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A proppant mechanical model in postfrac flowback treatment

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ABSTRACT

It is well known that proppant back flow is a key evaluation criterion in postfrac flowback treatments. Based on the analysis of the physical processes of proppant flowback, a proppant mechanical model is established, the model considers different stress situations before and after fracture closure. Through calculation and analysis, the results show that deposited proppant are carried difficultly and suspended proppant are carried easily before fracture closure. When fracture close down, the cementations of particles become closer and critical velocity become bigger. The viscosity of fracturing fluid for gel breaking directly affects flowback procedure, the bigger viscosity is, the smaller critical velocity is and proppant are easily flowed back. Reducing the viscosity of fracturing fluid for gel breaking, adopting a lower velocity before fracture closure and a higher velocity after fracture closure, cannot only carry fracturing fluid away from formation as soon as possible, but guarantee for the keeping proppant in fracture as much as possible. These results enrich the theories of postfrac proppant flowback.

Postfrac flowback is an important component in fracturing treatment. Especially in low permeability, unconventional oil and gas reservoirs, flowing back can directly decide the final treatment result. Nowadays, it has been paid widely attention and proppant back flow is an important parameter to evaluate fracturing treatment. To different formations, how to choose a flowback model and a critical velocity is a key problem. However, because of lack of a reasonable theoretical model, many experience factors exist in flowback treatments. If a higher velocity is selected before fracture closure, the flowback will occur, if a lower velocity is selected after fracture closure, fracturing fluid may stay in fracture and leak off along the fracture surface into reservoir, they cannot be discharged in time, reservoir secondary damage will occur. Therefore, a reasonable flowback procedure becomes very important.

Nowadays, proppant researches are mostly focused on physics model, such as perforating device (Mark and Diederik, 1999), slot device (Naval and Subhash, 1999), API linear groove (Barree and Mukherjee, 1995) .To the researches of flowback mechanical models, it is hardly found literature to particularly describe it. There are only some few scholars who have done some researches about proppant deposition mechanical model (Wang and Zhang, 1998). Dispersed cell methods are adopted to stimulate proppant stress situations in compacted mixture (Asgian and Cundall, 1995). Li et al. (2006) has done some researches on proppant moment equilibrium. However, there is not a suitable model to depict proppant stress situations before and after fracture closure and the choice of critical velocity also remains unresolved.

1. Model establishment and solution

Bottom hole pressure (fracture pressure) subtract closure stress is equal to net pressure. Fracture is deemed to close when net pressure is zero. To homogeneous reservoirs, closure stress is equal to the minimum main stress in one fracturing layer (Wang, 1987).

Fracture may close slowly as the effect of closure stress before fracture closure. Closure stress directly acts on proppant after fracture closure. The detailed analyses can be seen from Fig. 1.

The last injected proppant will not move a long distance in fracture although they have an initial velocity after fracturing treatment. They will deposit in a very short time when fracturing pump is stop. Therefore, the most important problem of flowback is fluid velocity, if fluid velocity is big enough, proppant back flow will occur. Then, how to control a reasonable flowback rate becomes a key problem. The establishment and analysis of a deposited proppant mechanical model become very important.

The analyses of different mechanical models about proppant are different before and after fracture closure. Before fracture closure, fracturing fluid will give a force on proppant and the name of force is down force. After fracture closure, this force will disappear, but liquid bridge force will come forth and proppant

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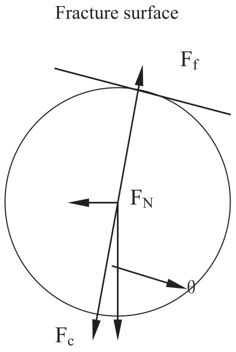

Fig. 1. Closure stress sketch chart.

may cement each other. Mechanical analyses can be seen from Fig. 2. The relative position between proppant and fracture surface is given in Fig. 3.

