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Three Dimensional Analysis Method and Application of Pressure Drop after Coal Seam Pressure

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Abstract. The analysis of pressure drop after compression is very important for obtaining coalbed gas reservoir parameters and optimizing coalbed gas fracturing design. However, there are some problems such as closed pressure analysis, inaccurate calculation of fracture geometry and effective permeability. In this paper, a three-dimensional analysis model of post-pressure pressure drop is established based on the principle of fluid volume balance during injection and closure. Based on the quasi-three-dimensional fracture model, the geometric size, fitting pressure and filtration coefficient of fracturing fluid are explained, and the practicability and accuracy of this method in the analysis of pressure drop after coal seam pressure are verified by field construction examples.

1. Introduction

Hydraulic fracturing is the most effective means to develop CBM at present. The actual geological conditions of coal seam are varied. Longitudinally, the strata often have multi-layer and heterogeneous characteristics, that is, the thickness of each layer may be different and the lithology may not be consistent. Besides, and the mechanical parameters of rock and the distribution of in-situ stress often have certain or even significant differences[2,3]. In order to better guide fracturing construction, people often analyze the pressure drop test curve after pressure to obtain formation parameters, understand formation characteristics, evaluate fracturing construction effect, and on this basis optimize fracturing construction design to achieve better yield benefit. Two-dimensional fracture model is usually used to analyze the geometric dimensions of cracks by using pressure drop data[4,5]. However, this method can not describe the expansion of seam height, which leads to the failure to verify the pressure analysis results after closure, the calculation of fracture geometry size is not accurate, and the effective permeability of reservoir can not be obtained[6], so not suitable for site. In this paper, based on the two-dimensional analysis model of pressure drop after compression, according to the principle of fluid volume balance in fracture during injection and closure, a three-dimensional model is established to analyze the data of pressure decline after fracturing stop pump, and the closed pressure of supporting fracture is studied to find out the closing time of supporting fracture. The applicability and accuracy of this model method are verified by example analysis and calculation.

2. Three dimensional analysis of pressure drop

Assuming that the formation is linear elastic body; there is no sliding between layers; the fracture no longer extends after fracturing stop pump; the fracture length and height remain unchanged during the closure period; the fracture height is elliptical distribution; and the proppant does not affect the free closure of the fracture. Then according to the principle of fluid volume balance in the fracture during injection process and closure, a three-dimensional model can be established to analyze the data of pressure decline after fracturing stop pump. In the fracture quasi-three-dimensional extension model, the fracture width cross section of the bottom hole is elliptical before the fracture penetrates the fracturing layer. After the fracture penetrates the fracturing layer, the irregular shape of the rock is approximately elliptical due to the difference of rock mechanical parameters (such as elastic modulus, poisson's ratio) and minimum principal stress between the upper and lower layers and the fracturing layer. According to the England formula and Green formula, the width of cracks at any part of the width profile is as follow:

$$w(x,z,t) = -16\frac{1-\nu(z)^2}{E(z)}\int_{|z|}^{l}\frac{f(\tau)+zG(\tau)}{\sqrt{\tau^2-z^2}}d\tau \tag{1}$$

Where, $F(\tau) = -\frac{\tau}{2\pi}\int_0^{\tau}\frac{f(z)}{\sqrt{\tau^2-z^2}}dz$, $G(\tau) = -\frac{1}{2\pi\tau}\int_0^{\tau}\frac{zg(z)}{\sqrt{\tau^2-z^2}}dz$

$F(\tau)$ and $G(\tau)$ are the even distributed stress function and the odd distributed stress function on the crack wall, respectively. The maximum crack width of the cross section is as follow:

$$W_{\max}(t) = \begin{cases} \dfrac{2(1-\gamma^2)H_w}{E}(p_w(t)-S_1), \quad H_w < H_p \\ \dfrac{2(1-\gamma^2)H_w}{E}(p_w(t)-S_1) - \dfrac{4(1-\gamma^2)H_w}{\pi E}(S_2-S_1)\left(\cos^{-1}\dfrac{H_p}{H_w} - \dfrac{H_p}{H_w}\ln\dfrac{H_w+\sqrt{H_w^2-H_p^2}}{H_p}\right), \quad H_w > H_p \end{cases} \tag{2}$$

