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Effective Parameters on Breakdown Pressure in Hydraulic Fracturing, Modeling with Finite Difference Method

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ABSTRACT: Although hydraulic fracturing has many applications, but breakdown pressure from hydraulic fracturing process is very important, since this pressure is related to the in situ stresses. The hydraulic fracturing fluid over time, injected into a borehole until it reaches to the limit such that tensile fractures occur in the wellbore wall. At the moment of occurrence of fracture, fluid pressure within the wellbore, said the breakdown pressure that is equivalent to the peak point of the pressure-time curve. There are simple and classical relations that related breakdown pressure to the in situ stresses. Estimation of in-situ stresses is a major challenge in Geomechanic. In this paper, the finite difference modeling of hydraulic fracturing will be discussed. Modeling is base on two-dimensional plane strain assumptions. The purpose of the modeling is to study on parameters affecting the breakdown pressure, parameters that do not exist in the classical relations but affect the breakdown pressure. After validation of the model and in accordance with the results of this paper, breakdown pressure not only is related to the in-situ stresses and rock tensile strength but also wellbore radius and pre-existing cracks in the wall of the wellbore are parameters that involved in hydraulic fracturing and breakdown pressure. For isotropic in situ stresses variation of wellbore radius don't effect on the breakdown pressure but for non-isotropic in situ stresses with increasing wellbore radius breakdown pressure decreases and with increasing deviatoric stresses (difference between in situ stresses), the rate of breakdown pressure reduction increases.

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1- Introduction

Hydraulic fracturing is a process for enhancing the production of oil and gas from reservoirs. The hydraulically induced fracture is a vertical fracture and the fracture plane is perpendicular to the minimum in situ stress. Initiation and propagation of a hydraulic fracture are important information in prediction of in- situ stresses and their direction.

In hydraulic fracturing fluid during the time, is injected into a wellbore until it reaches to the limit such that tensile fractures occur in the wellbore wall. At the moment of occurrence of fracture, fluid pressure within the wellbore, said the breakdown pressure that is equivalent to the peak point of the pressure-time curve (Figure 1). The rock tensile failure stress has a small effect on the magnitude of breakdown pressure, and the wellbore breakdown pressure is mainly to overcome the compressive circumferential hoop stress produced by in-situ stresses. There are simple and classic relations that related breakdown pressure to the in-situ stresses such as Hubbert and Willis criterion, Haimson and Fairhurst relation and Pine et al. criterion. But these relations are independent of wellbore size and initial fracture length.

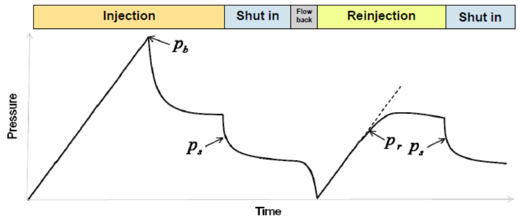

Figure 1. Pressure record vs. time during hydraulic fracturing test

2- The Classical Relations

H-W criterion- In this approach that had represented by Hubbert and Willis (1957) it is to assume that the rock mass is isotropic, homogeny, impermeability and elastic.

The breakdown pressure, according to H-W criterion, for elastic rock is [1]:

$$P_b = 3\sigma_h - \sigma_H - P_0 + T_0 \tag{1}$$

Where P_b is breakdown pressure, σ_h is the minimum horizontal stress and σ_H is the maximum horizontal stress, P_0 and T_0 refer to the pore pressure and the tensile strength of the rock, respectively.

H-F criterion- In the Haimson and Fairhurst criterion it is assumed that rock is elastic and permeable [2].

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$$P_b = \frac{3\sigma_h - \sigma_H - 2\eta P_0 + T_0}{2(1-\eta)} \quad (2)$$

In this relation η is poroelastic parameter.

Pine et al. criterion- In the case of the rock is non- porous, breakdown pressure can calculated based on the following equation [3]:

$$P_b = 3\sigma_h - \sigma_H + T_0 \quad (3)$$

3- Modeling

Modeling is based on two-dimensional plane strain assumptions. It is assumed that the rock is linear elastic and impermeable. Also it is assumed that one of the principal stresses is perpendicular to the wellbore axis. Modeling is in that way that the inner wall of the circular borehole is subjected to the equivalent fluid pressure. Then incrementally is increased to create the first cracks in the borehole wall, this moment equals the start of failure and the pressure at that is equivalent to the breakdown pressure. Based on the theory of fracture and in accordance with the direction of in situ stresses, that tensile cracks expected to develop and expand in the direction of maximum stress. Modeling is done in two parts; without initial cracking on the borehole wall and with the initial cracks at the borehole wall. The physical properties of the models are listed in Table 1 and their geometry is shown in Figure 2.

