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Main Control Factors of Fluid Loss in Drilling and Completion in Shunbei Oilfield by Unmanned Intervention Algorithm

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***Abstract*—**Quantitative research on the main control factors of lost circulation has few considerations and single data source. Using Unmanned Intervention Algorithm to find the main control factors of lost circulation adopts all measurable parameters. The degree of lost circulation is characterized by the loss rate as the objective function. Geological, engineering and fluid data are used as layers, and 27 factors such as wellhead coordinates and Weight on Bit (WOB) used as dimensions. Data classification is implemented to determine function independent variables. The mathematical equation of loss rate and 27 influencing factors is established by multiple regression method, and the undetermined coefficient method is used to solve the undetermined coefficient of the equation. Only three factors in t-test are greater than the test value 40, and the F-test value is 96.557%, indicating that the correlation of the model is good. The funnel viscosity, final shear force and drilling time were selected as the main control factors by elimination method, contribution rate method and functional method. The calculated values of the two wells used for verification differ from the actual values by -3.036 m^3/h and -2.374 m^3/h, with errors of 7.21% and 6.35%. The influence of engineering factors on the loss rate is greater than that of funnel viscosity and final shear force, and the influence of the three factors is less than that of geological factors. The best combination of funnel viscosity, final shear force and drilling time is obtained through quantitative calculation. The minimum loss rate of lost circulation wells in Shunbei area is 10 m^3/h. It can be seen that man-made main control factors can only slow down the leakage, but cannot fundamentally eliminate it. This is more in line with the characteristics of karst caves and fractures in Shunbei fault solution oil and gas reservoir.

***Keywords*—**Drilling fluid, loss rate, main controlling factors, Unmanned Intervention Algorithm.

I. Introduction

In the process of drilling and completion, Shunbei oilfield in Tarim Basin has high leakage probability and large loss, resulting in long drilling cycle, high cost and possible reservoir damage. In order to speed up the drilling progress, the effect of loss prevention and plugging must be improved. The main control factors of loss are the core to improve the success rate of loss prevention and plugging.

At present, many scholars theoretically analyze the formation characteristics and qualitatively believe that there are cracks, holes and pores in the formation, resulting in loss [1]-[3]. Similar conclusions generally suggest that fracture plugging materials or pore materials should be used in drilling operations, and the construction process parameters and fluid properties cannot be pointed out. This qualitative analysis method has low practical value for construction.

In order to improve the field guidance ability, many scholars use mathematical methods to analyze the types of drilling fluid and rheological parameters in logging information, and mathematical calculation methods such as lost circulation fault tree method [4], support vector regression method [5], artificial neural network [6]-[9], decision tree [10], [11], random forest (RF) [12], multiple linear regression [13] to predict the degree of loss, provide appropriate construction countermeasures for drilling. However, the data source used for calculation is single and the consideration factors are limited. Some important factors affecting well loss may be omitted. Some parameters cannot be measured in the underground, so the calculated results are inconsistent with the reality. Therefore, it is necessary to try to use all the measurement results as independent variable parameters to calculate the loss degree.

Lihui et al. put forward the multiple regression method by using the indoor experimental data to optimize the dosage of treatment agent [14], and optimize the rheological parameters of circulating microbubble drilling fluid [15]. By improving the evaluation of Liulin and Qinshui Coal Seam damage, determining the main control parameters of Liulin coalbed methane production, and evaluating reservoir damage by flow instead of permeability [16], the Unmanned Intervention Algorithm is proposed. The core idea is not to rely on experience, choose parameters and give weights from the perspective of professional knowledge. For the formation with complex structure of fault solution reservoir and high difficulty of process measures in Shunbei area, the conventional method is more difficult to determine the cause of leakage. It is suitable to use the Unmanned Intervention Algorithm to find the main control factors of loss from many factors without human intervention.

Firstly, to determine the objective function, we select all measurable operation parameters as independent variables, then establish the mathematical equation of the objective function and influencing factors, solve the undetermined coefficients, and then evaluate the accuracy of the equation. Then, we screen the main control factors and evaluate the rationality of the main control factors. The whole algorithm conforms to the three

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characteristics of big data: all parameters participate in the calculation, each parameter is a factor to each other, and shows the trend of the objective function. The algorithm solves the problem that the qualitative method cannot give targeted quantitative response strategies, and the quantitative method has a single consideration factor and cannot guide the field operation.

