OPTIMIZING WELLBORE INCLINATION AND AZIMUTH TO MINIMIZE INSTABILITY PROBLEMS

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Wellbore stability is of critical importance in the success of drilling operations. One of the main goals of any drilling mission is to drill the well as cost-effective as possible. Wellbore instability can be detrimental to this goal. Therefore, wellbore stability analysis has been included in well planning stage of many companies.

Wellbore stability is a function of several factors such as inclination and azimuth, in-situ stresses, mud weight, rock strength parameters, etc. Some of these factors are controllable and some are not. Among the controllable factors are inclination, azimuth and mud weight. By changing these parameters, one can reduce stability problems significantly. Theoretically, it is possible to design the well trajectory in a way to face least stability problems.

In this paper linear elastic constitutive model along with Mohr-Coulomb failure criterion have been utilized to perform stability calculation for different inclinations and azimuths. It is shown that drilling wells parallel to minimum in-situ horizontal stress causes less stability problems. Also the effect of in-situ stress field on wellbore stability has been investigated and it has been demonstrated that in the case of high difference between the in-situ stresses, the optimum path for a well is a low inclination and an intermediate azimuth.

Key words: *Optimization, Inclination, Azimuth, In-situ stress, wellbore Instability*.

1. INTRODUCTION

Curing wellbore stability problems needs a through knowledge about the mechanism upon which the instability has occurred. Misconception in failure mechanism recognition can even deteriorate the problem rather than solving it out. Therefore, it is of great importance to exactly determine what mechanism has caused the problem [1].

Wellbore instability problems are usually tackled with a combination of constitutive models and failure criteria. Constitutive models are a set of equations used to determine the stresses around the borehole wall after drilling the well. They range from simple linear elastic models to sophisticated thermo-poro-elsato-plastic models. The linear elastic model assumes the formation to be homogenous and isotropic and do not count for the plastic behavior of the rock. All the constitutive models have, only, studied the effect of a few parameters on the stability of the wellbore and have ignored the rest. There is no unifying constitutive model which can handle all the parameters that affect the stability of the wellbore [2].

There are various failure criteria which are used to determine the onset of failure in the rocks [3]. Some use only minimum and maximum principal stresses and some use all of the principal stresses [4]. They can be divided to linear and nonlinear criteria. In linear criteria, the relationship between the shear stress and normal stress is linear and in nonlinear criteria is not. For example, Mohr-Coulomb is a linear criterion and Hook & Brown is nonlinear.

In this study, a combination of linear elastic constitutive model and Mohr-Coulomb failure criteria has been employed to analyze the effect of inclination and azimuth as well as in-situ stress field on the stability of the wellbore. Tow cases have been assumed for the in-situ stress field. The difference between these tow cases is that, in the second case, the difference between the horizontal stresses is higher.

2. TECHNICAL APPROACH

To study the effect of inclination and azimuth on the wellbore stability, linear elastic constitutive model has been used along with Mohr-coulomb failure criterion to write a spreadsheet program using VBA programming language. This program is able to calculate the critical mud weight for any combination of inclination and azimuth and principal stresses. The formulas used in calculations are presented in appendix A. These formulas can be found in references [6] through [9]. The total stresses have modified to effective stresses by applying the concept of P_a . As shown in Figure 1, P_a is the pore pressure immediately adjacent to the borehole wall. By manipulating this variable, one can count for the presence or absence of the filter cake on the borehole wall but to establish the condition of linear elasticity, P_a is always set to be equal to formation pressure, P_f.

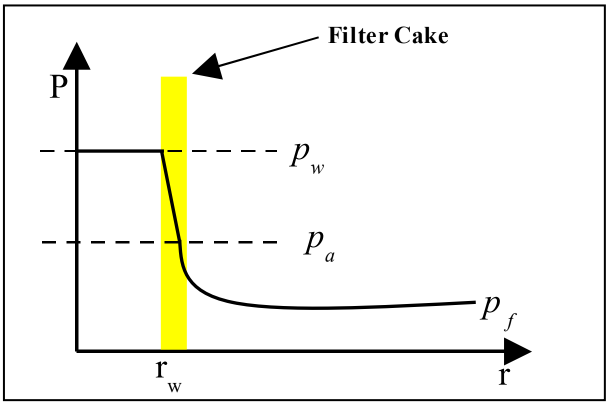

Figure 1. Illustration of P_w, P_a and P_f

The input data used in this analysis for well A are shown in Table 1. The input data for well B is exactly the same as well A except minimum horizontal stress gradient which is 0.75 *psi/ft* instead of 0.88 *psi/ft.*

