884.5m, the total thickness is 9.5 m, the thickness of the perforated zone is 3.0 m, the porosity is 13.41%, reservoir drainage radius is 200m, well-bore radius is 0.111 m, the pressure of formation is 13.073 MPa, the crude oil saturation pressure is 9.86 MPa, drilling pollution depth is 69.5mm, the drilling pollution degree is 0.6. The casing strength is 47.8MPa, reservoir heterogeneity is 0.7(vertical permeability / horizontal permeability), the water saturation is 30.21%, rock Poisson's ratio is 0.5, the inclination is 5°, the oil viscosity is 1.03 MPa.S, the perforation optimization scheme is shown as Table 1.

TABLE I. PERFORATION TABLE OF WHITE XX

Attributes / Program	productivity ratio	perforation phase angle （degree）	shot density （holes/m）	perforation penetration （mm）	perforation diameter （mm）	casing strength decreasing coefficient （%）
A1	0.5193	120	26	328.68	10.68	5.00
A2	0.5188	90	26	328.68	10.68	6.10
A3	0.5152	120	32	328.68	10.68	5.70
A4	0.5150	60	26	328.68	10.68	5.70
A5	0.5147	90	32	328.68	10.68	5.30
A6	0.5108	60	32	328.68	10.68	5.00
A7	0.5071	120	36	328.68	10.68	4.50
A8	0.5065	90	36	328.68	10.68	4.20
A9	0.5045	120	26	267.55	9.42	4.60
A10	0.5039	90	36	267.55	9.42	4.30
A11	0.5024	60	26	328.68	10.68	4.00
A12	0.5001	120	32	267.55	9.42	4.00
A13	0.4998	60	36	267.55	9.42	4.10
A14	0.4995	90	32	267.55	9.42	3.80
A15	0.4952	60	32	267.55	9.42	3.60
A16	0.4912	120	26	267.55	9.42	3.10
A17	0.4905	90	26	267.55	9.42	3.00
A18	0.4874	120	16	328.68	10.68	2.60
A19	0.4867	90	16	328.68	10.68	2.50
A20	0.4861	60	26	267.55	9.42	2.90
A21	0.4821	60	16	328.68	10.68	2.40
A22	0.4695	120	16	267.55	9.42	1.80
A23	0.4688	90	16	267.55	9.42	1.80
A24	0.4637	60	16	267.55	9.42	1.70

The initial feature matrix $D=(x_{ij})_{6\times 24}$ can be constructed from the data in Table 1 and the results are shown in Table 2.

The feature object matrix $R=(r_{ij})_{6\times 24}$ is established by the above equation (4) - (6) and the initial feature matrix D, is shown as table 3. The index data association matrix is established by the above equations (7) and (8):

$$\varepsilon=\begin{bmatrix} 1 & 0.9953 & 0.9499 & 0.9937 & 0.9937 & 0.9976 \\ & 1 & 0.5841 & 0.8571 & 0.8571 & 0.9176 \\ & & 1 & 0.7747 & 0.7747 & 0.9602 \\ & & & 1 & 1 & 0.9696 \\ & & & & 1 & 0.9696 \\ & & & & & 1 \end{bmatrix}$$

According to the correlation degree matrix, take the critical value $r=0.8$, R2, R4 and R5 can be regarded as same class, then take R2 represent this class. Then the influencing attributes of perforation program are adjusted to: productivity ratio R1, perforation phase angle R2, shot density R3, casing strength decreasing coefficient R6. Establishing new normalization matrix $R'=(r_{ij})4\times24$, shown as table 4.

TABLE II. ESTABLISH THE INITIAL FEATURE MATRIX D

$D = [\ldots]^T$

0.5193	120	26	328.68	10.68	5.50
0.5188	90	26	328.68	10.68	6.10
0.5152	120	32	328.68	10.68	5.70
0.5150	60	26	328.68	10.68	5.70
0.5147	90	32	328.68	10.68	5.30
0.5108	60	32	328.68	10.68	5.00
0.5071	120	36	328.68	10.68	4.50
0.5065	90	36	328.68	10.68	4.20
0.5045	120	26	267.55	9.42	4.60
0.5039	90	36	267.55	9.42	4.30
0.5024	60	26	328.68	10.68	4.00
0.5001	120	32	267.55	9.42	4.00
0.4998	60	36	267.55	9.42	4.10
0.4995	90	32	267.55	9.42	3.80
0.4952	60	32	267.55	9.42	3.60
0.4912	120	26	267.55	9.42	3.10
0.4905	90	26	267.55	9.42	3.00
0.4874	120	16	328.68	10.68	2.60
0.4867	90	16	328.68	10.68	2.50
0.4861	60	26	267.55	9.42	2.90
0.4821	60	16	328.68	10.68	2.40
0.4695	120	16	267.55	9.42	1.80
0.4688	90	16	267.55	9.42	1.80
0.4637	60	16	267.55	9.42	1.70

