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Evaluation Of Effect Of Drilling Fluids On Wellbore Stability

Sondaj Sıvılarının Kuyu Duraylılığı Üzerindeki Etkisinin Değerlendirilmesi

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ABSTRACT

Wellbore stability evaluation is one of the important applications of rock mechanics and should be regarded to prevent instabilities that may develop in the wells for various reasons (such as complex field conditions, interaction between rock and drilling fluid, directional drilling etc.). The saturation of rocks by drilling fluids causes significant changes on mechanical properties of rocks. However the level of these variations may be changed due to drilling fluid compositions. In this study, the effect of these variations on wellbore stability was examined for different well profiles. In order to assess the effect of saturation on stability of wellbores, three different drilling fluid compositions (bentonite, KCl and polymer based muds) were considered. The results of assessment suggested that the saturation by bentonite and KCl based drilling fluids create adverse effect on critical fracture and collapse pressures. However the pressure values determined as a result of saturation by polymer based drilling fluid are close to those obtained for dry condition. It should be also stated that the range of mud pressure ensuring the stability of wellbore is also significantly affected by variation of collapse and fracture pressures calculated under drilling fluid saturation.

Keywords: Rock mechanics, drilling fluid, wellbore stability, collapse pressure, fracture pressure

ÖZ

Kuyu duraylılığı değerlendirilmesi, kaya mekaniğinin önemli uygulamalarından biridir ve çeşitli nedenlerle (karmaşık saha koşulları, kaya ve sondaj sıvısı arasındaki etkileşim, yönlü sondaj vb.) kuyularda gelişebilecek duraysızlıkları önlemek için dikkate alınmalıdır. Kayaların sondaj sıvılarıyla doyurulması mekanik özelliklerinde önemli değişimlere neden olur. Ancak bu değişimlerin düzeyi, sondaj sıvısı bileşimlerine bağlı olarak değişebilir. Bu çalışmada, sözkonusu değişimlerin kuyu duraylılığı üzerindeki etkisi farklı kuyu profilleri için incelenmiştir. Doygunluğun kuyuların duraylılığı üzerindeki etkisini değerlendirmek için üç farklı sondaj sıvısı bileşimi (bentonit, KCl ve polimer bazlı çamurlar) dikkate alınmıştır. Değerlendirme sonuçları, bentonit ve KCl bazlı sondaj sıvıları ile gelişen doygunluğun kritik çatlatma ve çökme basınçları üzerinde olumsuz etki yarattığını ortaya koymuştur. Ancak polimer bazlı sondaj sıvısı ile doyurulma sonucunda belirlenen basınç değerleri kuru koşul için elde edilenlere yakındır. Ayrıca kuyu stabilitesini sağlayan çamur basıncı aralığının, *sondaj sıvısı doygunluğu altında hesaplanan çökme ve çatlatma basınçlarındaki değişimden de önemli ölçüde etkilendiği belirtilmelidir*

Anahtar Kelimeler: *Kaya mekaniği, sondaj sıvısı, kuyu duraylılığı, çökme basıncı, çatlatma basın*

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INTRODUCTION

Rock mechanics has widespread applications on oil and gas industry due to increment the number of directional wells and existence of harsh conditions (high temperatures and stresses) (Aadnoy et al., 2009). There are four main types of wellbore instability problems (hole clousure, hole enlargement, fracturing and collapse) and while lost circulation and possible kick occurence are developed as a result of fracturing, pipe sticking and possible loss of well problems are related to collapse induced failures (Azar and Samuel, 2007). The major factors and processes, which give rise to the development of wellbore instabilities, are interaction between rock and drilling fluid, existence of complex stress conditions, deviated wellbore orientations, variable reservoir behaviour, problematic drilling practices, the reservoir with high temperatures and high pressures (Aadnoy and Looyeh, 2011).

The interaction process between drilling fluid and rock is carried out across the invaded zone around the wellbore (Figure 1). So, the adverse effect due to pronuanced interaction is limited to this invaded zone. So, as emphasized by Karakul (2018), there are two regions (invaded and uninvaded) around a wellbore with different geomechanical parameters and the properties of invaded zone should be regarded in instability analyses.

Up to date, the adverse effect on mechanical properties (uniaxial compressive strength, triaxial strength, shear strength parameters, tensile strength and fracture toughness) ofrocks due to interaction by drilling fluids were examined by a few studies (Liu et al., 1998; Ewy et al., 2008; Yan et al., 2013; Yu et al., 2013; Mkpoikana et al., 2015, Karakul 2018; Karakul, 2021).

