Study on the Construction Method of Leakage Pressure Body in Fractured Formation

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Abstract

Lost-circulation is one of the major challenges in fractured formations limiting the optimized fast drilling, which is prone to huge economic and environmental losses. The leakage pressure prediction has been a major concern in the industry. To solve this problem, a method for the construction of leakage pressure body in fractured formations is proposed in this paper. First, a leakage pressure prediction model for different fracture scales is optimized. Secondly, a fitted relationship between leakage pressure differential and leakage rate is developed based on the leakage data of the actual drilled wells, which is used to correct the leakage pressure in the priority formation. Finally, a three-dimensional (3D) body of regional stratigraphic leakage pressure is established based on kriging interpolation. This paper presents an example analysis of a fractured formation in the Halfaya oil field. The result shows that the modified formation leakage pressure profile matches the field drilling conditions. The 3D visualization of the regional leakage pressure provides a more intuitive understanding of the distribution of leak-prone formations in the area, which can provide a targeted decision basis for leakage prevention and plugging in the area.

Keywords: Fractured formation, Leakage pressure, Kriging interpolation, 3D pressure body, Leakage correction

Introduction

Lost-circulation is one of the common downhole complications during the drilling process.[1,2] It is a working condition that drilling fluid leaks into the formation during the drilling process.[3,4] Lost-circulation is mainly subject to the following factors:

1. There is a positive pressure difference in the formation, and the pressure of the fluid column in the wellbore is greater than the pressure of the fluid in the rock.

2. The presence of various leakage channels in the formation and a large enough space to contain the liquid.

3. The opening size of the leakage channel should be larger than the particle size of the drilling fluid or working fluid solid phase in the wellbore.

Varying degrees of leakage occurs frequently in the drilling process. Once lost-circulation occurs, if not handled properly, it may induce a series of complex situations such as pipe sticking, blowout, collapse.[5,6] In serious cases, it may even lead to the scrapping of the borehole, causing significant economic losses.[7] The high-precision leakage pressure prediction is the basis for preventing lost-circulation.[2] At present, the research on leakage theory is not complete, and the traditional calculation models that treat formation fracture

pressure as leakage pressure are mostly for integrity formations.[8] While the existence of natural fractures in actual formations leads to their real leakage pressure being much smaller than the calculated values of traditional models. Since most of the commonly used 3D formation pressure calculation methods are based on seismic data.[9,10] When there is no regional seismic data in the block, the only data that can be used is the logging data of drilled wells in the region.[11] In this paper, the leakage pressure prediction methods for different fracture types of formations are selected through extensive research and field leakage examples, and the kriging interpolation method is applied to establish a 3D body of leakage pressure based on the logging data, so that the leakage pressure can be predicted more accurately and intuitively.

Leakage Pressure Prediction

Data pre-processing

Currently, pressure prediction using logging data is one of the widely used methods,[12] but due to external and human factors, it tends to produce large random influence values on the measurement results. This makes the pressure profiles predicted from the logging curves have statistical undulations and burr disturbances. Therefore, the logging data are first preprocessed to remove the noise using the unconfirmed rational number method by follow formulas.

$$M = [[P_{min}, P_{max}], \phi(x)](1 \le i \le n) \tag{1}$$

$$\phi(x) = \begin{cases} \dfrac{\xi_i}{\sum\limits_{i=1}^{n} \xi_i}, x = P \\ 0, x = else \end{cases} \tag{2}$$

Where, $\phi(x)$ denotes the confidence distribution function of pressure values; n denotes the number of pressure points in the selected formation; P_i denotes the pressure value corresponding to a certain depth within the selected formation; ξ_i denotes the number of $P_j (j \ne i)$ within the neighborhood $|P_j - P_i| \le \lambda$ of P_i; λ denotes the magnitude of the change in pressure value within a certain thickness.

By using the above method, the logging data can be pre-processed to eliminate burr interference while preserving the original trend of the log curve, based on which a more reasonable and credible pressure can be obtained.

