Well loss Risk Real-time Monitoring and Simulation Analysis of Key Parameters

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Abstract. The downhole engineering parameters measurement system (EPMS) can show the actual state in wellhole more intuitively, and significantly improve the accuracy of drilling construction decision. However, there was a big gap between domestic and foreign countries in the comprehensive management, analysis and processing of underground and surface drilling engineering parameters. For the well loss risk, the characteristic parameters were internal and external pressures, and the threshold limit values of well loss risk levels was selected, so the assessment system was established. Then through real-time processing and analysis of underground and surface engineering parameters, the characteristic parameters of the well loss risk was calculated real-time, according to the comparison of the calculated value and the measured value, and the assessment system, the wellbore risk level was monitored real-time. Beside the well loss depth could be calculated by these measured parameters, which was important for the well loss treatment. This technology was used in G1 well in GX blocks of Shengli oilfield, in which the well loss occurred frequently. The application result shows that well loss can be monitored at an early stage, reducing the cost of materials and processing the complex time.

Keywords: Wellbore risk; Real-time monitoring; Real-time analyzing; Application.

1. Introduction

Well loss occur frequently during block exploration wells and deep wells drilling in the new area, for example, the buried hill reservoir in shengli Oilfield. In terms of well loss risk monitoring and diagnosis, foreign companies are more mature, such as the risk-free drilling system (NDS) which was jointly developed by Schlumberger and BP company [1], the NDS has been successfully applied in the Gulf of Mexico and other regions, greatly saving drilling costs. Although a lot of researches has been carried out in the field of drilling risk diagnosis in China, but these researches mainly focused on expert knowledge system [2]. The domestic oil companies have carried out the research and development of drilling risk while drilling diagnosis system, but no extensive field application was reported. The main reason is lack of means to obtain downhole data and lack of data analysis ability. then the domestic engineering parameters measurement system (EPMS) appeared [3]. A hydraulic model and the a tubular model were build based on the measurement data of downhole engineering parameters measurement system (EPMS), then the characteristic parameters and evaluation system of wellbore complexity and well loss risk were selected, the well loss risk real-time monitoring system was established. The system could process and evaluate the drilling data to real-time diagnose the well loss risk. Meanwhile, the collected logging data and downhole data were simulated and analyzed to provide technical support for complex processing.
2. Foundation of Hydraulic Model

Hydraulic model was a kind of numerical model which uses computer to describe the fluid state in wellbore, including pressure, temperature and other parameters. The hydraulic model was composed of various parameters such as wellbore pressure, temperature, flow pattern and flow pattern. By analyzing the pressure profile, especially the change of the annular pressure and the internal pressure of the drill pipe with the surface injection parameters, the flow state of the drilling fluid in the wellbore could be calculated real-time. Combined with the real-time monitoring of the temperature, these parameters could be use to analyze the wellbore risk in real time through the risk assessment system. At the same time, the wellbore wind through the simulation analysis module could be analyzed and predicted according to the surface input parameters. So as to reduce the probability of wellbore complexity and risk[4].

Calculation of circulating pressure drop

\[ \Delta P = 2f \frac{\rho v^2}{D} L \]  

where:
- \( \Delta P \) — the confining pressure, MPa;
- \( f \) — friction coefficient.
- \( \rho \) — density, g/cm³;
- \( v \) — current speed, m/s;
- \( D \) — hydraulic diameter, m;
- \( L \) — length, m;

The friction coefficient \( f \) could be calculated by

\[
f = \begin{cases} 
  \frac{16}{Re} & \text{for laminar flow} \\
  \sqrt{\frac{4}{n.75}} \left[ \log_{10} \left( Re f (1-n/2) \right) - \frac{0.395}{n^{1/2}} \right] & \text{for turbulence flow} 
\end{cases}
\]  

(2)

\[
Q = \frac{n \pi R^2}{3n+1} \left( \frac{\tau_w}{K} \right)^{1/n} \left[ 1 - \left( \frac{\tau_0}{\tau_w} \right)^{(n+1)/n} \right]^{1+\left( \frac{2n}{2n+1} \frac{\tau_0}{\tau_w} \right)} + \frac{2n^2}{(n+1)(2n+1)} \left( \frac{\tau_0}{\tau_w} \right)^2 
\]  

(3)

where:
- \( Q \) — flow rate, m³/s;
- \( n \) — fluid index;
- \( R \) — hydraulic radius, m;
- \( \tau_0 \) — ultimate dynamic shear stress, MPa;
- \( \tau_w \) — dynamic shear stress of wall, MPa;
- \( K \) — consistency index;
- \( Re \) — Reynolds number.

In (2) and (3), \( K \) and \( Re \) and \( n \) could be measured in field, \( Q \) and \( R \) and \( \tau_0 \) was known, \( Re \) was basic calculated parameter.

In drilling engineering, temperature effect the rheology,

\[ \tau = A + BT + De^{\gamma T} \]  

(4)

where:
- \( T \) — temperature, K;
- \( A, B, D \) and \( E \) was constant, could be measured.

So the \( T \) must be calculated.