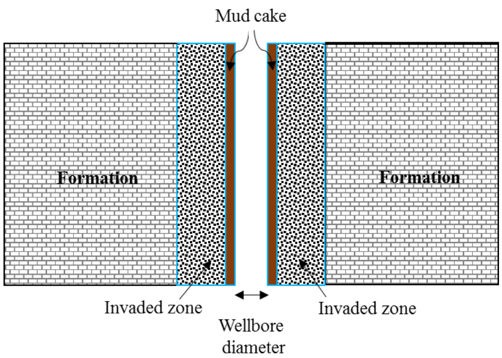

Figure 1. A general view of invaded zone around the wellbore.

Şekil 1. *Kuyu çevresindeki istila edilmiş bölgenin genel bir görünümü*

All of these studies state that drilling fluid saturation has a considerable effect on mechanical properties. Karakul (2018) stated that the geomechanical properties obtained for tested rocks saturated by polymer based drilling fluids have higher compared to those saturated by bentonite or KCl based muds. Similar trends were also found for fracture toughness values of rocks by Karakul (2021). On the other hand, Zhang et al (2021) studied the weakening effect of saturation with oil based drilling fluid on shale formation and stated that collapse pressure increment of 0.2 g/cm^3 was determined after soaking. The experimental results summarized above state that in-situ field conditions should be regarded to perform precise calculation of fracture and collapse pressures and to evaluate the stability conditions of wellbores.

If the symmetric conditions are regarded, wellbore fracturing pressure can be calculated by using the following equations (Aadnoy and Looyeh, 2011) .

$$P_{wf} = 3\sigma_x - \sigma_y - P_0 - \sigma_t \quad for\ \sigma_x < \sigma_y\ and\ \theta = 90° \tag{1}$$

$$P_{wf} = 3\sigma_y - \sigma_x - P_0 - \sigma_t \quad for\ \sigma_y < \sigma_x\ and\ \theta = 0° \tag{2}$$

Aadnoy and Looyeh (2011) stated that tensile strength parameter given above equations can be neglected if the rock contains cracks or fissures. However this assumption could not be always considered as valid. If there is no a discontinuity around the borehole wall, the rock material has a considerable tensile strength so this should be regarded in the calculations of fracture pressure. So, in order to take into account the tensile strength of rocks located around the borehole wall, tensile strength tests of rocks should be determined by experiments.

The critical borehole pressure at collapse can be calculated from the following equation (Aadnoy and Looyeh, 2019).

$$P_{wc} = \frac{1}{2}(3\sigma_x - \sigma_y)(1 - sin\phi) - \tau_0\ cos\phi + P_0\ sin\phi \quad for\ \sigma_x > \sigma_y\ and\ \theta = 90° \tag{3}$$

$$P_{wc} = \frac{1}{2}(3\sigma_y - \sigma_x)(1 - sin\phi) - \tau_0\ cos\phi + P_0\ sin\phi \quad for\ \sigma_y > \sigma_x\ and\ \theta = 0° \tag{4}$$

As can be understood from the equations given above, the shear strength parameters (cohesion and internal friction angle) of rocks located around the borehole are used for calculation of collapse pressure and should be determined by triaxial tests.

In order to reflect the field conditions, both tensile strength and shear strength parameters should be determined under the field conditions. As stressed by Zhang (2017), invasion (of drilling fluid) depth depends on porosity and permeability values and may take the values close to 3 m for formations with high permeability values. So the condition of drilling fluid saturation should be regarded for fracture and collapse pressure calculations. However, this effect was not comprehensively considered for saturation with water based drilling fluids in the studies performed up to date. By considering the defiency mentioned above, this study mainly aimed to evaluate the effect of drilling fluid saturation on fracture and collapse pressures for vertical and the deviated well profiles. The mud weight window variation was also examined and the parameters which are effective on these values were also investigated in this study.

MATERIAL AND METHOD

The mechanical properties of mudstone, which was previously determined by Karakul (2018), used in the analyses and given in Table 1. In addition to dry condition, the saturation created by three different drilling fluids (bentonite based drilling fluid, polymer based drilling fluid and KCl based drilling fluid) were also considered to explain the saturation effect on the fracture and collapse pressure values. In the analyses two different well trajectories (vertical and directional wells) were considered to simulate the drilling fluid effect on mud weight window. As the wellbore instability problems were freqıently encountered for directional wells, this profile was also considered in the analyses. The well profiles and related parameters used in calculations were given in Table 2.

Table 1. Mechanical and physical properties of mudstone [1] .