II. Establishment of Main Control Factor Model of Lost Circulation in Shunbei Drilling and Completion

A. Selection of Model Independent Variables

The Unmanned Intervention Algorithm requires that the selected independent variable parameters are not subject to human subjective restrictions. Therefore, when collecting data, all field measured data shall be selected as much as possible based on the requirements of data integrity and quantitative calculation. The independent variable parameters are divided into three categories: geology, engineering and fluid, which are called "layers", so as to ensure the integrity of the data in the category. For each category, we find the corresponding sub category with data records in the existing data, which is called "dimension".

According to the collected field data of Shunbei oilfield, the possible factors related to well leakage in Shunbei area are determined: (1) Geology: X coordinate, Y coordinate, well depth, vertical depth, well deviation angle, azimuth, porosity, permeability and lithology; (2) Engineering: pump pressure, rotating speed, drilling time, drilling pressure and displacement; (3) Fluid: funnel viscosity, initial shear force, final shear force φ600, φ300, φ200, φ100, φ6, φ3. There are 27 items in total, including water loss of drilling and completion fluid, solid content, drilling and completion fluid density, drilling and completion fluid pH, etc. At the same time, the well numbers collected were determined, including 48 wells such as SHB1-9 and SHB1-17h.

B. Determination of Model Objective Function

The value of objective function is a parameter used to characterize the degree of lost circulation, which can be called dependent variable; that is, the left side of the equation. Whether the objective function is correct or not is related to the correctness and objectivity of the model results. The loss rate reflects the whole process of lost circulation in operation, which cannot only reflect the severity of leakage, but also establish a real-time relationship with engineering parameters and fluid performance. It can not only be quantified, but also be easy to obtain the original data.

Among the 48 wells collected, 29 wells were found to have recorded loss rate data. The above independent variables are 27 items, indicating that the model can be solved with 27 objective function values. Therefore, the loss rate cannot only meet the physical significance of characterizing lost circulation, but also meet the modeling requirements in quantity. Therefore, the loss rate is selected as the objective function.

C. Establishment of Mathematical Relation Equation

Among the four commonly used mathematical methods: BP neural network, support vector machine, decision tree and multiple regression, the mathematical relationship equation established by multiple regression method has intuitive expression, and their variable parameters have clear physical significance. At the same time, it is also convenient to cut elements and determine the contribution rate of each parameter, which is in line with the idea of the Unmanned Intervention Algorithm. The mathematical relationship between the leakage rate and influencing factors established by this method is shown in (1):

$$V_{(t)} = a_1 X_1 + \ldots + a_n X_n + b_1 Y_1 + \ldots + b_n Y_n + c_1 Z_1 + \ldots + c_n Z_n + C_0 \tag{1}$$

where, $X_1 \ldots X_n$, $Y_1 \ldots Y_n$, $Z_1 \ldots Z_n$ represent the data of geological structure, engineering and fluid performance respectively; $a_1 \ldots a_n$, $b_1 \ldots b_n$, $c_1 \ldots c_n$ denote undetermined coefficient, C_0 denotes constant term.

From the 29 wells with recorded loss rate, the data of 27 wells are selected and substituted into (1). The coefficient of the equation is solved by the undetermined coefficient method to obtain (2). The remaining two wells are used for model inspection.

$$\begin{aligned} V_{(t)} &= 131.941 + 37.936W_1 + 32.468W_2 \\ &+ 19.715W_3 + 6.852W_4 + 4.717W_5 + 2.285W_6 \\ &+ 2.066W_7 + 0.318W_8 + 0.318W_9 + 0.284W_{10} \\ &+ 0.114W_{11} + 0.103W_{12} + 0.09W_{13} + 0.046 * W_{14} \\ &+ 0.040W_{15} + 0.017W_{16} + 0.005W_{17} + 0.000W_{18} \\ &+ 0.000W_{19} - 0.001W_{20} - 0.003W_{21} - 0.008W_{22} \\ &- 0.042W_{23} - 0.161W_{24} - 0.167W_{25} - 0.434W_{26} \\ &- 2.4W_{27} \end{aligned} \tag{2}$$