Heat transfer relationship in wellbore
\[
\frac{d (w_m C_m T_a)}{dz} = \frac{1}{B} (T_a - T_f) - \frac{1}{A} (T_f - T_a)
\]

(5)

\[
A = \frac{1}{2\pi r_a U_a}, \quad B = \frac{1}{2\pi r_i U_i}
\]

(6)

\[
U_a = \left[ \frac{d_w}{d_i h_a} + \frac{d_i}{2k_p} \ln \frac{d_{oc}}{d_i} \right]^{-1}, \quad U_i = \left[ \frac{1}{h_i} + \frac{d_i}{2k_p} \ln \frac{d_{oi}}{d_i} h_a d_w \right]^{-1}
\]

(7)

\(w_m\) — quality flow rate, kg/s;

\(C_m\) — specific heat, J/(kg·K);

\(T_a\) — annulus temperature, K;

\(T_f\) — temperature in drill pipe, K;

\(T_i\) — temperature in stratum, K;

\(z\) — length, m;

\(r_{oc}, r_i\) — casing outer radius, drill pipe inter radius, m;

\(U_a, U_i\) — annulus heat transfer coefficient, drill pipe heat transfer coefficient, W/(m²·K);

\(d_{oc}, d_{ci}\) — casing outer diameter, casing inter diameter, m;

\(d_{oi}, d_{ti}\) — drill pipe outer diameter, drill pipe inter diameter, m;

\(k_p\) — coefficient of heat conductivity of drill pipe, W/(m·K);

\(h_a, h_i\) — annulus and drill pipe convective heat transfer coefficient, W/(m²·K);

\[
h_a = \frac{N_{ua} k_a}{D} = \frac{N_{ua} \int_{r_o}^{r_i} \left[ \alpha_r k_g + (1 - \alpha_r) k_t \right] 2\pi r dr}{D 2\pi (r_i^2 - r_o^2)}
\]

(8)

\[
h_i = \frac{N_{ui} k_i}{d_{ti}}
\]

(9)

\(k_a, k_p\) — coefficient of heat conductivity in drill pipe and annulus, W/(m·K);

\(k_g, k_l\) — gas and liquid coefficient of heat conductivity, W/(m·K);

\(N_{ua}, N_{ui}\) — Nusselt number in drill pipe and annulus;

\(\alpha_r\) — gas void;

**pressure distribution in case of simulated well loss**

When the well loss occurred, part of the drilling fluid in annulus flowed into the stratum, so the flow model could be seen as distributing pipe, so the flow model was built as below.

\[
P_{loss} + \rho_i v_i^2 = P_f + \frac{\rho_{loss} v_{loss}^2}{2}
\]

(10)

\[
P_f + \frac{\rho_{loss} v_{loss}^2}{2} = \rho_f v_f^2 + f \left( Q_{loss}^2 \right) + \rho g H_{loss}
\]

(11)

\[Q = Q_{loss} + Q_{loss}
\]

(12)

\[v_i = \frac{Q}{S}
\]

(13)
\[ Q_{\text{loss}} = \frac{P_{\text{loss}} - P_f}{S_{\text{loss}}} \]  

\[ Q_{\text{f}} = \frac{P_{\text{f}} - P_{\text{loss}}}{S_{\text{f}} + S_{\text{loss}}} \]  

\[ P_{\text{loss}} = P_{\text{f}} + f\left(Q_{\text{f}}^2\right) \]  

\[ f\left(Q_{\text{loss}}^2\right) = \text{sum of annulus friction above leakage point, MPa;} \]

\[ P_{\text{loss}} \quad \text{pressure of leakage point, MPa;} \]

\[ P_{\text{f}} \quad \text{formation pressure of leakage point, MPa;} \]

\[ v_{\text{loss}} \quad \text{leakage speed, m/s;} \]

\[ v_{\text{f}} \quad \text{annular velocity above leakage point, m/s;} \]

\[ H_{\text{loss}} \quad \text{depth of leakage point, m;} \]

\[ Q_{\text{loss}} \quad \text{leakage flow rate, m}^3/\text{s;} \]

\[ Q_{\text{f}} \quad \text{flow rate above leakage point, m}^3/\text{s;} \]

\[ S, S_{\text{loss}} \quad \text{annulus area, leakage point area, m}^2. \]

### 3. Establishment of Well Loss Risk Assessment System

Wellbore risk characteristic parameters referred to formation characteristic parameters, mechanical parameters or composite parameters directly related to wellbore risk, mainly including hydraulic and drill string mechanics parameters. In the process of drilling, through calculation and analysis of the change of real-time monitoring well loss characteristic parameters, combined with the previous research results, the risk characteristic parameter judgment standard was established, so as to establish the well loss evaluation and trigger mechanism.

