Study on fracturing fluid filtration fracturing technology

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Abstract. The filtration of fracturing fluid is one of the important factors that affect the effect of fracturing construction. Therefore, it is of great significance to study fracturing fluid loss for fracturing technology. Based on the fracturing fluid filtration theory, the fluid loss coefficient is used to describe the loss of the fracturing fluid in the formation. At the same time, according to the different formation conditions, the corresponding pressure drop analysis model is used to describe the pressure falling process. According to a target area, the filter loss parameter is calculated by combining the filtration mechanism and the pressure drop pressure drop analysis model. It is necessary to study the fracturing fluid technology and optimize the fracturing fluid with the concentration of 4% of the filtrate reducer, which is compared with the original formula with the concentration of 1% of the original filtrate loss agent. The loss coefficient is reduced by 44.13% on average, which can better meet the actual demand.

1. Introduction
In hydraulic fracturing, the excessive filtration of fracturing fluid[1-2] can cause serious consequences, such as the increase of the density of sand in the crack and the reduction of the volume of the fracture, so that the degradation function[3] of the fracturing fluid can not be fully played. It is easy to cause sand blockage, blockage of clay particles and so on, which will reduce the permeability[4] of oil layer and cause oil damage. It is difficult to create cracks, increase the difficulty of construction of oil and gas development process, or even destroy the formation, resulting in waste of resources and environmental pollution. Therefore, it is very necessary to effectively control the filtrate loss of fracturing fluid.

The basic characteristic of the two-dimensional fracture model[5] is that the height of the crack does not change with time and position, and the height of the fracture is always greater than or equal to the thickness of the production layer. Although a large number of laboratory experiments and field tests have shown that the height of the cracks in the formation is often not fixed but varies with time and position, but the fracture two-dimensional model has the characteristics of mature theory, less input parameters and simple calculation. Under the condition of formation (such as uniform distribution of ground stress and little change in rock mechanical parameters), it is still applied.
2 Analysis of filtrate loss characteristics of fracturing fluid

2.1 Analysis of filtration mechanism
The filtration rate of fracturing fluid is controlled by the comprehensive filtration coefficient \(C\) of fracturing fluid. The comprehensive filtration coefficient \(C\) is defined by three mechanisms: \(C_1\), \(C_2\), \(C_3\). Their expressions are as follows:

\[
\eta_d = \frac{K_1 - K_2}{K_1} \times 100\% \quad (1)
\]

\[
C_2 = 0.138\Delta p \left[ \frac{K C_T \varphi}{\mu} \right] \quad (2)
\]

\[
C_3 = C_3 \left( \frac{\Delta p}{\Delta p^*} \right) \quad (3)
\]

The filtrate loss of fracturing fluid is controlled by three mechanisms, and its comprehensive filtration coefficient \(C\) can be calculated by harmonic average method:

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad (4)
\]

\[
C = \frac{2C_1 C_2 C_3}{C_1 C_3 + \sqrt{C_2^2 C_1^2} + 4C_2^2 (C_1^2 + C_3^2)} \quad (5)
\]

2.2 Analysis method of pressure drop after pressure
A two-dimensional model for pressure drop analysis after fracturing is established according to the principle of fluid volume balance in the cracks during construction injection and crack closure. The relationship between pressure drop and time function is derived from the fracture elongation index:

\[
p_w(t) - p_w(t) = p^*G(t_1, t) \quad (6)
\]

\[
t_D = \frac{t - t_{inj}}{t_{inj}} \quad (7)
\]

\[
G(t_2, t) = \frac{4}{\pi} [g(t) - g(t_2)] \quad (8)
\]

\[
g(t) = \begin{cases} 
\frac{4}{3} \left[ (1 + t_D)^3 - t_D^3 \right] & \text{(high efficiency)} \\
(1 + t_D) \sin^{-1} (1 + t_D)^{-\frac{1}{2}} + t_D^{-\frac{1}{2}} & \text{(low efficiency)} 
\end{cases} \quad (9)
\]

In practical application, because of the difficulty in determining the fracture elongation index in advance, the arithmetic mean of the upper and lower limit of fracture extension index is obtained:

\[
g(t) = \frac{2}{3} \left[ (1 + t_D)^{\frac{3}{2}} - t_D^{\frac{3}{2}} \right] + \frac{1}{2} \left[ (1 + t_D) \sin^{-1} (1 + t_D)^{-\frac{1}{2}} + t_D^{-\frac{1}{2}} \right] \quad (10)
\]