In order to calculate the crack volume conveniently, the irregular crack width profile at the bottom of the well is replaced by the elliptical crack width profile with equal area.

$$W'_{\max}(t) = \begin{cases} \dfrac{2(1-\gamma^2)H_w}{E}(p_w(t)-S_1), \quad H_w < H_p \\ \dfrac{2(1-\gamma^2)H_w}{E}(p_w(t)-S_1) - \dfrac{4(1-\gamma^2)H_w}{\pi E}(S_2-S_1)\left(\cos^{-1}\dfrac{H_p}{H_w} - \Phi\dfrac{H_p}{H_w}\ln\dfrac{H_w+\sqrt{H_w^2-H_p^2}}{H_p}\right), \quad H_w > H_p \end{cases} \tag{3}$$

Where, ϕ is the shape factor of the irregular fracture width profile of bottom hole into elliptical fracture width profile, namely:

$$\Phi = \frac{\dfrac{2}{\pi f_p}\ln\sqrt{1-f_p^2} + \dfrac{2f_p}{\pi}\ln\dfrac{f_p}{\sqrt{1-f_p^2}} + 2\sqrt{1-f_p^2} - \dfrac{1}{\pi f_p} - \dfrac{4}{\pi f_p}\int_0^1 f'_p\ln\left(f'_p\sqrt{1-f_p^2} + f_p\sqrt{1-f'^2_p}\right)df'_p}{\ln\dfrac{1+\sqrt{1-f_p^2}}{f_p}} \tag{4}$$

The maximum width of the horizontal seam is as follow:

$$
\begin{aligned}
W_{\mathrm{up,H\,max}} &= \frac{8(1-\nu_1^2)}{\pi E_1}\int_0^{R_{\mathrm{up}}}(p(x,t)-S_1)\cos^{-1}(\frac{x}{R_{\mathrm{up}}})\mathrm{d}x + \frac{8(1-\nu_2^2)}{\pi E_2}\int_0^{R_{\mathrm{up}}}(p(x,t)-S_2)\cos^{-1}(\frac{x}{R_{\mathrm{up}}})\mathrm{d}x \\
W_{\mathrm{low,H\,max}} &= \frac{8(1-\nu_1^2)}{\pi E_1}\int_0^{R_{\mathrm{low}}}(p(x,t)-S_1)\cos^{-1}(\frac{x}{R_{\mathrm{low}}})\mathrm{d}x + \frac{8(1-\nu_3^2)}{\pi E_3}\int_0^{R_{\mathrm{low}}}(p(x,t)-S_3)\cos^{-1}(\frac{x}{R_{\mathrm{low}}})\mathrm{d}x
\end{aligned}
\tag{5}
$$

Since the length and height of the cracks are constant during the crack closure and only the crack width changes, the increment of the crack volume between t1 and t at any two times is as follow:

$$\Delta V_c(t_1,t)=\frac{2\pi(1-\gamma^2)}{3E}L_f\left[p_w(t)-p_w(t_1)\right]H_w^2\beta_s \tag{6}$$

Since it is difficult to determine the fracture extension index in advance according to the Carter filtration model and the fracture extension index introduced by the Nolte, taking the arithmetic average of the results of the upper and lower limits of the fracture extension index, the fracturing fluid filtration amount is as follow:

$$V_{ls}(t_1,t)=\pi CL_f H_p\sqrt{t_{inj}}\,G(t_1,t) \tag{7}$$

where, $G(t_1,t)=\frac{4}{\pi}\left(g(t)-g(t_1)\right)$

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

$$t_D=\frac{t-t_{inj}}{t_{inj}}$$

According to the principle of volume balance of fluid in cracks during crack closure, we can get:

$$p_w(t_1)-p_w(t)=p^*G(t_1,t) \tag{8}$$

Fracturing fluid filtration coefficient C is as follow:

$$C=\frac{2(1-\gamma^2)H_w^2\beta p^*}{3EH_p\sqrt{t_{inj}}} \tag{9}$$

Maximum fracture width at bottom when fracturing stops pumping is as follow:

$$W_{\max}(t_{inj})=\begin{cases}\dfrac{2(1-\gamma^2)H_w}{E}(p_{ISI}-S_1), & H_w<H_p\\[2ex] \dfrac{2(1-\gamma^2)H_w}{E}(p_{ISI}-S_1)-\dfrac{4(1-\gamma^2)H_w}{\pi E}(S_2-S_1)\left(\cos^{-1}\dfrac{H_p}{H_w}-\dfrac{H_p}{H_w}\ln\dfrac{H_w+\sqrt{H_w^2-H_p^2}}{H_p}\right), & H_w>H_p\end{cases} \tag{10}$$