Tablo 1. *Çamurtaşının mekanik ve fiziksel özellikleri [1]*

	Test Condition			
	Dry	**Saturated (Bentonite mud)**	**Saturated (KCl mud)**	**Saturated (Polymer mud)**
Cohesion, c (MPa)	19.90	17.82	19.79	21.10
Internal Friction Angle, ϕ (°)	49.70	53.03	50.71	53.87
Tensile Strength,σ_t (MPa)	12.65	10.61	10.69	11.64
Biot Coefficient, α	0.87			
Young Modulus, E (GPa)	17.59			
Poisson's ratio, ν	0.25			
Unit Weight,γ (kN/m^3)	26.67			

(1) Karakul (2018)

Table 2. The considered well profiles and related properties used in the analyses.

Tablo 2. *Dikkate alınan kuyu profilleri ve analizlerde kullanılan ilgili özellikler.*

(*) Aadnoy and Looyeh (2011)

	Type	**Azimuth angle ,ϑ (°)**	**Inclination Angle, φ (°)**	**Maximum Depth (ft)**	**Pore Pressure Gradient (psi/ft)**
Well 1	Vertical	0	0	10000	0.465(*)
Well 2	Deviated	10	10-90		

The calculation of collapse and fracture pressures was carried out assuming that the horizontal stresses are equal. So the horizontal stress induced by tectonical processes was neglected. The anisotropy effect was not also considered in the analyses.

RESULTS

As emphasized previous section, the fracture and collapse pressures are functions of tensile and shear strength properties, respectively. On the other hand, it is known and proved by a few studies mentioned above that the saturation.

Table 3. Fracture and collapse pressures of 10000 ft depth calculated for vertical and deviated well (φ=10°) profiles.

Tablo 3. *Düşey ve yönlü kuyu profilleri için 10000 ft derinliğinde hesaplanan çatlatma ve çökme basınçları*

	Vertical Well Profile		Deviated Well Profile	
Condition	**Fracture Pressure, P_{wf} (psi)**	**Collapse Pressure, P_{wc} (psi)**	**Fracture Pressure, P_{wf} (psi)**	**Collapse Pressure, P_{wc} (psi)**
Dry (σ_t is neglected)	8602,05	3251.77	8446,58	3307.18
Dry	10436.78	3251.77	10281.3	3307.18
Saturated (Bentonite-mud)	10140.90	3492.51	9985.43	3539.47
Saturated (KCl-mud)	10152.50	3278.64	9997.03	3331.42
Saturated (Polymer-mud)	10290.29	3224.99	10134.8	3269.91

with drilling fluids has a considerable effect on mechanical properties of rocks. However, the level of this effect is controlled by the type and composition of drilling fluid. In order to explain the effect of drilling fluid compositions on wellbore stability, the fracture and collapse pressures were calculated for vertical and deviated well profiles under dry and saturated conditions and given in Table 3.

The fracture pressures calculated by ignoring the tensile strength is considerably lower than the those calculated by regarding the tensile strength. So if there isn't any discontinuity around the borehole wall, tensile strength values of rocks should be regarded in the calculations of fracture pressure. In order to take into account the tensile strength of rocks located around the borehole wall, tensile strength tests should be carried out on rock samples located at interested depth.

It is clear from Table 3 that while the fracture pressures obtained for deviated well is lower than those calculated for vertical well, the collapse pressures of deviated well profile are higher than those determined for vertical well profile for all conditions regarded in the calculations. On the other hand, tha data given in Table 2 refers that the drilling composition is also effective on both fracture and collapse pressure values. The most critical condition in terms of fracture pressure (lower fracture pressures) and collapse pressure (higher collapse pressure) was obtained under bentonite-based drilling fluid saturation. The optimum fracture and collapse pressure values were calculated under dry and polymer-based drilling fluid saturation, respectively. The variations in fracture and collapse pressures due to saturation are also represented in Figure 2.

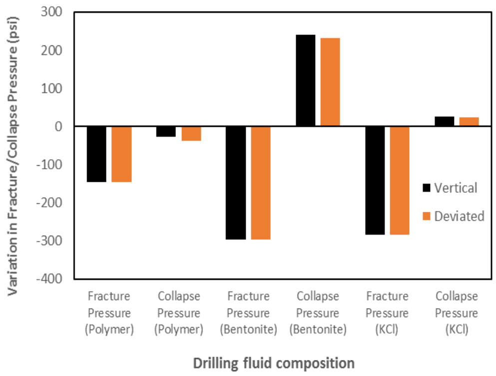

Figure 2. The variation in fracture and collapse pressures due to saturation by different drilling fluids.