The filtration coefficient \(C\) of the fracturing fluid is as follows:

\[
C = \frac{p_w(1 - g^2) \beta}{f_p E_d t_{inj}} \begin{cases} 
H & \text{(PKN mod e l)} \\
L_f & \text{(KGD mod e l)} \\
32/3\pi^2 & \text{(Radil mod e l)} 
\end{cases} \quad (11)
\]
Among them:

$$f_p = H/H_p$$

$$\beta = \begin{cases} 
    (2n + 2)/(2n + 3 + \alpha) & (PKN\ mod\ e\ l) \\
    0.9 & (KGD\ mod\ e\ l) \\
    3\pi^2/32 & (Radil\ mod\ e\ l) 
\end{cases}$$

$$\rho = \frac{p_{ist} - p_c}{p} \begin{cases} 
    3\pi/16 & 1/2 
\end{cases}$$

$$\eta = \frac{\rho}{1 + \rho}$$

$$\frac{2nQ_{in}}{\pi(p_{ist} - p_c)(1 - \gamma^2)} = \begin{cases} 
    \frac{\beta H^2 L_f}{\beta H L_f} & (PKN\ mod\ e\ l) \\
    \frac{\beta H L_f}{\beta(32/3\pi^2) L_f} & (KGD\ mod\ e\ l) \\
    \frac{\beta(32/3\pi^2) L_f}{(32/3\pi^2) L_f} & (Radil\ mod\ e\ l) 
\end{cases}$$

$$W = \frac{\pi(1 - \gamma^2)(p_{ist} - p_c)H}{2E} \begin{cases} 
    \frac{H}{L_f} & (PKN\ mod\ e\ l) \\
    \frac{L_f}{(32/3\pi^2)L_f} & (KGD\ mod\ e\ l) \\
    \frac{L_f}{(32/3\pi^2)L_f} & (Radil\ mod\ e\ l) 
\end{cases}$$

$$g(t_c) = 1 + \frac{3WH}{8CH_p\sqrt{T_{inj}}}$$

The above is a two-dimensional model of pressure drop analysis after fracturing. Since different fracturing models are suitable for different formation conditions, the corresponding analysis models should be selected according to the formation conditions in the analysis of pressure drop curves. In practical application, the analysis model can be selected according to the construction pressure curve or the distribution of ground stress. The following are as follows: (1) the PKN model is suitable for the formation conditions that the construction pressure increases with time; (2) the KGD model is suitable for the formation strip with the construction pressure falling slightly or unchanged with time; (3) the Radil model is suitable for the construction pressure with time. The formation conditions of a great decrease in speed.

3. Design of fracturing fluid filtration process

3.1 Experimental test results

Taking a target block as an example, the fracturing fluid filtration process scheme is designed. In the coal bed pressure crack of the target block, the fracturing fluid usually uses the active water pressure fracturing fluid, and the wall loss coefficient $C_2$ is not existed at this time, mainly for the filtration coefficient $C_1$ of the viscosity control of the fracturing fluid and the filter loss coefficient $C_2$ synthesis controlled by the fluid compressibility of the ground layer. At the same time, the pressure drop data (Figure 1) of the 3# layer of SX-005 well in the target area is calculated by using the pressure drop two-dimensional model.
Figure 1. Post pressure drop map of a target block well

Aiming at the target area, 28 kinds of fracturing fluid formulations are used to test the performance of the filtrate reducer, and the filtration loss experiment shows that there are 15 kinds of fracturing fluid formulations that can't complete the filtration. Therefore, the 15 formulas are selected to carry out the fracturing fluid filtration experiment, and the 15 fracturing fluid formulations are shown in Table 1.

| Fracturing fluid name | Formula of fracturing fluid                        |
|-----------------------|----------------------------------------------------|
| Fracturing fluid 1    | Clean water +3%PF-PAC-LV+0.5%PAC-LV+5%EP-1        |
| Fracturing fluid 2    | Clean water +3%PF-PAC-LV+0.5%PAC-LV+4%EP-1        |
| Fracturing fluid 3    | Clean water +3%PF-PAC-LV+0.3%PAC-LV+3%EP-1        |
| ...                   | ...                                                |
| Fracturing fluid 13   | Clean water +2%KCl+0.2%YB-1+0.2%JF-2+0.1%FP-2+0.1%TY-2 +3%PF-PAC-LV+0.3%PAC-LV+3%EP-1 |
| Fracturing fluid 14   | Clean water +2%KCl+0.2%YB-1+0.2%JF-2+0.1%FP-2+0.1%TY-2 +3%PF-PAC-LV+0.3%PAC-LV+2%EP-1 |
| Fracturing fluid 15   | Clean water +2%KCl+0.2%YB-1+0.2%JF-2+0.1%FP-2+0.1%TY-2 +3%PF-PAC-LV+0.3%PAC-LV+1%EP-1 |

The filtrate loss performance parameters of the 15 fracturing fluids obtained by filtration test are shown in Table 2.