Table 1

The input data for well A

Variable	Magnitude	Dimension
Vertical Stress Gradient	1.15	psi/ft
Max. Horiz. Stress Gradient	0.96	psi/ft
Min. Horiz. Stress Gradient	0.88	psi/ft
Depth	9358	ft
Mud Weight	11.45	ppg
Pore Pressure Gradient	0.465	psi/ft
Poisson's Ratio	0.25	Dimensionless
Biots Coefficient	0.75	Dimensionless
Friction Angle	35	Degrees
Cohesion	1305	psi
Tensile Strength	25	psi

2.1 EFFECT OF INCLINATION ON WELLBORE STABILITY

The data shown in Table 1 were used to investigate the effect of inclination on stability of the borehole. As the inclination increases, the effect of overburden stress on the borehole wall increases as well and this makes the wellbore less stable. This fact is better shown in figures below. The calculations were done 45° and 90° azimuths. As shown in Figure 2, at inclinations below 50°, well B is more stable but at inclinations above 60°, it gets less stable compared to well A. In other words, when the difference between in-situ horizontal stresses is high, low inclination wells are more stable than highly inclined boreholes. This figure also shows that sensitivity to inclination is higher in the case of high difference between the in-situ horizontal stresses.

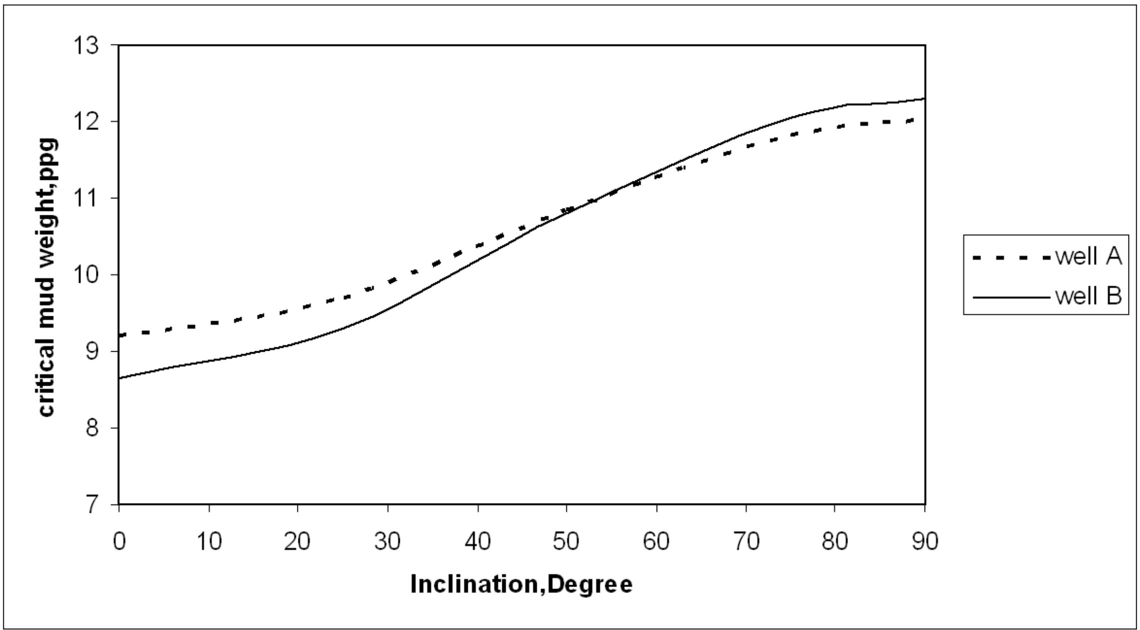

Figure 2. Critical mud weight as a function of inclination for a well with 45° azimuth

Figure 3 shows the same situation but this time azimuth is 90° instead of 45°. It is shown that for inclinations below 30° and above 80°, the wellbore collapse pressure is constant and independent of inclination for both wells. It means that, when drilling low inclination and highly inclined wells parallel to the minimum in-situ horizontal stress, the collapse pressure is only a function of overburden stress and maximum horizontal stress and it is independent of minimum horizontal stress. It seems that the contrast between horizontal stresses only appears at intermediate stresses, i.e. greater than 30° and less than 80°, which result in more stability for well B.

