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Research on drilling fluid leakage model

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Abstract. The leakage model of Herschel-Bulkley rheological model based drilling fluid under the condition of natural fracture was established to obtain that rheological parameter is the crucial factor affecting drilling fluid leakage of fractured formation; the stronger the shear dilution effect, the higher the leakage rate of drilling fluid, especially at the initial stage of leakage, the final leakage is controlled by the dynamic shear force of drilling fluid. This model proposed took the influence of formation fluid into account, indicating that as the viscosity of formation fluid is equivalent to that of drilling fluid, the property of formation fluid (viscosity and compressibility) significantly influences the final leakage and leakage rate of drilling fluid. Moreover, it may match the field data with the predicted result of the model in a better way to gain a more accurate fracture aperture if the influence of formation fluid is considered into this model.

Key words. Radial flow, non-newtonian fluid, herschel-bulkley model, drilling fluid, lost circulation.

1. Introduction

The some typical ere are numerous experts and scholars researching the drilling fluid leakage rule by applying the method of quantitative analysis, among which there areleakage models: leakage model of Bingham model based drilling fluid under single smooth fracture proposed;leakage model of Herschel-Bulkley model based drilling fluid under smooth radial fracture established; 2D drilling fluid leakage model considering fractal fracture roughness proposed based on Reynolds equation and verified through indoor leakage simulation experiment regarding its correctness; leakage model of Herschel-Bulkley model based drilling fluid under the fracture at any 2D dip angle established without considering the influence of the roughness of fracture surface.

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2. Drilling Fluid Leakage Model in Natural Fracture

The steady-state linear flow model of Herschel-Bulkley fluid between two parallel plates was applied to simulate the flow of drilling fluid in single fracture; the constitutive equation describing the shear stress and shear rate of Herschel-Bulkley fluid is:

$$RSET = t_{perc} + t_{resp} + t_{move} \tag{1}$$

$p_w$refers to the dynamic shear force, p_w and p_w respectively refer to consistency factor and liquidity index of drilling fluid. The relationship between the pressure gradient and the flow rate inside the fracture was given via the approximate solution of radial flow momentum balance equation:

$$t_{move} = \frac{Q}{NB} + \frac{L}{V} \tag{2}$$

p_w refers to the pressure gradient, p_w means the flow rate, p_w is the hydraulic fracture width, and the second item of 3 is the smallest pressure gradient required by flow of fluid with dynamic shear force. In formula 3, flow rate p_w is not the function of position p_w, because suppose the fluid is incompressible, the well pressure at the leakage stage is constant, besides, all pressures are applied on drilling fluid, the integral of drilling fluid invasion depth p_w from well p_w to fracture is:

$$t_{move} \leq \text{ASET} - t_{perc} - t_{resp} \tag{3}$$

p_w refers to the wellhole pressure; p_w is the initial formation pressure. Flow ratep_w is gained by solving equation,

$$\Delta T = \frac{T_{proposed} - T_{JMVC}}{T_{JMVC}} \times 100\% \tag{4}$$

As for radial flow, relationship between the front position p_w and flow rate of drilling fluid in fracture is:

$$\Delta PSNR = PSNR_{proposed} - PSNR_{JMVC} \tag{5}$$

p_w is the leakage volume of drilling fluid, drilling fluid invasion depth p_w is the function of time; the expression of front position of drilling fluid changing along with time can be obtained by substituting 5 into 6:

$$\Delta B = \frac{BR_{proposed} - BR_{JMVC}}{BR_{JMVC}} \times 100\% \tag{6}$$

In order to gain more adaptable solution, the dimensionless variables (dimensionless invasion radius, leakage, drilling fluid invasion factor and time factor) are defined as follows:

$$J_i = \min_a\{f_a\} + \frac{W_0 - 1}{B_i - 1} \cdot (\max_a\{f_a\} - \min_a\{f_a\}) \ , \quad a = 1, 2, \cdots A \tag{7}$$

$$mag = \frac{\langle T_j, y \rangle}{\langle T_j, T_j \rangle} \tag{8}$$

p_w is the dimensionless time factor, then p_w. The dimensionless expression of movement about the front position of drilling fluid in fracture can be obtained if dimensionless variable is applied:

$$M_{pq} = \int\int x^p y^q f(x,y)dxdy \ p,q = 0,1,2... \tag{9}$$

p_w in formula 9refers to the dimensionless drilling fluid invasion factor, and formula 9 is the first-order differential equation, and can be solved through initial conditions.

Can be solved through the initial conditions p_w=1 and p_w.

Namely:

$$F_{pq} = \int\int f(r,\theta)g_p(r)e^{jq\theta}rdrd\theta \tag{10}$$

When the filed data fit well with the specific ideal curve, the corresponding fracture width can be gained. Hydraulic width of fracture is selected as the regression parameter to find out the optimal matching relation between the predicted value and field data.

