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Elastoplastic Fracture Model Improves Predictions in Deviated Wells

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Abstract

A 10-years research program at the U. of Stavanger has shown why the commonly used Kirsch equation underpredicts the fracture pressure. The reason is that the plasticly behaving mudcake is not properly accounted for. A new elastoplastic model results from this work, and forms the basis for this paper. This model consists of an anisotropic part (the in-situ stresses) and a hydrostatic part (the plastic mud cake). The paper presents the complete models, which has application to all inclined wells.

"Wellbore strengthening" or "wellbore stress cage" are described by the new analytical model. Several cases demonstrate these concepts. Numerous tests in the fracture lab have led to mud design procedures to build a mechanically strong bridge across a fracture. A well was recently drilled using interactive mud design through the lab. The result was a trouble free well giving leak-off value exceeding any other wells in the area.

Several cases will be presented. Calibrating models to measured leak-off data, it is shown that the Kirsch equation severely underpredicts the fracture pressure.

The New Theory

Numerous experiments have shown that the Kirsch equation[1] works well for penetrating fluids without filtrate control. Fracture initiation pressures during well stimulation can therefore be modeled with the Kirsch equation, which in its simplest form reads:

$$P_w = \sigma_h \qquad (1)$$

It simply states that the borehole will fracture when the minimum in-situ stress is exceeded. The condition here is a penetrating fluid such as water.

In a drilling operation the fluids build a filter cake barrier. For this case the Kirsch equation uses a non-penetrating boundary condidion. It assumes a perfect step function separating the borehole pressure and the pore pressure. This result in a stress concentration factor of 2 as shown in the simple form below:

$$P_{wf} = 2\sigma_h - P_p \qquad (2)$$

Our experiments have shown that this equation in general underestimates the fracture pressure. The problem rests with the assumptions of linear elasticity and a perfect (zero filtrate loss) mudcake. The non-penetrating boundary condition actually consists of several parts, a particle bridge that yields during fracturing and a crack in the rock that opens up with increasing borehole pressure. This is developed by Aadnoy and Belayneh[2]. In reality the stress concentration factor of 2 in Eqn.2 is not properly defining the fracture initiation pressure because of an ill defined boundary condition.

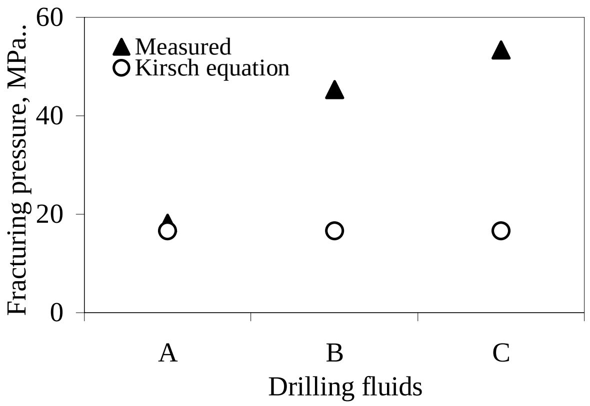

Figure 1: Comparison between theoretical and measured fracture initiation pressures[3].