TABLE III. ESTABLISHMENT OF FEATURE OBJECT MATRIX R

$R = [\ldots]^T$

1	2	1.3	5.3767	8.4762	2.9412
0.9990	1.5	1.3	5.3767	8.4762	3.5882
0.9921	2	1.6	5.3767	8.4762	3.3529
0.9917	1	1.3	5.3767	8.4762	3.3529
0.9911	1.5	1.6	5.3767	8.4762	3.1176
0.9836	1	1.6	5.3767	8.4762	2.9412
0.9765	2	1.8	5.3767	8.4762	2.6471
0.9754	1.5	1.8	5.3767	8.4762	2.4706
0.9715	2	1.3	4.3767	7.4762	2.7059
0.9703	1.5	1.8	4.3767	7.4762	2.5294
0.9675	1	1.3	5.3767	8.4762	2.3529
0.9630	2	1.6	4.3767	7.4762	2.3529
0.9624	1	1.8	4.3767	7.4762	2.4118
0.9619	1.5	1.6	4.3767	7.4762	2.2353
0.9536	1	1.6	4.3767	7.4762	2.1176
0.9459	2	1.3	4.3767	7.4762	1.8235
0.9445	1.5	1.3	4.3767	7.4762	1.7647
0.9386	2	0.8	5.3767	8.4762	1.5294
0.9372	1.5	0.8	5.3767	8.4762	1.4706
0.9361	1	1.3	4.3767	7.4762	1.7059
0.9284	1	0.8	5.3767	8.4762	1.4118
0.9041	2	0.8	4.3767	7.4762	1.0588
0.9028	1.5	0.8	4.3767	7.4762	1.0588
0.8929	1	0.8	4.3767	7.4762	1

TABLE IV. DEALS WITH THE FEATURE MATRIX BY GREY CLUSTER RELATION R'

$R' = [\ldots]^T$

1	2	1.3	2.9412
0.9990	1.5	1.3	3.5882
0.9921	2	1.6	3.3529
0.9917	1	1.3	3.3529
0.9911	1.5	1.6	3.1176
0.9836	1	1.6	2.9412
0.9765	2	1.8	2.6471
0.9754	1.5	1.8	2.4706
0.9715	2	1.3	2.7059
0.9703	1.5	1.8	2.5294
0.9675	1	1.3	2.3529
0.9630	2	1.6	2.3529
0.9624	1	1.8	2.4118
0.9619	1.5	1.6	2.2353
0.9536	1	1.6	2.1176
0.9459	2	1.3	1.8235
0.9445	1.5	1.3	1.7647
0.9386	2	0.8	1.5294
0.9372	1.5	0.8	1.4706
0.9361	1	1.3	1.7059
0.9284	1	0.8	1.4118
0.9041	2	0.8	1.0588
0.9028	1.5	0.8	1.0588
0.8929	1	0.8	1

The attribute weight vectors ω =(0.0036,0.2826, 0.2797,0.4340) are calculated according to formulas (10) and (11).

Then the evaluation function Z is established according to (12):

Z={2.2090,2.2348,2.4716,2.1051,2.2282,2.0103, 2.2211,2.0032,2.1068,2.0288,1.6710,2.0375,1.8364,1.8451,1.6527,1.7238,1.5569,1.4562,1.2894,1.3900,1.1225,1.2519,1.1105,0.9437}. The optimal scheme is A3 because the Z value of scenario A3 is the largest. It means under the existing formation conditions, the best perforation program is: perforation bullet SYD127-1, phase angle 120°, hole density 32m, wearing depth 328.68mm, aperture 10.68mm.

IV. CONCLUSION

In this paper, a Perforation plan-decision based on Grey Cluster Relation is putted forward. This method can be widely used to predict the productivity of wells under different perforation conditions, determine the perforating efficiency of perforated bombs, and study how different factors (the perforation elasticity, perforation penetration, shot density, perforation diameter, perforation phase angle) impose influence to productivity ratio, and casing strength decreasing coefficient. According to the pending reservoir, it also let the oil production capacity to achieve the higher perforation operating parameters and process of excellent combination. It also saves a lot of manpower, materials and time cost, and provide the theoretical basis for the design of completion perforation construction.

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