Leakage pressure calculation

Leakage can be classified by the cause of the leak into the following categories: induced leakage, fracture leakage and differential pressure leakage.[13] Induced leakage is caused by the fluid column pressure in the well. The channels in the formation that were not enough to cause well leakage are connected to each other and extend deeper into the formation, forming a larger channel and causing well leakage.[11] Fracture leakage is caused by the formation being fractured because the fluid column pressure in the well exceeds the maximum pressure-bearing capacity of the weak formation downhole, resulting in the formation of new leakage channels.[14] Differential pressure leakage is caused by the natural pore or fracture in the formation while drilling, this kind of leakage will not change the connectivity of the leakage channel under the limited pressure.[15] In this paper, for conventional microfracture-induced and fracture leakage pressure calculations, based on logging data, the minimum horizontal ground stress is considered as the formation leakage pressure, and the equation is as follow

$$P_l = \sigma_v \frac{\mu_s}{1-\mu_s} + P_p(1 - \frac{\mu_s}{1-\mu_s}) \tag{3}$$

Where, P_l denotes the leakage pressure; σ_v denotes the vertical principal stress; P_p denotes the formation pore pressure; μ_s denotes the static elastic modulus.

Natural hole pressure-differential leakage has a larger leakage channel size, resulting in less resistance to fluid flow in the channel, which allows drilling fluid to enter the formation more easily, resulting in a larger drilling fluid leakage situation.[1] Therefore, for the calculation of natural pore differential leakage pressure, a combination of conventional calculation model and a correction method of fitting relationship between leakage rate and leakage pressure difference in regional leakage prone layer is used for the calculation of formation leakage pressure. The leakage pressure difference is the difference between the drilling fluid column pressure and the pore pressure in the well, and the leakage pressure difference has a good correlation with the leakage rate. From the field leakage data, the leakage rate is fitted to the leakage pressure difference, and the leakage pressure can be recognized as the drilling fluid column pressure when the leakage occurs, so that the leakage pressure can be corrected Figure 1.
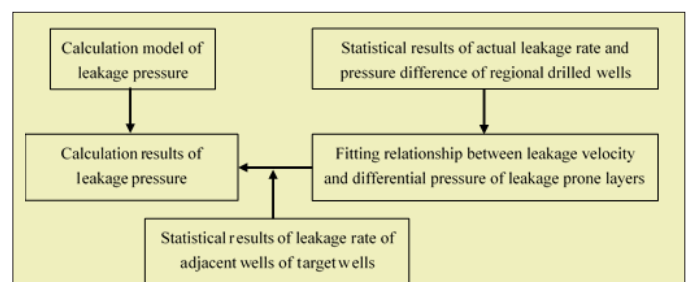

Figure 1: Flowchart for calculation of stratigraphic leakage pressure.

Establishment of Seismic Body Based on Kriging Interpolation Model

Longitudinal section of formation

Based on the well deployment and geological stratification information obtained from the logging data of completed wells in the

region, the same formation was vertically sliced according to the stratigraphic trend (N equal longitudinal splits were made for each well location). The horizontal is based on geodetic coordinates, and the vertical is the number of layers in the slice. Wells in the same layer are considered to be at the same relative depth in that layer. The higher the density of slices, the more computationally intensive it is, but the accuracy increases. The elements of the matrix represent the formation pressure information of each well in the region:

$$P(X,Y,N_H) = \left\{ \min \left\{ P(X,Y,h) \middle| P=P_l, h \in \left[h_{(X,Y,N_H-1)}, h_{(X,Y,N_H)} \right] \right\} \right\}$$

(4)

Where X and Y denote geodetic coordinates; N_H denotes the number of layers in which the formation pressure is located vertically; h denotes the well depth; $h_{(X,Y,N_H-1)}$ denotes the top boundary depth of the N_H layer; $h_{(X,Y,N_H)}$ denotes the bottom boundary depth of the N_H layer.

Epitaxial transposition algorithm for stratigraphic leakage pressure

Spatial interpolation method is a numerical method, which treats known point information as a function of space, and uses the position relationship between unknown points and known points to find the unknown point information.[16,17] Spatial interpolation is able to convert point information into surface information in the lateral direction and a small amount of drilled well information into area information in the spatial direction. In this paper, the ordinary kriging interpolation method is used,[18,19] and the specific steps are as follows:

Finding the plane variation function in different layer cells

For simplicity of expression, let $p_k(G)$ be the regionalized random variable of formation leakage pressure, (x, y) denotes the plane coordinates, x, y represent the geodetic coordinates respectively, and k represents the number of layers. Let d denotes the separation distance on the center plane of the grid where the two well points are located. $p_k(G_i)$ and $p_k(G_i + d)$ are the formation pressure values of the regionalized variable $p_k(G)$ at locations G_i and $G_i + d$, respectively. $N(d)$ represents the total number of pairs of grids separated by a distance d in the center plane of the grid where the two well points are located, and according to the definition of the variance function, the formula for calculating the variance function is:

$$\gamma_k(d) = \frac{1}{2N(d)} \sum_{i=1}^{N(d)} [p_k(G_i) - p_k(G_i + d)]^2$$

(5)

Selection of variance function theoretical model for fitting

According to step (1) and the formation leakage pressure calculation resluts of neighboring wells, a series of variation function values $\gamma_k(d)$ can be calculated for each grid layer at different separation distances d.

The variance function theoretical model chosen is the spherical model.

$$\gamma(d) = \begin{cases} 0 & d=0 \\ C_0 + C\left(\frac{3}{2}\frac{d}{a} - \frac{1}{2}\frac{d^3}{a^3}\right) & 0<d \le a \\ C_0 + C & d>a \end{cases}$$

(6)

Where, C_0 denotes the block gold constant; $C_0 + C$ denotes the abutment value; C denotes the arch height; a denotes the variable range.

Prediction of formation leakage pressure at unknown well locations

According to the kriging method, the formula for calculating formation pressure at unknown well location is

$$p_k(G^\#) = \sum_{i=1}^{n} \lambda_i \cdot p_k(G_i)$$

(7)

Where, $p_k(G^\#)$ denotes the stratigraphic leakage pressure of the k layer at the unknown point $G^\#$; $p_k(G_i)$ denotes the known stratigraphic leakage pressure at the k layer of point $G^\#$; λ_i denotes the weighting factor, and $\sum \lambda_i = 1$.

λ_i is obtained by solving the following system of kriging equations:

$$A \begin{bmatrix} \lambda \\ \mu \end{bmatrix} = B$$ (8)

Among,

$$A = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} & 1 \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n} & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_{n1} & \gamma_{n2} & \cdots & \gamma_{nn} & 1 \\ 1 & 1 & \cdots & 1 & 0 \end{bmatrix} \quad B = \begin{bmatrix} \gamma_{10} \\ \gamma_{20} \\ \vdots \\ \gamma_{n0} \\ 1 \end{bmatrix} \quad \begin{bmatrix} \lambda \\ \mu \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \\ \mu \end{bmatrix}$$

where, γ_{ij} in matrix A denotes the value of the variation function between each known point; γ_{i0} in matrix B denotes the value of the variation function between known and unknown points; and μ denotes the Lagrangian operator.

Example Analysis

Experimental block overview

There are complex geological conditions in the Halfaya oil field in Iraq, which is characterized with the coexistence of a composite salt layer in the upper and middle parts, a high-pressure brine layer and a low-pressure leaky layer, and a variable pressure system. In addition, the reservoir giant thick carbonate rocks are developed in combination with sandstone and shale, and the distribution of

pores and local fractures is irregular. From the well history statistics of more than 200 wells collected in the Halfaya area, it appears that more than half of the wells have experienced downhole complications, 137/213 wells have experienced various degrees of leakage during drilling, and the loss of drilling time due to drilling leakage accounts for 9% of the total NPT. This indicates that well leakage is the main problem in this region. From the stratification statistics of each formation, the well leakage mainly occurred in the Mishrif, Nahr Umr and Shuaiba formations. Among them, the Mishrif and Nahr Umr formations belong to pressure differential leakage, and the Shuaiba formation is fracture leakage Figures 2,3.

Figure 2: Pie chart of the main risk types in the Halfaya field.

Figure 3: Risk histogram of the main layers in the Halfaya field.

Calculation of leakage pressure

Eleven drilled wells in the Hafaya block are selected as samples for the study. Based on the available logging data, the leakage pressure is calculated for these eleven wells according to the calculation method in Section 2.1. The calculation method is specified below using well H1 as an example Figure 4.