Fracturing efficiency η is as follow:

$$\eta=\frac{\frac{\pi}{3}L_f W'_{\max}(t_{inj})H_w\beta}{Q_{inj}t_{inj}} \tag{11}$$

Fracture closing time tc can be calculated from the following equation:

$$g(t_c) = \frac{\pi W'_{\max}(t_{inj}) H_w \beta}{12 C H_p \sqrt{t_{inj}}} \tag{12}$$

3. Application and Analysis of Examples

H well is located in a coalbed methane block in Xinjiang oil field. Based on the three-dimensional analysis, model of post-pressure pressure drop of coal seam, the post-pressure pressure drop of H well is tested. Data of the H well are shown in Table 1, and the construction curve is shown in Figure 1.

Table 1. Basic data for H wells

Depth (m)	Thickness (m)	Poisson's ratio	Young modulus (MPa)	Maximum horizontal principal stress (MPa)	Minimum horizontal principal stress (MPa)
2382	2.9	0.18	4860	37.5	36.2
Reservoir porosity (%)	Pressure drop test time (min)	Liquid viscosity (mPa·s)	Injection volume (m^3)	Bottom-hole instantaneous stop pump pressure (MPa)	Pump injection time (min)
6.38	100	1	90.6	47.9	40

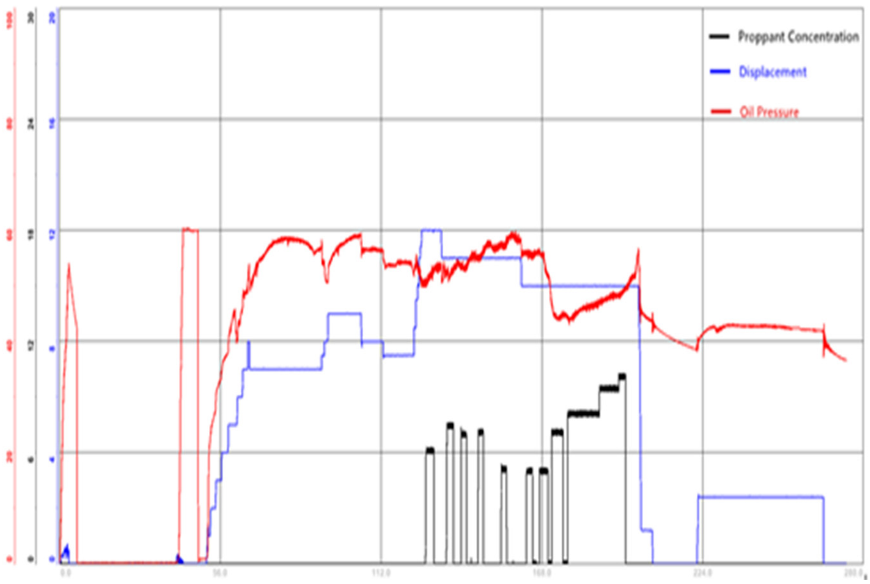

Figure 1. Construction curve of well H

According to the three-dimensional model of post-pressure pressure drop proposed in this paper and the calculation of closed pressure point, the corresponding software is compiled by using Visual Basic6.0, and the basic information of H well is input into the software. the closed pressure of H well crack is shown in Figure 2, and the result of pressure drop after well pressure is shown in Figure 3.

According to figures 2 and 3, it can be seen that the closed pressure of supporting cracks in H well is 41 MPa, the fitting pressure is 10.7 MPa, the crack half length is 201.8 m, the crack width is 0.013 m, the fracturing fluid efficiency is 35.78%, the filtration loss coefficient is 0.0014 m/min0.5, and the crack closure time is 17.93 minutes.