\[ P_{\text{Tian}} - P_{\text{Tian-1}} < 0.7, P_{\text{Tan}} - P_{\text{Tan-1}} < 0.7, |\Delta P_{\text{man-1}} - \Delta P_{\text{max}}| < 0.7, P_{\text{man-1}} - P_{\text{man}} > 0.5 \]

\[ P_{\text{Tia}} \quad \text{the average value of drill pipe pressure calculation value, MPa;} \]

\[ P_{\text{Tia}} \quad \text{the average value of annulus pressure calculation value, MPa;} \]

\[ P_{\text{ma}} \quad \text{the average of the drill pipe pressure measured value, MPa;} \]

\[ P_{\text{ma}} \quad \text{the average of the annulus pressure measured value, MPa;} \]

\[ \Delta P_{\text{ma}} \quad \text{the average value the differential pressure measured value, MPa;} \]

\[ N \quad \text{the nth calculation point.} \]

### 4. Risk Simulation Analysis of Lost Circulation

Based on the established hydraulic model, the fluid state in the wellbore is diagnosed. Firstly, before spudding, the wellbore parameter profile during normal drilling is established according to the simulation model and design parameters, especially the wellbore risk characteristic parameter profile. Then, the constant in the model is modified according to the actual drilling data. At the same time, the wellbore risk characteristic parameter changes during risk occurrence are simulated and predicted according to the working condition characteristics of different risks occurrence, as the supplement of risk identification and reference resources. Finally, in the process of practical application, through the simulation and prediction of the parameters while drilling, the next step of construction is guided, and the type of drilling risk is diagnosed. For example, when judging the occurrence of lost circulation, it is important to calculate the simulated loss depth as follows

\[ (1) \quad \text{loss rate is less than the injection rate} \]

\[ f\left(Q_{\text{loss}}^2\right) + f\left(Q_{\text{f}}^2\right) + \rho gH = P_B \]  

\[ P_{\text{B}} \quad \text{Bottom hole annulus pressure, MPa;} \]

\[ H \quad \text{Vertical depth, m} \]
Therefore, only the well loss depth was unknown.

(2) loss of recurrence

Due to the large amount of well loss in the well at this time, the position of the upper end of the liquid level (i.e. static liquid level) was known.

\[ f(Q_t^2) + \rho g (H - H_t) = P \]  \hspace{1cm} (17)

\[ Q_{loss} = Q_t \]  \hspace{1cm} (18)

\( H_t \)——static flow level, m

Therefore, only the well loss depth is unknown.

5. Well Loss Risk Real-time Monitoring System

Based on the models build above, a program of “Well Loss Risk Real-time Monitoring System” was made, the program real-time read, saved and processed the underground and surface engineering parameters, especially the internal and external pressures, from the logging data and the EPMS. Then calculated the characteristic parameters as theoretical values based on the logging data and drilling fluid parameters. Then the program will compare the calculated value and the measured value, and the assessment system, if the result reach risk level, the program will alarm. So the wellbore risk level was monitored real-time.

6. Application

Well loss risk while drilling monitoring technology was applied on G1 well in GX blocks of Shengli oilfield, in which the well loss occurred frequently, and caused a loss of several million yuan. The technology was used from 416m to 2347m (1931m in total). When the well depth came to 2347m in the third part of Shahejie Group, the lost circulation occurred. The monitoring progress of “Well Loss Risk Real-time Monitoring System” was showed in Fig.1. The lithology of this stratum was igneous rock, the density of drilling fluid was 1.18g/cm³, and the displacement was 1.9m³/min. At 19:49, the measured annulus pressure dropped 0.7MPa (the red rectangle in Fig.1), while the calculated annulus pressure remained unchanged, which conformed to the characteristics of bottom hole well loss, the monitoring system alarmed “well loss”. At 20:00, 2m³ of drilling fluid loss was found by logging. The displacement was immediately reduced to 1.5m³/min for circulation observation. At 20:07 it was found that the drilling fluid could not get out, so the mud pump was stopped immediately, and 10 drilling strings was tripped out. Well loss was detected 18 minutes in advance by the monitoring system, during this period, 10m³ drilling fluid was lost. The accuracy of the monitoring system was verified in the field application. So this example indicated that well loss could be monitored at an early stage.

And to deal with the well loss, the well loss depth must be calculated. According to equation 15, the calculated well loss depth was 2338m, and according to the later electrical logging results, the igneous rock was drilled at 2343m, so the absolute error of the lost circulation depth was 5m, and the relative error was 0.38%. The application results showed that the use of the wellbore risk monitoring system combined with the EPMS could be used to monitor well loss at an early stage, so as to reduce the complexity and lost, finally reduce the cost of materials and processing time.
7. Conclusion
(1) Based on the establishment of accurate wellbore hydraulic model, and the characteristics of wellbore flow during lost circulation, the calculated model of well loss and well loss depth were got. (2) For the well loss risk, the characteristic parameters were internal and external pressures, and the threshold limit values of well loss risk levels was selected, then the assessment system was established. (3) through real-time processing and analysis of underground and surface engineering parameters, the characteristic parameters of the well loss risk was calculated real-time, according to the comparison of the calculated value and the measured value, and the assessment system, the wellbore risk level was monitored real-time. (4) The results of field application verify the reliability and accuracy of the technology. For the development law and detailed risk division of well loss risk, as well as the difference of risk assessment system and risk characteristic parameters in different regions and blocks, it is still in the exploration and improvement stage, which requires a lot of measures analysis to form mature application and promotion technology.

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