As is shown in Figure 4, the results of the conventional leakage pressure calculation method are large relative to the differential pressure leakage due to natural fracture faults, and cannot be used for accurate leakage pressure prediction. So, it is necessary to correct the leakage pressure for the key layers. And since natural fracture-based leakage in the Halfaya area is influenced by geographic location, the variability of leakage between wells in different areas is large, which will cause large errors if they are counted together, so for different layers, the relationship between leakage rate and leakage pressure difference can be fitted by sub-region for leak-

prone layers. Through the statistical analysis of the leakage pressure difference and leakage velocity of the main leakage levels in the block, the probability distribution of leakage velocity and the fitting relationship between leakage pressure difference and leakage velocity for each main leakage level were obtained, so that the safe drilling fluid density window could be corrected. The corrected results are shown in Figure 5, and it can be seen that the corrected results are consistent with the actual leakage situation.

Figure 4: Results of the traditional method of calculating the leakage pressure of well H1.

Figure 5: Leakage pressure correction results for well H1.

Create a 3D seismic body

The three-dimensional bodies of leakage pressure for each formation in the Hafaya area are established according to the method described in this paper, and the results are as follows:

Taking the Mishrif formation as an example, we can see from Figure 6 that the trend of leakage pressure distribution is highest in the northwest and southeast and lower in the middle part. According to the well history of drilled wells in the Halfaya area, the leakage in the Mishrif formation is more serious in the northwestern and southeastern part of the wells drilled, and there is a complex fractured leakage layer, which is consistent with the actual situation Figure 7,8.
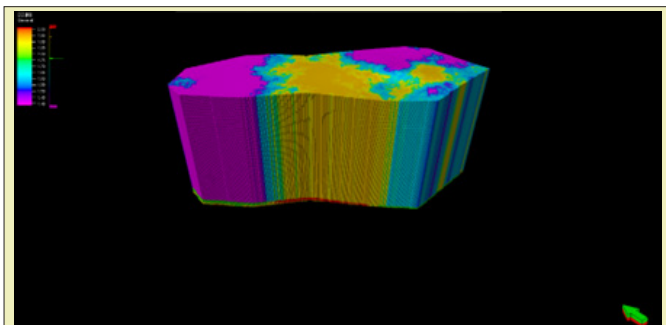
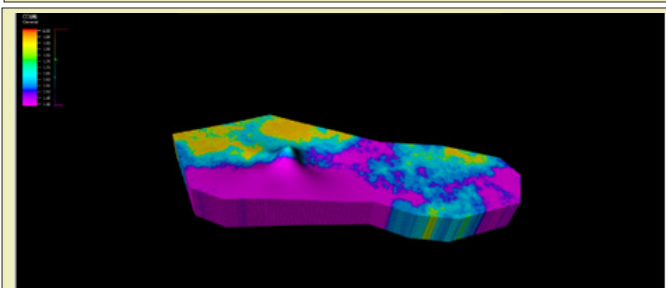**Figure 6:** Leakage pressure body of Mishrif layer in Halfaya area.

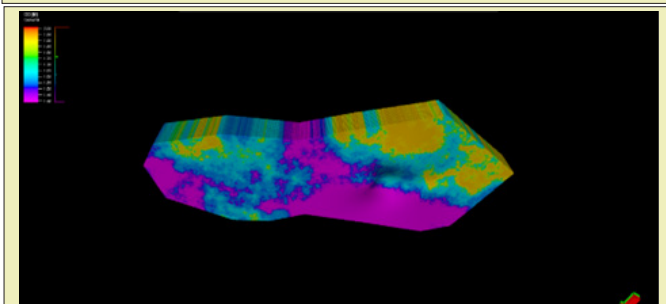**Figure 7:** Leakage pressure body of Nahr Umr layer in Halfaya area.

Figure 8: Leakage pressure body of Shuaiba layer in Halfaya area.

Conclusion

1) Let stratigraphic formations be the basic studied units, using basic information from drilled wells in this area, the leakage pressure of each single well is first calculated based on the logging data of drilled wells. Then the leakage pressure is cor-rected according to the leakage type, and finally the leakage pressure is expanded outward according to the kriging inter-polation method. The regionalized leakage pressure prediction is realized and the error is within 5%.

2) The 3D visualization of regional leakage pressure can provide a more intuitive understanding of the distribution of leakage pressure in the area, which provides a better technical support for preventing lost circulation and using effective plugging materials to achieve safe drilling.

Acknowledgments

Funding

Conflicts of Interest

Authors declare that there is no conflict of interest.

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