D. Rationality Evaluation of Equation

The rationality of the evaluation equation includes single factor reliability evaluation and multi factor reliability evaluation. The t-test method is used to evaluate the reliability of single factor action. The larger the value, the more inaccurate the information provided by the factor; the F-test method is used to evaluate the reliability of multi factor interaction. The larger the value, the higher the accuracy of the model, and the higher the reliability of target prediction. According to the above test method, the relevant factor data are substituted into the t-deviation statistics formula (3) for calculation.

$$t = \frac{X - \mu}{\frac{\sigma_X}{\sqrt{n-1}}} \tag{3}$$

where X is the average number of samples, μ is the overall average, σ_x is the sample standard deviation and n is the sample size.

The calculation results show that the t-test value of most single factors is less than 40, which is relatively small; factors exceeding 40 are: Φ 200 is 41.503, drilling and completion fluid density is -632.953, drilling and completion fluid loss is 124.587, displacement is 94.242.

Relatively speaking, the t-test values of drilling and completion fluid density, drilling and completion fluid loss and displacement are too large. According to the t-test standard, these three factors need to be further excluded.

Through calculation, the F-test value of the leakage rate model is 96.557%, greater than 95%, which belongs to the case of large F-test value. According to the F-test standard, it is considered that the significance of each factor and the objective function is obvious, so the equation is accurate and can be used for the screening of main control factors in the next step.

E. Screening of Main Control Factors of Lost Circulation in Shunbei Drilling and Completion

The Unmanned Intervention Algorithm is used to screen the main control factors, which is divided into three progressive levels. Firstly, the non-main-control factors are eliminated by unmanned intervention clipping method. Then, from the remaining factors, the factors whose contribution rate of each factor to leakage is greater than 90% are selected, that is, the final main control factor. Finally, in order to facilitate the field application, the functional idea is adopted to combine the related factors in the main control factors into a representative factor, which is called functional screening.

1) Cutting Method Screening

The screening process of this method refers to the subtraction and equal sequence statistical method [17] used by [18]-[20], and tries to remove each factor in the equation one by one. When the ranking of the remaining factors does not change, it shows that the removal factor has little impact on the well loss and is a non-main-control factor, so it is screened out. The above process is repeated until all main control factors remain. 17 factors are selected from the above 27 factors, as shown in:

$$\begin{aligned}V_{(t)} &= 0.5574*X1+2.2605*X2+0.6678*X3\\&+0.1783*X4+0.5876*X5+4.3681*X6\\&+0.1184*X7-3.1583*X8-0.1017*X9\\&-0.4847*X10-7.5184*X11-0.8003*X12\\&-4.2287*X13-0.4192*X14-0.6284*X15\\&-1.6597*X16-0.5639*X17+0.0913\end{aligned} \tag{4}$$

where X1 is the pH of drilling and completion fluid; X2 is the pump pressure; X3 is the vertical depth; X4 is the well depth; X5 is the speed; X6 is drilling time; X7 is WOB; X8 is funnel viscosity; X9 is the initial shear force; X10 is the final shear force; X11 is φ600; X12 is φ300; X13 is φ200; X14 is φ100; X15 is φ6; X16 is φ3; X17 is the Y coordinate.

The clipping method has eliminated all non-main-control factors, but there are still too many factors and the operability of practical application is poor. It needs to continue to reduce the number of factors.

2) Screening by Contribution Rate Method

The contribution rate method is to divide the single factor coefficient by the sum of all factor coefficients to obtain the contribution rate of the single factor to the loss rate, then sort it according to the order of contribution rate from large to small, and select all factors with the sum of contribution rate greater than 90% as the main control factor. Using this method, 13 main controlling factors affecting the loss rate are further selected from 17 influencing factors.

Among the 13 main control factors, the highest contribution rate to the loss rate is the drilling time, which reaches 29.94%, followed by the funnel viscosity, which is 16.84%, and the contribution rate of other factors ranges from 9.40% in Y coordinate to 1.67% in initial shear force. The first two factors have a great influence, indicating that they are the dominant factors and both are external factors. The contribution rate of other factors is relatively low, but the impact cannot be ignored.

