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A criterion to estimate the minimum and maximum underbalanced pressures of drilling mud in Iranian carbonate reservoirs

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Abstract

The ever-increasing importance of non-renewable natural oil and gas reservoirs has made the use of optimal drilling and recovery methods inevitable in such reservoirs. Underbalanced drilling is in fact the best drilling method for oil reservoirs that their pressure has been reduced due to continuous oil production. The use of overbalanced drilling will cause much damages and increased costs. Underbalanced drilling is an advanced technology and a drilling operation in which the drilling fluid pressure inside the well is less than the pore pressure of the formation. This optimal drilling method reduces the total oil production costs and damages to the oil reservoirs leading to an increase in the productivity index of oil and gas wells. This study aimed at obtaining a criterion for estimating the minimum and maximum underbalanced pressures of the drilling mud for enhancing oil recovery and preventing damages to the formations in the Iranian carbonate reservoirs. To this end, data on 13 wells in with the help of the finite difference method (FDM)-FLAC2D. The elastoplastic normalized yielded zone various Iranian oil fields were first collected. The oil wells were simulated at different drilling mud pressures area (NYZA) method was used for stability analysis and estimation of the minimum and maximum underbalanced pressures of the drilling mud. The NYZA diagram was plotted separately for each well. Considering the drilling mud pressures on the NYZA diagram in the range of NYZA=1 to the pore pressure, a minimum and maximum drilling mud pressure of NYZA=1 and NYZA=0.2 was calculated, respectively. Eventually, a correlation was proposed as a fraction of the pore pressure to estimate the minimum and maximum underbalanced pressures. This correlation is expressed as a factor or fraction of the pore pressure. The minimum and maximum underbalanced pressures of the drilling mud to enhance oil recovery and prevent damage to the formation can be estimated solely by inserting the pore pressure of the formation in this correlation.

Keywords: *Oil well stability, Drilling mud pressure, Underbalanced drilling, NYZA method*

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Extended Abstract:

1. Introduction

Wellbore drilling is the main activity to access oil reservoirs for oil production. Analysis and prediction of borehole stability is critical in drilling operations. Borehole instability is considered a great challenge in drilling of oil and gas wells. Borehole stability is a guarantee of safe and efficient drilling in the field, and hence it has been continually receiving much attention (Yousefian et al., 2018). Underbalanced drilling is an advanced technology and an optimal method in drilling in which the pressure of the drilling fluid inside the well is less than the pore pressure of the formation (Bennion and Thomas, 1999).

Reduction of formation damage, increase of drilling speed, reduction of drilling mud loss, increase of bit life, no need or less need for well working acid, reducing environmental pollution are the advantages of underbalanced drilling method (Lake et al., 2007).

This study aimed at obtaining a criterion for estimating the minimum and maximum underbalanced pressures of the drilling mud for enhancing oil recovery and preventing damages to the formations in the Iranian carbonate reservoirs.

2. Materials and methods

To obtain a criterion for estimating the minimum drilling mud pressure to prevent shear failure of oil wells, 13 wells in south Iran oilfields were modeled by FLAC2D at different mud pressures. A 3 m×3 m model with a wellbore radius of 15 cm was considered. The model boundaries were considered 10 times the wellbore radius from the well center. Meshing density is higher around the well and decreases with increasing the distance from the borehole center. Given the more realistic results of elastoplastic analysis than simple elastic analysis, the former was used for modeling. The Mohr-Coulomb criterion, as the most commonly used criterion, was used for wellbore stability analysis.

The mechanical properties of the rock layer are also given in Table 1. The data in Table 1 were extracted from petrophysical logs of oil wells in carbonate formations of Iranian South Oil Company by the correlations presented in this paper.

Table 1. Input data used for modeling 13 wells

Well number	H (m)	K (GPa)	G (GPa)	C (MPa)	Φ (Degree)	UCS (MPa)	T (MPa)	σ_v (MPa)	σ_{Hmax} (MPa)	σ_{hmin} (MPa)	P_P (MPa)
1	3720	36.66	16.92	14.205	38.775	136	13.6	96.7	59.4	44.5	31.1
2	3838	38.49	17.76	9.055	57.366	53	5.3	99.8	84	63.5	43.5
3	4146	40.22	18.56	11.205	51.592	78	7.8	107.8	71.2	57.8	42
4	4300	33.33	15.38	8.418	55.655	52	5.2	111.8	94.7	84.5	53.5
5	3980	26.04	19.53	11.411	49.993	83	8.3	103.5	75	68	54.3
6	4192	36.66	22	11.418	54.973	72	7.2	109	79.8	60	40
7	3011	26.353	14.612	7.66	55.11	47	4.7	78.29	54.8	50.89	32.56
8	3764	6.8	3.14	13.07	38	40	4	97.87	59	49.5	34.4
9	3743	30.178	17.501	9.8	53.5	65	6.5	97.37	68.16	63.29	31.61
10	3759	30.197	15.488	8.1	54	51	5.1	97.83	68.48	63.59	34.42
11	2634	13.55	10.16	6.564	49.805	48	4.8	68.5	51.4	37.8	27
12	2851	25	11.53	9.762	40.716	89.5	8.95	73.6	66	56	40
13	3167	25.445	16.155	9	53	60	6	82.36	57.65	53.54	31.44