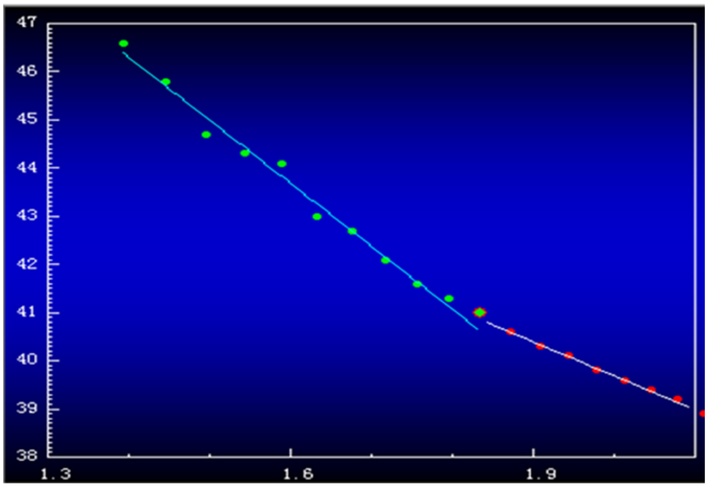

Figure 2. Fracture closure pressure analysis of well H

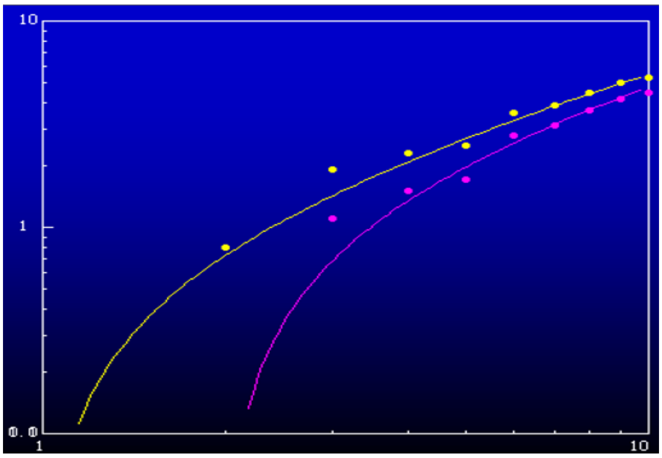

Figure 3. Results of pressure drop after well pressure of well H

During the fracturing process of this well, the whole process of microseismic fracture monitoring is carried out, and the total length of the fracture is 190 m (Figure 4) when the fracturing stop pump is retrieved from the monitoring data. This is 5.8% error with the model results, which indicates that the fracture geometric parameter analysis method obtained by the 3D model of pressure drop after pressure has high accuracy.

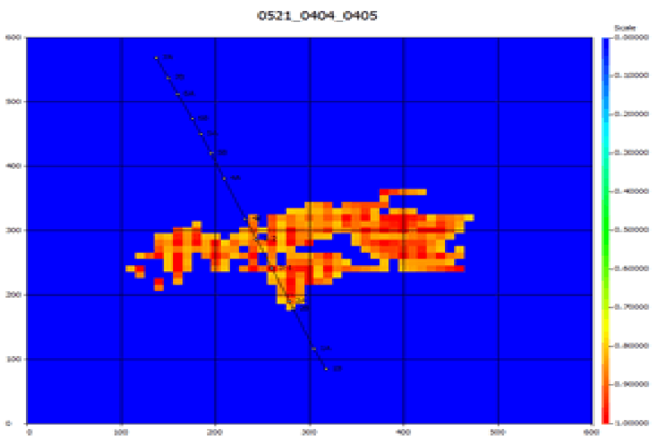

Figure 4. Monitoring results of microseismic fractures in H well

4. Conclusions

Based on the two-dimensional analysis model of post-pressure pressure drop and the principle of fluid volume balance in fracture during injection and closure, a three-dimensional model is established to analyze the data of pressure decline after fracturing stop pump, and the closing pressure of supporting fracture is studied to find out the closing time of supporting fracture.

The fracture geometry parameters, fracturing fluid loss coefficient and fracturing fluid efficiency can be obtained by using post-pressure pressure drop data through three-dimensional analysis model.

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