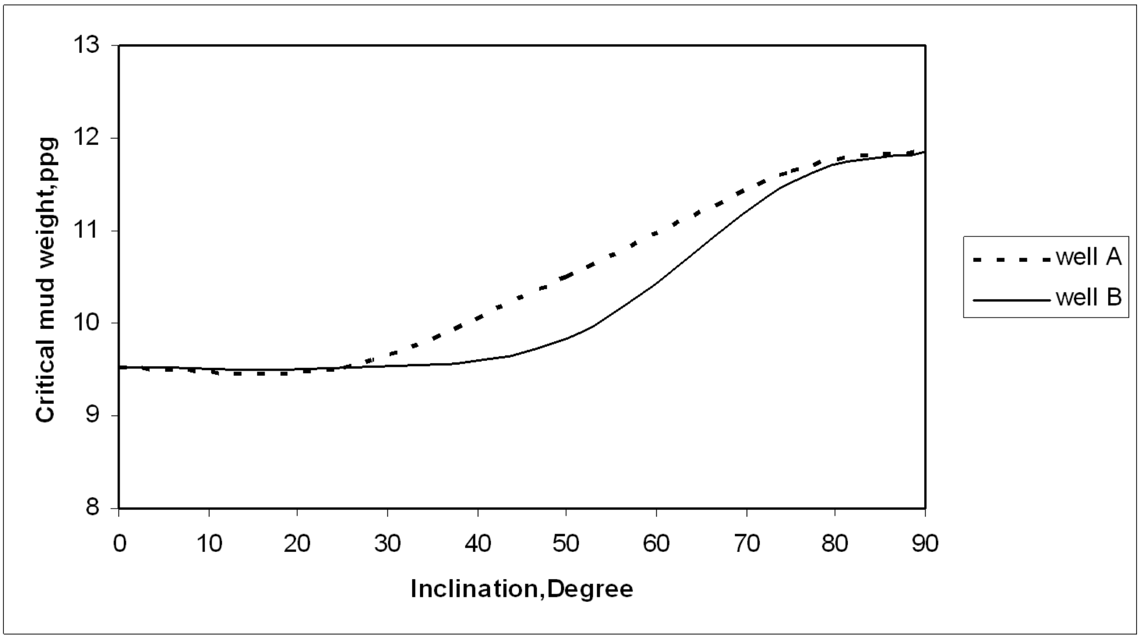

Figure 3. Critical mud weight as a function of inclination for a well with 90° azimuth

2.2 EFFECT OF AZIMUTH ON WELLBORE STABILITY

Generally, the higher the azimuth, the more stable the wellbore but well B is an exception to this rule. As shown in Figure 4 which is for a 20° degree inclination, the optimum azimuth for well B is around 50°. But well A shows a normal trend in regard to changing the azimuth. The optimum azimuth for well A is an azimuth grater than 60°.

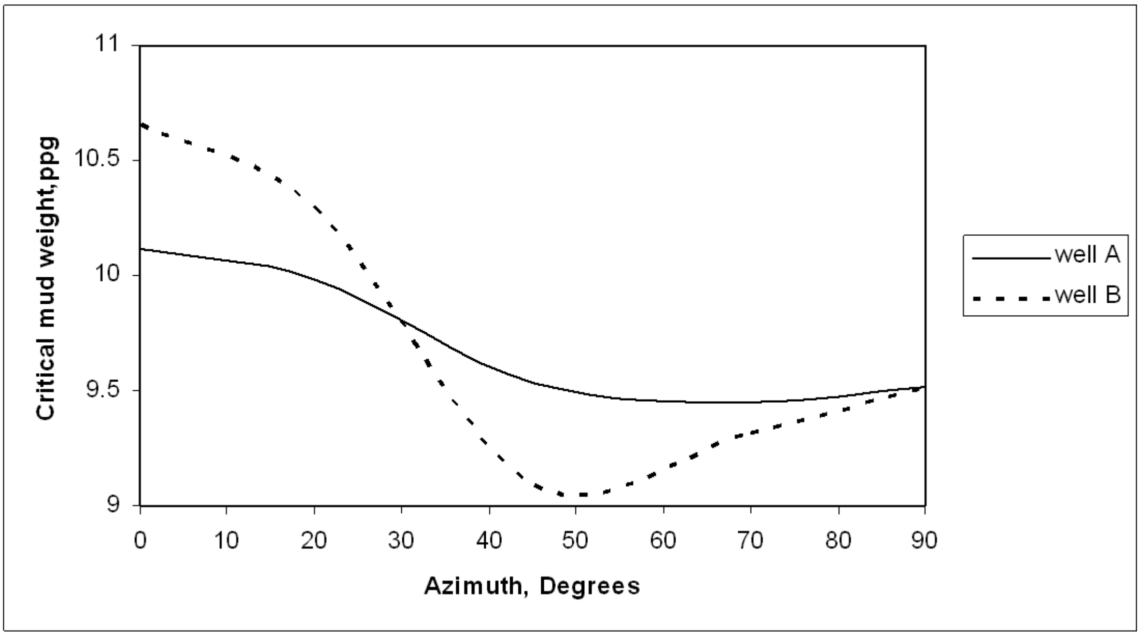

Figure 4. Critical mud weight as a function of azimuth for a well with 20° inclination

In figure 5, again the effect of azimuth on stability has been analyzed but this time for a higher inclination. For both wells the wellbore get more stable upon increasing the azimuth but the rate of stabilization is higher in well B. Also both Figure 4 and 5 demonstrate that at low azimuths, higher contrast between the in-situ horizontal stresses causes more stability problems but at higher azimuths this effect is lowered.

