COBEM 99
XV Congresso Brasileiro de Engenharia Mecânica
15th Brazilian Congress of Mechanical Engineering
22 - 26 de Novembro de 1999 / November 22 - 26, 1999 Águas de Lindóia, São Paulo,

ANALYSIS OF VERTICAL GROWTH OF FRACTURES IN FRAC PACK OPERATIONS IN RESERVOIR ROCKS

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Abstract. *A study on the vertical fracture growth in hydraulic fracturing treatments is presented. A pseudo-three-dimensional, quasi-analytical model is used to compute fracture height as a function of the fracturing fluid volume, injection rate, thickness of the reservoir and stress contrast between the pay zone and the adjacent ones. An application to a frac pack treatment is developed, presenting plots of vertical growth as function of the variables involved in the process.*

Keywords: *Hydraulic Fracturing, Frac Pack, Petroleum, Fracture Propagation, Pseudo Three-Dimensional Models.*

1. INTRODUCTION

The Frac Pack technique has proven one of the most efficient methods for sand production control in cased wellbores completed in non-consolidated sandstones very frequent in deep waters. Frac Pack consists in treatment very similar to the conventional hydraulic fracturing in which, by means of a pressurized fluid, the pay zone is subject to a rupture by tensile stresses. The generated fracture propagates when a highly viscous fluid is injected. When pumping stops, after reaching the desired fracture size, the fracture is sustained by a granular material, proppant, which was added to the fracturing fluid.

The basic difference between hydraulic fracturing and frac pack lies in the objectives. The objective of hydraulic fracturing treatments is the creation of a highly conductive channel between the formation and the wellbore, aiming at an increase of productivity. By the other hand, the objective of frac pack is to change the stress state in the near-wellbore region as well as to pack the fracture to avoid sand production by the formation, in the case of non-consolidated sandstones.

One of the limiting factors in the use of the frac pack technique is the vertical growth of the fracture, once the vertical penetration of the fracture in the adjacencies of the production region might damage the hydraulic isolation between the zones containing different fluids.

In some particular cases, the intercalation of shale acts as a barrier to the production of water from the cones existing in the lower member of the sandstone. In this case, it is important that the physical integrity of the shale be maintained, in order to preserve the hydraulic isolation between two permeable members of the pay zone.

This paper presents a study on the vertical growth of fluid-induced fractures in reservoir rocks to support analysis of technical feasibility of frac pack treatments in fields where the maintenance of the physical integrity of the caping shale is a critical issue for the wellbore production.

2. DESCRIPTION OF SP3D MODEL FOR PROPAGATION OF HYDRAULIC FRACTURES

The model SP3D (Fernandes, 1998) is based on the semi-analytical solution of the equation system that describes the mechanical and hydraulical behavior of a fluid-induced fracture propagation process:

- England and Green's equation (1963)

$$w(f_h) = \frac{2(1-\nu)h}{\pi.G} \int_{f_h}^{1} \frac{f_2.df_2}{\sqrt{f_2^2 - f_h^2}} \int_{0}^{f_2} \frac{\Delta p.df_1}{\sqrt{f_2^2 - f_1^2}} \tag{1}$$

- Flow of a Newtonian fluid between two parallel plates (see Perkins, 1961)

$$\frac{dp}{dx} = -\frac{12\mu v}{\bar{w}^2} = -\frac{12\mu q}{h\bar{w}^3} \tag{2}$$

- Rice's equation for the mode I stress intensity factor for a fracture of length 2a loaded by σ(x):

$$K_I = \frac{1}{\sqrt{\pi.a}} \int_{-a}^{a} \sigma(z)\sqrt{\frac{a+z}{a-z}}dz \tag{3}$$

The following hypotheses are assumed:

- The fluid flow is predominantly linear, in the main direction of fracture propagation. Only the pressure gradient in the main direction of propagation is considered (x). Pressure is considered constant in the vertical direction, since the pressure gradient is negligible in this direction when compared to the pressure gradient in the horizontal direction (Clifton, 1989);
- Injection rate is constant during the propagation process;

The solution of the governing equation for the propagation process leads to the following equations for the vertical penetration of the fracture:

$$\frac{h_R}{h} = f_R = \mathrm{sen}\left(\frac{\pi}{2}\frac{|\Delta p_2|}{\Delta\sigma}\right) \tag{4}$$

where:

$$\Delta p_2 = \Delta\sigma - 1{,}19\frac{\Delta\sigma^{0,341}\mu^{0,136}q_0^{0,271}}{h_R^{0,795}C_L^{0,019}}\left(\frac{G}{1-\nu}\right)^{0,523} t^{0,126}$$

h_R = pay zone height
h = fracture height
$\Delta p_2 = p - \sigma_2$
$\Delta\sigma = \sigma_2 - \sigma_1$
q_0 = injection rate
σ_1, σ_2: confining stresses (Figure 1)
C_L = global leakoff coefficient
μ = apparent viscosity of the fracturing fluid
G = shear modulus
ν = Poisson's ratio
t = pumping time