Although the contribution rate method has screened out the main controlling factors that contribute greatly to the loss rate, it is observed that there is a close correlation between some factors, such as funnel viscosity and Φ600, Φ300, change the former, and the latter two parameters will change accordingly. Therefore, it is necessary to combine relevant factors from the perspective of petroleum engineering to form a representative parameter to facilitate field application.

3) Functional Screening

The 13 main control factors are divided into three categories according to their types and physical meanings. The characteristics of each category of factors are analyzed respectively, and then a representative parameter is selected for each category, and the contribution rate of other related parameters to the loss rate is superimposed on the representative parameter. The idea of this method is similar to that of universal function, so it is called functional method.

(1) Funnel viscosity: Φ600 and Φ300 values are used to characterize the rheological properties of drilling and completion fluid, which are negatively correlated with leakage; if the former is changed, the latter two will change accordingly. Therefore, the funnel viscosity is taken as the representative value of rheology, and the contribution rate of Φ600 and Φ300 to the loss rate is superimposed on the funnel viscosity. The funnel viscosity after superposition treatment completely retains the contribution value of the original three parameters to the loss rate, which will not cause the essential error of the result. In practical application, one only needs to input the funnel viscosity, which is convenient for calculation.
(2) The initial shear force and the final shear force belong to the rheological parameters related to time. The final shear force is selected as the representative parameter, and the contribution rate of the initial shear force is superimposed with it.
(3) The drilling time represents the comprehensive results produced by certain fluid performance and engineering conditions under formation conditions. Therefore, the drilling time represents the WOB, pump pressure and

rotating speed, and the contribution rate of these three parameters to the loss rate is superimposed on the drilling time. At the same time, the contribution rate of pH value of drilling and completion fluid to the loss rate is reduced.

(4) Vertical depth, well depth and Y coordinate belong to geological structure factors. For specific construction objects, these factors are fixed values, so they are classified as constant items.

After screening by functional method, the final leakage rate equation becomes (5):

$$V_{(t)} = k1 * T1 + k2 * T2 + k3 * T3 + C \quad (5)$$

where T1 is funnel viscosity, T2 is drilling time and T3 is final shear force; k1, k2 and k3 are coefficients with functional factors, and C is a new constant term.

According to (5), the final loss rate model has only three representative parameters: funnel viscosity, drilling time and final shear force. k1, k2 and k3 are directly multiplied by the actual values of their respective representative parameters, but the values of several related factors are different. For example, the average funnel viscosity is 60 s, and the Φ300 value is 36, if the contribution rate of Φ300 is superimposed on the coefficient k1 and multiplied by the funnel viscosity value, which is obviously inappropriate. Therefore, a new variable is defined, called the scale coefficient λ, it is equal to the actual value of the representative factor divided by the actual value of the representative factor, regardless of the unit dimension. Multiplying the proportion coefficient by the contribution rate and then superimposing it on k1 will comply with the above superposition idea, see Table I for the proportion coefficients of all represented factors calculated.

TABLE I
PROPORTION COEFFICIENT OF REPRESENTATIVE FACTORS

Factor	Final shear force (Pa)	Initial shear force (Pa)	Funnel viscosity (s)	Φ600	Φ300
Measured value	8.6	3.6	60	55	36
Scale factor	1	0.419	1	0.917	0.6
Factor	Drilling time (min/m)	Pump pressure (MPa)	WOB (kN)	Revolution (r/min)	Drilling and completion fluid pH
Measured value	31	20	19	21	8.5
Scale factor	1	0.645	0.6123	0.677	0.274

Using the calculated contribution rate and the scale coefficient data in Table I, the values of k1, k2 and k3 are calculated as follows:

$$k1 = -(a1 * \lambda 1 + a2 * \lambda 2 + a3) = -(6.66\% * 0.917 + 3.25\% * 0.6 + 20.84\%) = -0.28897$$

$$k3 = -(a4 * \lambda 3 + a5) = -(1.67\% * 0.419 + 3.50\%) = -0.04199$$

$$k2 = a6 * \lambda 4 + a7 * \lambda 5 + a8 * \lambda 6 - a9 * \lambda 7 + a10 = 9\% * 0.645 + 4.59\% * 0.6123 + 1.93\% * 0.677 - 2.22\% * 0.274 + 29.94\% = 0.39254$$

The value of the new constant term C is the sum of the product of Y coordinate, well depth and vertical depth and their respective contribution rates, plus the value of the original constant term, which is equal to 38.6, with a slight process.