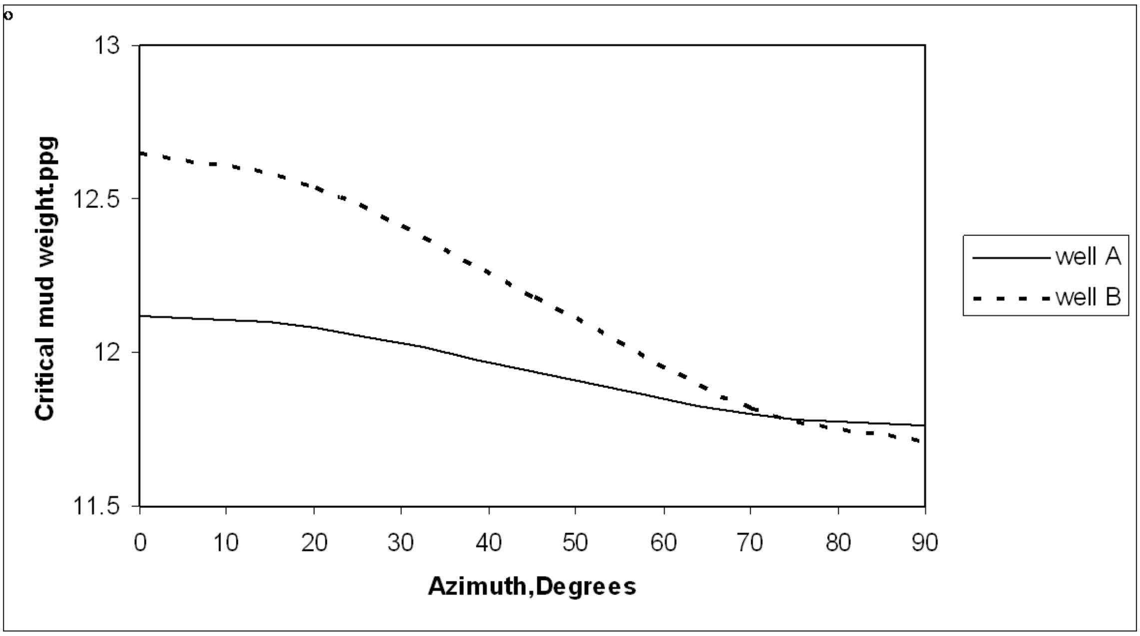

Figure 5. Critical mud weight as a function of azimuth for a well with 80° inclination

3. CONCLUSIONS

In this study, the following points were concluded:

- Trough knowledge about the in-situ stress magnitudes and directions is essential in assessing wellbore stability.

- When the difference between in-situ horizontal stresses is high, low inclination wells are more stable than highly inclined boreholes.

- Sensitivity to inclination is higher in the case of high difference between the in-situ horizontal stresses.

- When drilling low inclination and highly inclined wells parallel to the minimum in-situ horizontal stress, the collapse pressure is only a function of overburden stress and maximum horizontal stress and it is independent of minimum horizontal stress.

- In the case of high difference between the in-situ stresses, the optimum path for a well is a low inclination and an intermediate azimuth.

- Drilling the well parallel to the minimum in-situ stress gives the lowest instability instances.

- These results are valid only for a normal stress field. In the case of an abnormal stress field the formulas and the graphs will be different.

4. NOMENCLATURE

a =	Wellbore radius, *ft*
P_a =	Pore pressure adjacent to borehole wall, *psi*
P_f =	Formation pore pressure, *psi*
P_w =	Wellbore pressure, *psi*
r =	Radial distance from the centre of the wellbore, *ft*
σ_1 , σ_2 , σ_3 =	Maximum, intermediate and minimum principal stress, respectively, *psi*
σ_r , σ_θ , σ_z =	Radial, tangential and axial stresses, respectively, *psi*
USC, S_c =	Uniaxial compressive strength, *psi*
σ_v =	In-situ vertical stress, *psi*
σ_{Hmax}, σ_{Hmin}	Maximum and minimum in-situ horizontal Stresses, respectively, *psi*
ν =	Poisson's ratio, dimensionless
φ =	Rock friction angle, Wellbore azimuth, Degrees
Θ =	Angular position around wellbore periphery, Degrees
γ =	Wellbore inclination, Degrees
α =	Biot's coefficient, dimensionless

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