3. APPLICATION TO A FRAC PACK TREATMENT

3.1 Problem description

Figure 1 describes a hypothetical permeable formation, with an upper member containing hydrocarbons, characterizing a production zone, and a lower one, containing water located below the shale intercalation, which promotes the hydraulic isolation between them. It is assumed that both permeable members are subject to the same confining stress (σ_1).

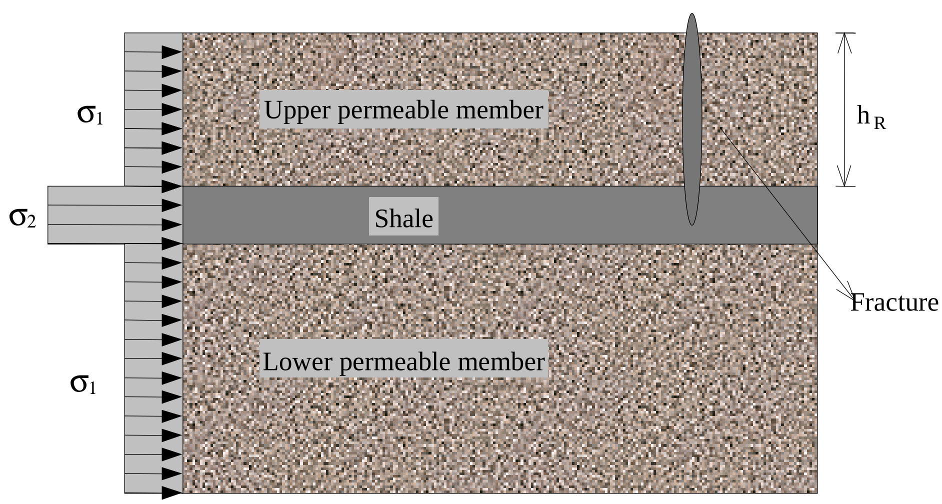

Figure 1 - Description of formation and fracture for example application

In some particular cases, the intercalation of shale acts as a barrier to the production of water from the cones formed in the lower member of the sandstone. In this case, it is important that the physical integrity of the shale be maintained, in order to preserve the hydraulic isolation between two permeable members of the pay zone.

Tables 1 to 3 present the data used in the simulation of the fluid-induced propagation process in the upper permeable interval. The values were obtained from field conditions.

Table 1 Mechanical properties, from laboratory tests

Young´s modulus	145 000 psi (1 GPa)
Poisson´s ratio	0,25

Table 2 Confining stress field data

Depth	8860 ft (2700 m)
Confining stress for sandstone (σ_1)	2330 psi (16.1 MPa)

Table 3 Fracturing fluid data (fluid normally used in frac pack treatments)

Behavior index (n’)	0.52
Consistence index (k’)	0,104 $lb/ft^2\ s^{n'}$ (4,98 Pa $s^{n'}$)
Global leakoff coefficient	0,04 $ft/min^{1/2}$ (1,57 x 10^{-3} $m/s^{1/2}$)
Treatment injection rate	15 bpm (0.0398m^3/s)

3.2 Analysis results

The simulation of fluid-induced fracture propagation was performed with SP3D, for a treatment injection rate of 15 bpm (0.0398m^3/s). Two different values for the stress contrast between the permeable zone and the shale. In the first case, the stress contrast was assumed as 6.21 MPa (900 psi), computed from laboratory data for the formation depth. In the second case, a stress contrast of 500 psi (3.45 MPa) was assumed to represent an abnormal condition, with the objective of simulating a highly severe condition (consequently more pessimistic) for the shale rupture.

For each stress contrast value, results of fracture penetration into the shale zone were computed for six different values of thickness for the upper permeable member (h_R): 5, 10, 15, 20, 25 and 30 meters. Figure 2 and 3 present these results for treatment volumes up to 50 000 gallons (189.3 m^3). The total volume used in the frac pack treatment was 16 000 gallons (60.6 m^3), what can be considered a usual amount for this type of operation.

