ABSTRACT

Lost circulation generates significant costs and risks in drilling operations. To mitigate this, hoop stress enhancement technique emerged some years ago. Despite of current and developed technology in this area, there is yet a lack of understanding of the importance of mechanical rock when performing Wellbore Strengthening. In this work, a sensivity analysis of the geomechanical parameters involved in Wellbore Strengthening design, such as mechanical properties of rock and anisotropic stress is performed.

KEYWORDS: Lost circulation, Wellbore Strengthening, Hoop stress enhancement, Fracture induced, Anisotropic stress, Rock mechanics.

1. INTRODUCTION

The oil industry has made important advances in the development of technologies for drilling operations, especially those related to maintaining the structure of the well. However, the search and maintenance of new sources of hydrocarbons require to access reservoirs with more difficult operating conditions such as geologically complex reservoirs, depleted formations, and deepwater reservoirs, among others. In these scenarios, the operating drilling windows between the pore pressure and the fracture gradient is very narrow, lost circulation is a recurring problem [1, 2].

Lost circulation increases significantly well costs during non-productive time; likewise, high expenses in remediation treatments. To mitigate this, hoop stress enhancement techniques emerged some years ago. In these techniques, fractures are induced in the formation and propped with an “impermeable” bridge of lost prevention material. Thus, the stresses in the near-wellbore region are increased and the mud weight window is improved.
The success of a wellbore strengthening operation depends on the design of each of the parameters involved and one of the most important is the fracture opening design. Hoop stress enhancement technique requires predicting of induced fracture width for pressure and geometry well specified variables. Fracture width could be strongly influenced by the mechanical properties of the rock and the anisotropy of stress, modifying the effectiveness of the Wellbore Strengthening operation. For this reason, a sensitivity analysis on the parameters involved in the fracture width design under isotropic and anisotropic regimes is performed.

2. LOST CIRCULATION

Lost circulation occurs when the mud density is increased to the point where the formation fracture pressure is exceeded. This is one of the major causes of non-productive time and it is increasing as more complex pay zone are pursued by drillers, such as depleted reservoirs, HTHP fields, deep water reservoirs and extended reach wells [2,3].

![Mud Weight Window](image)

**Figure 1.** Mud Weight Window

3. HOOP STRESS ENHANCEMENT

The hoop stress enhancement is a preventive method to lost circulation that consists plugging induced fractures with loss prevention material in the drilling fluid by changing the stress state around the wellbore and therefore elevating the pressure at which uncontrolled losses occur and widthn the mud weight window. It is important to mention that in this method the borehole “appears” stronger, although no actual change in rock strength [2, 4].
3.1. Fracture width design [5]

Some analytical and semi-analytical solutions have been proposed for estimation of fracture width. These solutions only include one horizontal stress, which could underestimate the fracture width resulting from depletion.

An example is an analytical solution proposed by Alberty and McLean (2004):

\[ W(X) = \frac{4(1-v^2)}{K_E} \left( P_w - S_h \right) \sqrt{(L + R)^2 - X^2} \]  

(1)

A semi-analytical solution for the fracture width is proposed by Zhang and Alberty (2016):

\[ W(X) = \frac{4(1-v^2)}{K_E} \left[ P_w - S_h + C(S_H - S_h) \right] \sqrt{(L + R)^2 - X^2} \]  

(2)

\[ C = \frac{0.368R^{1/2}}{(L+3X_w)^{1/3}} \]  

(3)

The expression is a function of \textit{in-situ} stresses, mechanical properties, wellbore pressure and geometric factors. This includes the maximum horizontal stress and therefore the stress anisotropy can be considered in depleted formations for instance.

Where, \( w(x) \) is the fracture width (mm) and depend of formation Poisson’s ratio \( v \), formation Young's modulus \( E \) (Psi), wellbore pressure \( P_w \) (Psi), minimum horizontal stress \( S_h \) (Psi), maximum horizontal stress \( S_H \) (Psi), target fracture length \( L \) (in), Wellbore radius \( R \) (in), distance from the center of the wellbore \( X \) (in), Stress anisotropy factor \( C \) and distance from the wellbore wall \( X_w \) (in).
Finally it is important to do notice that the sensitivity study has been made using @RISK software. It a statistic analyzed software, which takes a probability distribution function to related to particular variables and study its effects on the main variable.

4. PROCEDURE

A sensitivity analysis is performed in the @RISK software. It a statistic analyzed software, which takes a probability distribution function to related to particular variables and study its effects on the main variable. The parameters evaluated for this case are the mechanical properties of rock and minimum and maximum horizontal stresses. The objective is analyzing the effect of these parameters upon fracture width.

5. RESULTS AND DISCUSSION

It methodology has been apply to one case of Cupiagua field which is located in at active tectonically area. Also, it presents a high anisotropic in the stresses state [6]. The range of the variables of interest are specified by Osorio and coworkers [6]. They are showed in Table 1:

<table>
<thead>
<tr>
<th>Variables</th>
<th>Minimum value</th>
<th>Average</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stress State</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum horizontal Stress (Psi)</td>
<td>7000</td>
<td></td>
<td>10500</td>
</tr>
<tr>
<td>Maximum horizontal Stress (Psi)</td>
<td>12500</td>
<td></td>
<td>18050</td>
</tr>
<tr>
<td><strong>Mechanical properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young’s modulus (Psi)</td>
<td>1x10^6</td>
<td></td>
<td>1x10^7</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.18</td>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>

Notice that in the Table 1 the state stress values are reported to one depth of 10000 foot, which is an average located in vertical direction of Cupiagua’s field. Thus, it allows to generate a band of possible accessible states in which the width of fracture could be found.

Now a sensitivity methodology is applied over the equation (2). Initially, each one of variables present on the Table 1, are used to obtain the range of variation of width. Parallel, the variable with mayor impact over width fracture is identified. So, a simple statistical procedure has been utilized to build these intervals. Figure 3 show a plot of twister shape of state stress and mechanical properties selected in this study. Here a base line has been specified, where the average values of both state stresses and mechanical properties has been used to obtain a width average value of 0.17016 mm.

In Figure 3 it is possible observe that width of fracture shows some grade of affectation by changes in the parameters of the study. Also, the minimum horizontal stress is variable, which causes the mayor variation of width in the interval evaluated. This stress caused a variation of width of 0.017078 mm to 0.32909, that are equivalent to perceptual changes in the width of fracture (referred to average value) of 90% and 81%, respectively.

On the other hand, the rest of parameter studied show a moderate sensitivity of the width of fracture. Where maximum horizontal stress, Young’s modulus and the Poisson’s ratio generate the following interval (0.13027 mm, 0.28927 mm), (0.08472 mm, 0.24549 mm), (0.073294 mm, 0.22383 mm) correspondently.
6. CONCLUSIONS

In this study the methodology applied permit identify that the minimum horizontal stress is the variable which cause mayor variation of the fracture width in the evaluation interval. Also, the other parameter involve in the study showed a moderated affectation of the behavior of width of fracture. In first case the percentage change is near to 90 % and another the maximum percentage change is the 70%.

The stress state and mechanical properties cause a significant variation in fracture aperture and therefore must be considered in the wellbore strengthening design, especially in geomechanically complex reservoirs.

REFERENCES