Among them, λ1~λ7 are the proportional coefficients of Φ600, Φ300, initial shear force, pump pressure, WOB, rotating speed and pH of drilling and completion fluid, a1~a10 are contribution rate of Φ600, Φ300, funnel viscosity, initial shear force, final shear force, pump pressure, WOB, rotating speed, pH of drilling and completion fluid and drilling time respectively. Then, (5) becomes (6):

$$V_{(t)} = -0.28897 * T1 + 0.39254 * T2 - 0.04199 * T3 + 38.6 \quad (6)$$

F. Example Verification

The two inspection wells SHB1-3 and SHB1-15 have completely recorded the loss rate data of the leakage interval, and have all the data requirements required by the model. We substitute the data into the mathematical relation (6) of loss rate and calculate the theoretical value of the model, see Table II for the results.

TABLE II
CALCULATION RESULTS OF THEORETICAL VALUE OF THE MODEL

Well	Funnel viscosity (s)	Drilling time (min/m)	Final shear force (Pa)	Calculated value (m^3/h)	Actual value (m^3/h)
SHB1-3	60	31	8.5	39.074	42.11
SHB1-15	56	33	8	35.036	37.41

The results in Table II show that the difference between the calculated value and the actual value of the loss rate of the two wells is -3.036 m^3/h and -2.374 m^3/h, respectively, with errors of 7.21% and 6.35%, and the coincidence rate is relatively good. It shows that it can be used for field prediction.

III. RESULT DISCUSSION

Starting with the final mathematical relationship (6), by analyzing the physical significance of the model and studying the optimal combination of funnel viscosity, static shear force and drilling time corresponding to different leakage rates, the important practical significance of this method is further discussed.

A. Solving the Shortcomings of Previous Qualitative Analysis Methods

The right side of (6) contains four items, namely funnel viscosity representing fluid viscosity term, drilling time representing engineering factor term, static shear term related to time and constant term including geological structure and unknown factors.

1. The weight coefficient of the main control factor reflects the effect on the loss rate.

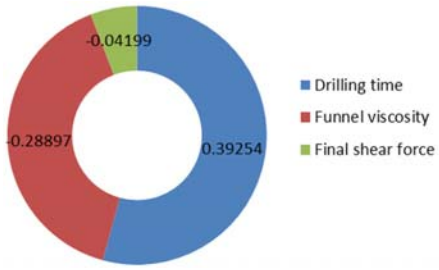

Fig. 1 Weight coefficient of funnel viscosity, drilling time and final shear

It can be seen from Fig. 1 that the funnel viscosity and final shear force are negatively correlated with the leakage rate. Increasing these two values can slow down the leakage. The drilling time is positively correlated with the leakage rate. Reducing this item can slow down the leakage, which is consistent with the understanding of field practice. Usually, people will deal with the leakage by increasing the viscosity or preparing thicker plugging slurry. At the same time, under the requirements of stopping drilling or slow drilling, small displacement plugging will be carried out.

The absolute value of the weight coefficient during drilling is greater than the funnel viscosity, and also greater than the sum of the funnel viscosity term and the static shear force term, indicating that in the artificially controllable factors, the role of controlling engineering factors is greater than that of fluid rheological properties. Especially in the operation with high control loss rate, this phenomenon is more and more obvious.

2. Human uncontrollable factors determine the loss rate. The first three items are all human controllable factors. When the viscosity value into the funnel is 60 s, the final shear force is 8.6 Pa and the drilling time is 31 min/m, the sum of the three items is -5.53, which is far less than the constant term of 38.6. The results show that geological factors and other unknown factors dominate the leakage, while man-made control can only slow down the leakage, but cannot fundamentally eliminate it. At the same time, the results also show that it is necessary to continue to mine unknown leakage factors from two aspects of professional knowledge and calculation methods, and then put forward more accurate leakage prevention and control measures.

It can be seen that this method can give specific countermeasures for the lost circulation, which has obvious practical significance compared with the previous method of judging the type of lost circulation or the location of lost circulation layer only from geological analysis.