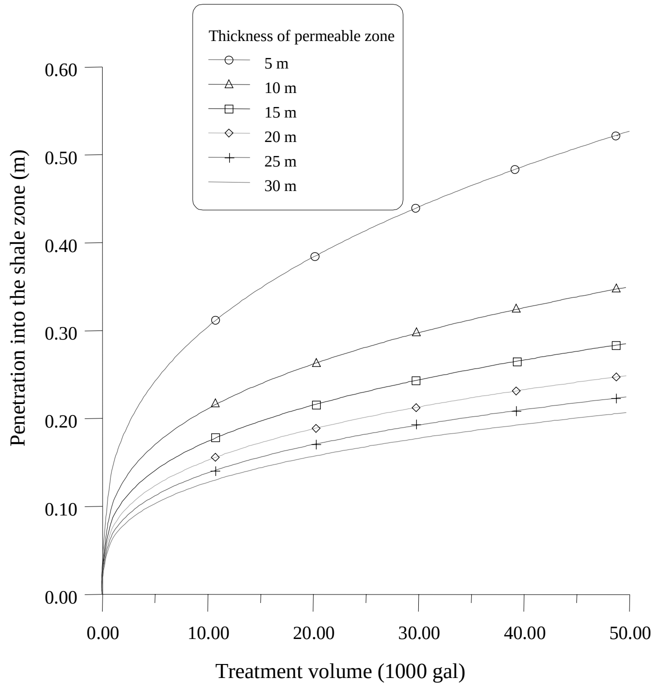

Figure 2 Vertical penetration x treatment volume for Δσ = 900 psi (6.21 MPa)

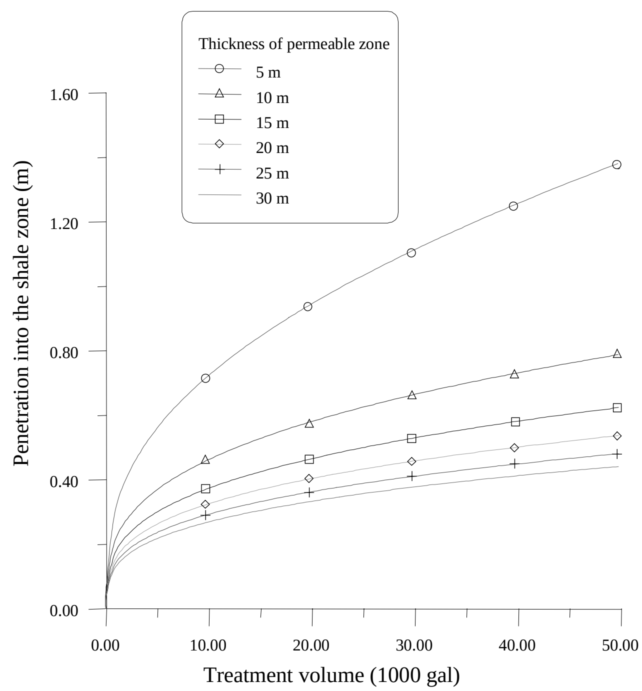

Figure 3 Vertical penetration x treatment volume for Δσ = 500 psi (3.45 MPa)

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Plots in Figures 2 and 3 allow the conclusion that, for a shale intercalation thickness around 2 to 3 meters, a treatment volume of 15 000 gallons does not break completely the shale. In the extreme case of a upper permeable portion thickness over 5 m, there is a penetration of 0.36 m for a stress contrast of 900 psi (6.21 MPa), and 0.87 for a contrast of 500 psi (3.45 MPa).

4.2 The most realistic stress contrast for the analysis is 900 psi (6.21 MPa), corresponding to the values based on the formation data obtained in laboratory tests, considering that the basin is tectonically relaxed. The 500 psi (3.45 MPa) contrast, represent a lower bound more severe with respect to the vertical penetration, was used only for comparison.

4.3 For treatment injection rates under 15 bpm (0.0398 m^3/s), the values of vertical penetration are smaller than the values presented here, resulting in less probable shale rupture. However, for higher injection rates, the penetration values are larger, requiring that new simulations be performed for the specific value programmed for the treatment.

4.4 In highly permeable pay zones, consequently with high leakoff coefficients and low volumetric efficiencies, it is recommended that fluid with a higher concentration of leakoff reduction agents and lower values of injection rates and treatment volumes are used.

4.5 In cases where a premature screenout be detected, the injection rate should be reduced immediately in order to avoid that the treatment pressure increases suddenly, what would result in a fracture height growth out of control.

Acknowledgments

The authors would like to ackowledge the support provided by the Research Center of Petrobras S. A. (CENPES/Petrobras), and the Petroleum Engineering Excellence Center (PRONEX-MCT). The continuous support provided by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) is also appreciated.

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