The effect of closure stress on proppant will become bigger accompanied with fracture closure. The expression of closure stress on proppant is angle (α). Angle (θ) is used to describe the relative location between proppant and fracture surface, after fracture closure, closure stress may directly give a vertical force on proppant, and F_N is equal to zero (because angle (θ) is equal to zero). Therefore, stress F_N is ignored, the expression of closure stress on proppant is liquid bridge force. After fracture closure, particle cementation and liquid bridge force should be considered. With the increasing of liquid bridge force, the cementation between proppant becomes tighter. Therefore, the critical velocity may become bigger. Explicit mechanical analysis is as follows:

Drag force may occur when fracturing fluid flow back, in X direction the name is drag force (F_x), in Y direction the name is uphold force (F_y).

(1) Drag force F_x

$$F_x = C_d \frac{\rho A v^2}{2} \tag{1}$$

(2) Uphold force F_y

$$F_y = C_L\left(\frac{\rho A v^2}{2}\right) \tag{2}$$

which $C_d = k/N_{Re}^{\tau}$;$N_{Re} = \rho d_s v/\mu$;$dN_{Re} = (\rho d_s/\mu)dv$.

In formula (1) and (2), C_L is uphold force coefficient, C_d is resistance coefficient, $\beta = C_L/C_d$, and this is equal to 0.25 (Tong, 1982).

(3) Proppant is assumed as round, net weight W_o

$$W_o = \frac{\pi}{6} d_s^3 g(\rho_s - \rho) \tag{3}$$

(4) Liquid bridge force F_c (Li and Guo, 2002)

$$F_C = \pi\gamma d_s \tag{4}$$

In which, γ is surface tension, N/m.

(5) One obvious character of film is that it cannot transfer hydrostatic pressure, as this reason, down force F_p (Tong, 1982) is obtained as followed.

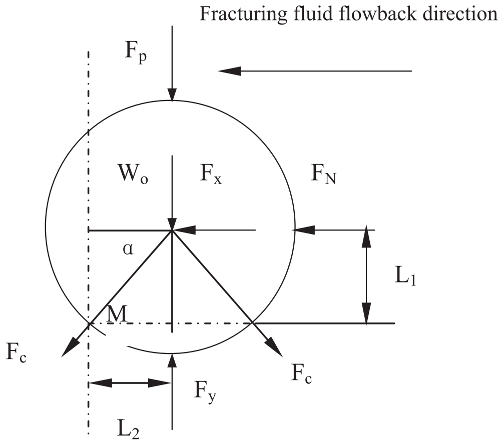

Fig. 2. Proppant stress analysis sketch chart.

$$F_p = \frac{\pi}{32}\rho g h d_s \delta \tag{5}$$

In which, δ is film parameter, $\delta = 0.213 \times 10^{-6}$ m. h is the distance between proppant and the top of fracture, m. d_s is the diameter of a proppant, m.

(6) Force (F_N) comes from the effect of closure stress, which acts on fracture surface

$$F_N = \left(P_c - P_f\right)10^6 A \sin\theta \tag{6}$$

$$L_2 = (d_s/2)\cos\alpha; \quad L_1 = (d_s/2)\sin\alpha$$

In which, P_c is closure stress, MPa; P_f is bottom hole pressure, MPa; A is proppant sectional areas, m^2.

During the course of flowback, some suspended proppant will move with fracturing fluid, some proppant will move as other manners, such as slippage, rolling and jumping. Form the above three modes, rolling needs the minimum energy and easily occur. Therefore, this model is adopted. At the early course of flowback, liquid bridge force can be ignored because most proppant are decentralization, but down force (F_p) should be considered as the effect of fracturing fluid in fracture. Then, closure stress has already paid an influence on fracture surface, but don't directly act on proppant. Moment equilibrium formula is built as the center point M.

$$F_x L_1 + F_y L_2 = W_0 L_2 + F_p L_2 \tag{7}$$

Combined formula (1), (2), (3), (5) with (7)

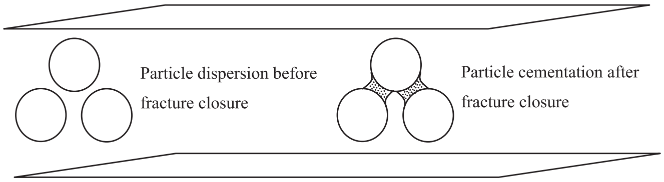

Fig. 3. Relative position between proppant and fracture surface.