Şekil 2. *Farklı sondaj sıvılarıyla doyurulmaya bağlı olarak çatlatma ve çökme basınçlarındaki değişim*

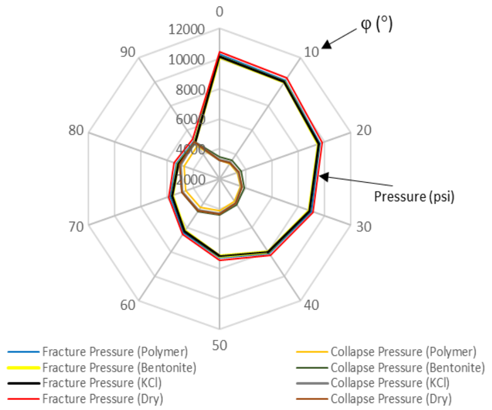

Figure 3. The effect of inclination angle of well on the fracture and collapse pressure values

Şekil 3. *Kuyunun düşeyden sapma açısının çatlatma ve çökme basınç değerleri üzerindeki etkisi*

The effect of inclination angle of well on the results was also examined in this study. Figure 3 shows that as the inclination angle increases, the collapse pressure is also increased. However, inclination angle is inversely proportional to the fracture pressure. It means that as the inclination angle increases collapse and fracture pressure values close to each other. In order to satisfy the borehole stability, the mud weight window should be kept between collapse and fracture pressure values. So the mud pressure should be selected by considering the fracture and collapse pressures. Therefore mud pressure interval, which should be used not to give reason any kind of instability problems, is reduced as the inclination angle increases. However, this general trend may differ if drilling mud of different composition is used.

The gradient curves of fracture and collapse pressure are overlapped at inclination angle of 84.15° due to saturation by bentonite based mud as shown in Figure 4. It shows that a stable mud pressure interval does not exist for inclination angle values greater than 84.15° in case of using bentonite drilling mud.

A similar situation is valid due to saturation by KCl based mud. On the other hand, if the polymer based drilling fluid is used, stable mud pressure interval is satisfied for all inclination angle values and this interval is larger than the interval obtained for dry condition for high inclination angle values (Figure 3).

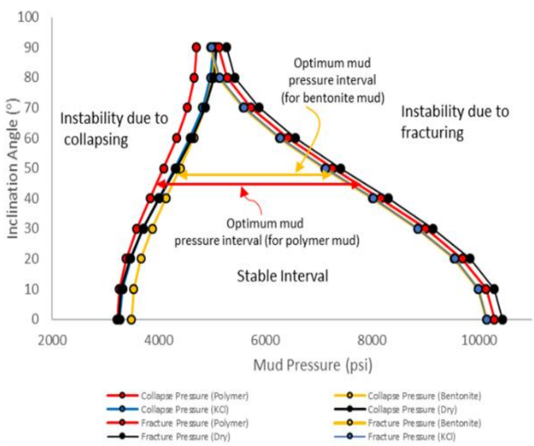

Figure 4. The gradient curves of fracture and collapse pressure under dry and saturated conditions.

Şekil 4. *Kuru ve doygun koşullar altında çatlatma ve çökme basınçları gradyan eğrileri*

As stated by Zosel (1985), higher strength values are generated as a result of polymer usage and this is mainly due to adhesive bond created by polymers. It is clear from the results of analyses that in-situ field conditions should be regarded for sensitive calculation of collapse and fracture pressure. It means that the geomechanical properties of rock samples around the borehole walls should be determined under the drilling fluid saturation. Therefore mud weight window should be calculated by considering the experimental data obtained under the in-situ conditions.

CONCLUSIONS

The effect of driling fluid type on collapse and fracture pressures was evaluated in this paper. Considerable effect of saturation on mechanical properties for different kind of rocks studied a few investigators was firstly examined. Then two different wellbore trajectories (vertical and deviated) were considered to measure the effect of variation of geomechanical properties under the saturation on collapse and fracture pressures. The results of analyses showed that type of drilling mud has an significant effect on fracture and collapse pressure values. While the bentonite and KCl based drilling fluids create adverse effect on fracture and collapse pressure values, the values calculated under polymer based drilling fluid saturation are close to the values calculated for dry condition. The results are also effective on mud weight window, which is important to satisfy the stability condition of wellbores. However the analyses conducted in this study use a few assumptions and literature data, it should be also noted that new studies considering in-situ geomechanical and stress data may also be helpful for further improvement.

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