3. Influence of Formation Liquid on Leakage

The influence of formation fluid on drilling liquid is combined into the model. Formation liquid is weak and compressible liquid, and the compressibility factor is constant;Formation liquid is Newtonian fluid, and the viscosity is constant. Similar to formula 11, the linear flow in width w is used to describe the flow of Herschel-Buckley model based liquid in fracture. According to momentum conservation, the local pressure differential through drilling liquid belt is

$$\|F_{pq}^{rotated}\| = \sqrt{F_{pq}^{rotated} \times (F_{pq}^{rotated})^*} = \|F_{pq}\| \tag{11}$$

p_w is the well pressure, and p_f is the front pressure of drilling liquid. Formula 11 is the integral from well radius r_w to drilling liquid front r_f.

$$F_{pq} = \int s_q(r)g_p(r)rdr \tag{12}$$

Dimensionless drilling liquid flow rate is:

$$g_p^{Zerinke}(r) = \sum_{s=0}^{(p-|q|)/2} (-1)^s \times \frac{(p-s)!}{s!(\frac{p+|q|}{2}-s)!(\frac{p-|q|}{2}-s)!} r^{p/2-s} \tag{13}$$

$$q_D \tag{14}$$

Formula 14 should be combined with the flow equation of formation liquid. Formation liquid like crude oil is generally weak and incompressible, and the compressibility factor is certain constant c. Pressure distribution in this area is described with pressure diffusion equation.

$$\psi_{ab}(r) = \frac{1}{\sqrt{b}}\psi(\frac{r-b}{a}) \tag{15}$$

16 is the function of r_{fD}, while r_{fD} is the function of time t_D.

$$W_{m,n-1} = \int\int f(r,\theta)[\psi_{m,n}(r)e^{jq\theta}]^* r dr d\theta \tag{16}$$

To solve , this formula should be discretized into multiple time steps for solution. Initial conditions =1, =0 are known.

Formula 17 is the discretization form of 18, the integral item is approximated to the exponential integral result at the boundary, the flow item is extracted from the integral; suppose the flow rate changes slightly in each time interval.

$$\psi(r) = \frac{4a^{n+1}}{\sqrt{2\pi(n+1)}}\sigma_w \cos(2\pi f_0(2r-1)\cdot \exp\left(-\frac{(2r-1)^2}{2\sigma_w^2(n+1)}\right) \tag{17}$$

4. Field Application

Most field leakage reports only provide the rough values of total leakage and leakage rate, which have lower precision if applied into model, so that an accurate measurement should be made for the relationship between the leakage rate and time of drilling liquid by applying flowmeter in model.

The data come from certain leakage zone of LC01, and through these data the leakage rate can be calculated.

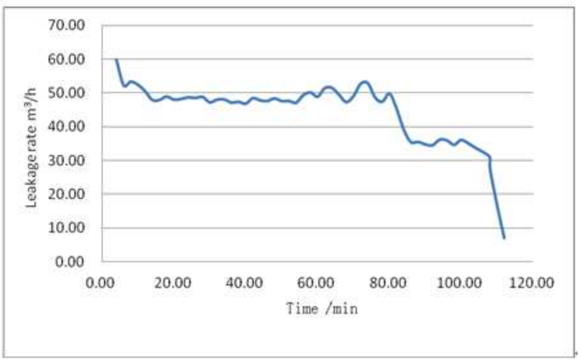

Fig. 1. Relationship between leakage rate and time of certain section of well at lc01

The predicted final leakage volume is 341.33m^3. To include the influence of formation liquid into the model, suppose the fracture is filled with liquid (viscosity:

1cp; compressibility factor: $1.45\times10^{--3}$ MPa^{--1}), and the rheological ratio can be calculated as 0.02. Low rheological ratio slightly influences the solution of model; while as the viscosity of formation liquid is 100 cp and the rheological ratio is 2, it significantly influences the curve fitting result. Fig. 3-2 shows the predicted result including the influence of formation liquid.

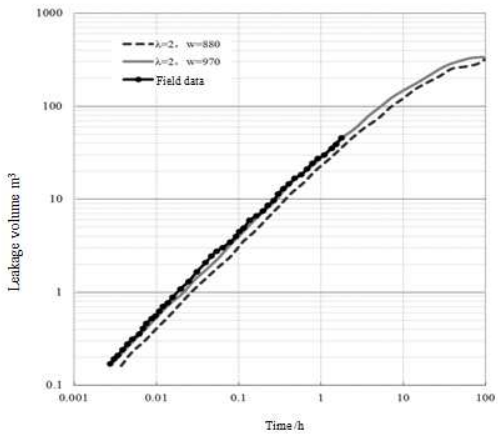

Fig. 2. Relationship between leakage and time considering the influence of formation liquid

At the best fit, the mean fracture width is 970μm and the final leakage is 385.53m^3.

5. Conclusion

1. The mathematical model about leakage of Herschel-Bulkley model based drilling liquid was established, and based on this model, a research was carried out concerning the influence of rheological parameters of drilling liquid such as dynamic shear force, shear dilution property (liquidity index) on the leakage of fractured formation. The research shows that dynamic shear force can influence the initial leakage, while shear dilution effect may significantly influence the leakage rate.

2. With this model, the value of fracture width can be estimated through quantitative analysis on field data. Fracture width is of great significance to formulation of leaking stoppage measures. The fracture width can be better estimated with this model. When the viscosity of formation liquid is equivalent to that of drilling liquid, $\lambda1$, the property of formation liquid (viscosity and compressibility) can significantly influence the final leakage and leakage rate of drilling liquid.

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