| Fracturing fluid | Filtration area $A$ (cm$^2$) | Slope $m$ (ml/min$^{0.5}$) | Intercept $h$ (cm$^2$) | Filtration coefficient $C_3$ (10$^{-5}$m/min$^{0.5}$) | Filtration rate $v_c$ (10$^{-5}$m/min$^{0.5}$) | Initial filter loss $Q_{SP}$ (m$^3$/m$^2$) |
|------------------|-------------------------------|-----------------------------|------------------------|--------------------------------------------------------|-------------------------------------|---------------------------------------------|
| Fracturing fluid 1 | 22.6                          | 0.5357                      | 34.305                 | 1.18518                                               | 1.9753                             | 1.517920354                                |
| Fracturing fluid 2 | 22.6                          | 0.9644                      | 39.539                 | 2.13363                                               | 3.5561                             | 1.749513274                                |
| ...               | ...                           | ...                         | ...                    | ...                                                   | ...                                | ...                                         |
| Fracturing fluid 14 | 22.6                          | 2.8549                      | 76.732                 | ...                                                   | ...                                | 3.395221239                                |
| Fracturing fluid 15 | 22.6                          | 2.9933                      | 85.543                 | 6.62235                                               | 11.0372                            | 3.785088496                                |
3.2 Process plan design

Through the fracturing fluid filtration experiment, it can be seen that the first fracturing fluid formula 1~5 has a relationship with the change of the filtrate loss concentration and the change of the filtration coefficient and the filtration rate: with the increase of the filtrate loss concentration, the filtration coefficient and the filtration rate will be smaller, the filtration coefficient is lower when the filtrate loss concentration is 5%, and the concentration of the concentration is considered. The degree is more economical and effective. With the change of the concentration, the variation of the filtration coefficient and the filtration rate of the second fracturing fluid formula: with the increase of the concentration of the filtrate reducer, the filtration coefficient and the filtration rate become smaller, and when the concentration of the filtrate reducer is 4%, it is more economical and effective; the third fracturing fluid formula, 11~15, is with the concentration of the formula 6~10. The change, the coefficient of loss of filtration and the loss of filtration rate: with the increase of the concentration of the filtrate reducer, the filtration coefficient and the filtration rate become smaller, and it is more economical and effective when the concentration of the filtrate reducer is 4%.

![Figure 2](image)

Figure 2. Comparison of filtration coefficients of three fracturing fluids

According to Figure 2, the fracturing fluid with the concentration of 4% of the filtrate reducer is more effective, that is, the formula of fracturing fluid with 3%PF-PAL-LV+0.3%PAC-LV+4%EP-1 filtrate reducer is more economical and effective.

As can be seen from Table 2 and Figure 2, the filtration coefficient decreases obviously compared with the formula with the concentration of 4% for the filtrate loss of 4% and the formula with the filtrate loss concentration of 1%, and the comparison analysis is shown in Table 3.

| fracturing fluid     | Filtrate loss concentration | Filtration coefficient | The percentage of the loss of the loss coefficient |
|----------------------|-----------------------------|------------------------|-----------------------------------------------|
| The first formula    | 1%                          | 7.1552                 | 50.30%                                        |
|                      | 4%                          | 3.5561                 |                                               |
| The second formula   | 4%                          | 9.0398                 | 46.33%                                        |
|                      | 1%                          | 4.8521                 |                                               |
| The third formula    | 1%                          | 11.0372                | 35.75%                                        |
|                      | 4%                          | 7.0911                 |                                               |
| Average decrease percentage of filter loss coefficient of filtrate reducer | | | 44.13% |

After using the filtrate reducer, although the filtration coefficient of fracturing fluid is low. The measures to reduce the silt filtration are as follows: first, the first part of the pre fluid is injected into the first section to open the crack and make it form a certain scale, and then 2% of the silt is added to the second segment of the pre fluid. On the one hand, the method can plug the open micro cracks and reduce the filtration of fracturing fluid; on the other hand, it can also play the role of proppant slug.
4 Conclusion

(1) In view of the actual target block, based on the filtration mechanism and the pressure drop analysis method, the filtration mechanism can be determined through the use of the actual fracturing fluid in the block, and the pressure landing analysis model is selected in combination with the actual formation conditions. The filtration loss coefficient of the fracturing fluid is calculated and the filter loss situation of the target block is determined in order to determine the target area. Whether the block needs to be studied for fracturing filtration process.

(2) To reduce the filtration loss experiment on the target block, select 15 kinds of fracturing fluid in the 28 fracturing fluid formulations to carry out the fracturing fluid filtration experiment, calculate the filtration loss parameters, analyze the relationship between the filtrate loss concentration and the filtration coefficient and the filtration rate, and optimize the fracturing fluid with the concentration of the filtrate reducer to be 4%. Compared with the formula with a concentration of 1%, the filtrate loss coefficient is reduced by 44.13% on average, and the design scheme can meet the actual requirements.

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