Table 1. Physical properties of the models [4]

d	kg/ m^3	2600	Density
K	MPa	15.6	Bulk modulus
G	MPa	11.7	Shear modulus
C	MPa	28.4	Cohesion
ϕ	degree	35.2	Frictional angle
T_0	MPa	10	Tensile strength
a	cm	25	Borehole Radius

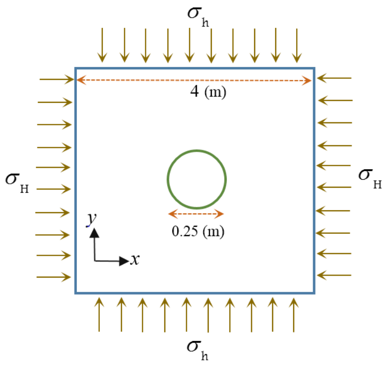

Figure 2. Geometry of the models

4- Results and Discussion

In Figure 3, the changes in breakdown pressure versus borehole radius for anisotropic stresses illustrated.

The results of changing in breakdown pressure versus deviatoric stresses, for different tensile stresses, have been illustrated in Figure 4.

To investigate the hydraulic fracture phenomenon in the presence of primary cracks in the borehole, the physical crack characteristics is considered such as normal and shear stiffness 70.8 and 58.8 (GPa/m) respectively, crack cohesion 28.4 (MPa) and frictional angle of 35.2 degree. The changes in breakdown pressure versus length of crack, for anisotropic stresses, showed in Figure 5.

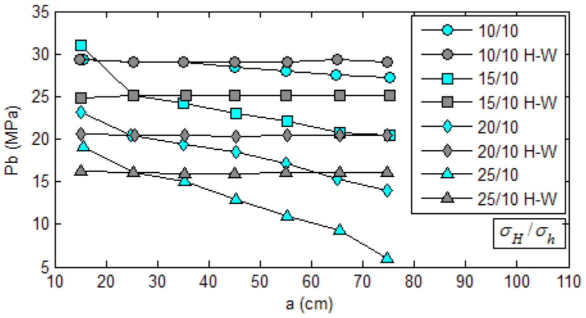

Figure 3. Changes in breakdown pressure versus borehole radius for anisotropic stresses

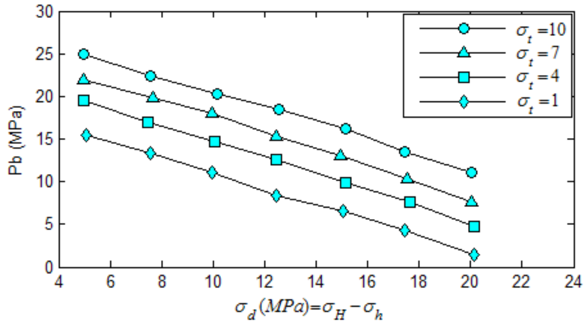

Figure 4. Changes in breakdown pressure versus deviatoric stresses for different tensile stresses

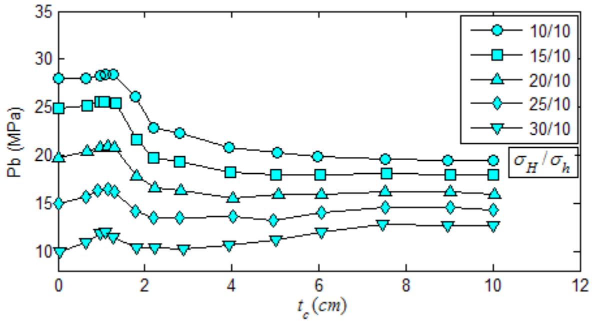

Figure 5. Changes in breakdown pressure versus length of crack for anisotropic stresses

5- Conclusions

The purpose of the modeling is to study on parameters affecting the breakdown pressure, parameters that do not exist in the classical relations but affect the breakdown pressure. Modeling is done in two sections, without pre-existing transverse cracks and with two pre-existing symmetric transverse cracks, in this case it is assumed that pressure in the cracks is uniform that is equal to in viscid fluid. After validation of the model by Hubbert and Willis criterion and in accordance with the results of this paper breakdown pressure not only is related to the in-situ stresses and rock tensile strength but also wellbore radius and pre-existing cracks in the wall of the wellbore are parameters that involved in hydraulic fracturing and breakdown pressure. For isotropic in situ stresses variation of wellbore radius don't effect on the breakdown pressure but for non-isotropic in-situ stresses with increasing wellbore radius breakdown pressure decreases.

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