B. Solving the Problem of Single Factor in Previous Quantitative Methods

Relational expression (6) has only four items in form, but each item implies multiple influencing factors. This is closer to the field reality than the quantitative method mentioned above, which only considers a single factor (such as fracture width) or few data sources (such as logging data).

In order to further understand the influence threshold of funnel viscosity, final shear force and drilling time on loss rate, five loss rate values in the range of 0 m^3/h to 20 m^3/h are assumed. We substitute each loss rate value into the left side of (6), and then change the value of final shear force from 6 Pa to 17 Pa and the value of funnel viscosity from 40 s to 138 s to calculate the value of corresponding drilling time in turn. In the calculation process, it is found that because the final shear force coefficient is very small, when its value changes from 6 Pa to 17 Pa, the value of this term only changes from 0.252 to 0.629. Compared with other terms, the change process can be ignored. Therefore, the average value is used to replace the change process. The calculation results are shown in Fig. 2.

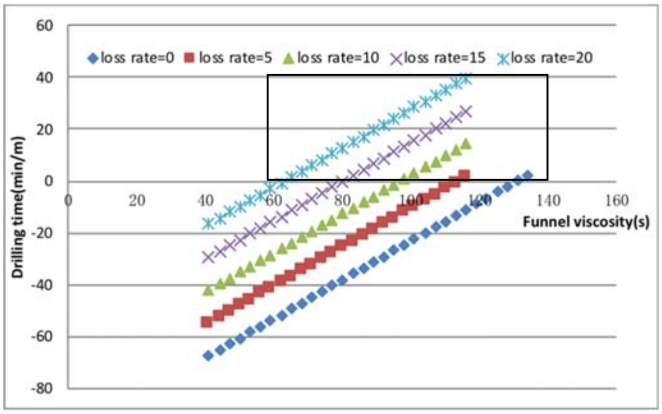

Fig. 2 Variation of funnel viscosity and drilling time under different leakage rates

In Fig. 2, the ideal situation is no leakage, that is, the leakage stall rate is 0. However, it can be seen from the figure that the corresponding drilling time value is always less than 0 (the lowest blue diamond dot line in the figure) as the funnel viscosity increases from 40 s until the funnel viscosity reaches 131 s, which is obviously wrong, and the drilling time cannot be negative; even if it barely reaches a positive value, the fluid viscosity will be too high to use. Thus, it is wrong to assume that the loss rate is 0. Similarly, this is the case when the loss rate is less than 10 m^3/h (red square dotted line and green triangular dotted line in the figure). It does not become positive until it is more than 10 m^3/h and the funnel viscosity is close to 100 s.

In the rectangular box in Fig. 2, the overall variation range of leakage rate is 10 m^3/h ~ 20 m^3/h. At this time, the funnel viscosity and drilling time are within the normal variation range of 60 s ~ 100 s and 10 min/m ~ 40 min/m, respectively, indicating that the minimum loss rate in Shunbei area is usually not less than the above range. In addition, when leakage occurs during operation in the new drilling area, given an expected target value of loss rate, the best matching combination of funnel viscosity and drilling time can be found in Fig. 2, and then combined with the final shear force, so as to minimize the loss rate as far as possible. To sum up, this method can quantitatively give the best independent variable parameter value according to the expected target value, and can guide the field operation more accurately.

IV. Conclusions and Suggestions

1. This method belongs to the category of big data. The modeling process includes multi-dimensional data such as geology, drilling and completion engineering and fluid performance. Compared with the existing mathematical methods, it has the advantages of large amount of modeling data, many data types and less affected by experience. It is more in line with the characteristics of large data in the field of petroleum engineering. The representative values which are convenient for application and include many factors are selected by cutting and screening the model factors without intervention, screening according to the contribution rate and using the functional idea, which has a good guiding significance for the on-site quantitative adjustment of process parameters.
2. This method is applicable to the engineering field with many data types, complex relationship between factors and clear physical meaning of parameters.
3. It is suggested to strengthen the processing means with large data volume difference between different data types, and deeply study the clipping method and functional processing method to improve the operation efficiency. On this basis, data types such as seismic data can be further increased and potential unknown influencing factors can be further mined to improve the accuracy of the model.

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