3. Results

The normalized yielded zone area (NYZA) was used to analyze the results of modeling. To this end, the plastic deformations around the wellbore from various drilling mud pressures obtained from numerical modeling including FLAC outputs were exported to AutoCAD. Then, the plastic zone area (NYZA) around the wellbore wall was calculated at different mud pressures and divided by the initial area of the wellbore to calculate NYZA.

After plotting the NYZA chart against different drilling mud pressures for each well, such as the graph in Fig. 1 obtained from numerical modeling (Well No. 13), the mud pressure was calculated at NYZA = 0.2 and NYZA = 1 for all 13 wells and the results were presented in Table 2.

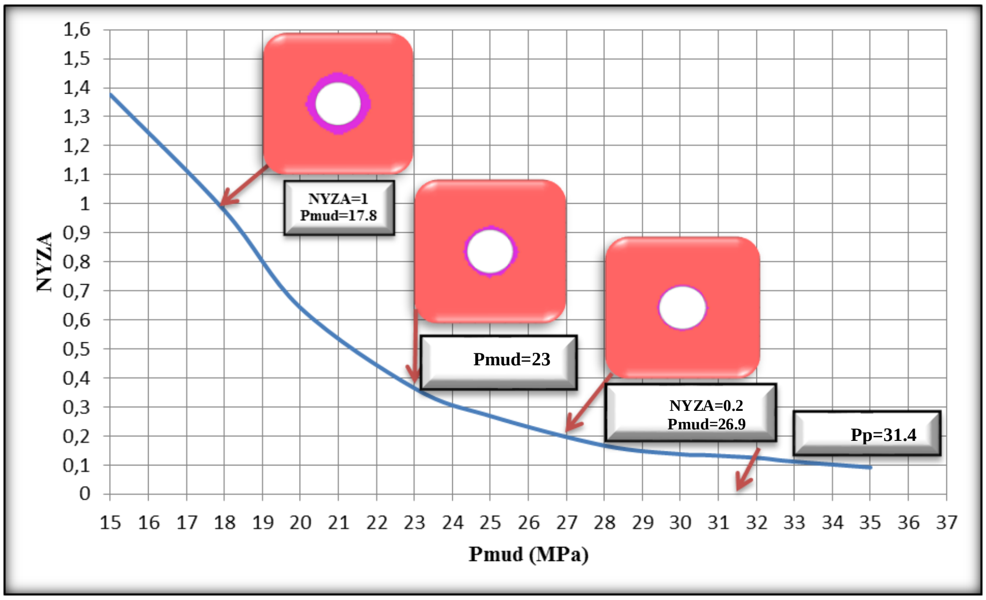

Fig. 1. NYZA at different drilling mud pressures (Well No. 13)

Table 2. Drilling mud pressures at NYZA = 0.2 and NYZA = 1 and the ratio of drilling mud pressures to pore pressure for 13 wells

Well number	P_p (MPa)	$Pmud_{UBDmin}$ (MPa) NYZA= 1	$Pmud_{UBDmax}$ (MPa) NYZA=0.2	$Pmud_{UBDmin}$ / P_p (MPa)	$Pmud_{UBDmax}$ / P_p (MPa)
1	31.1	19.85	29	0.638	0.932
2	43.5	30.25	40.6	0.695	0.933
3	42	30.25	39.4	0.720	0.938
4	53.5	38.9	50.8	0.727	0.949
5	54.3	39.8	49.8	0.733	0.917٠
6	40	24.7	37.3	0.617	0.932
7	32.56	21.15	29.6	0.649	0.909
8	34.4	22.15	32.6	0.644	0.947
9	31.61	16.25	28.7	0.514	0.908
10	34.42	21.75	32.7	0.632	0.95
11	27	18.25	25	0.676	0.926
12	40	24.3	34.8	0.607	0.87
13	31.44	17.8	26.9	0.566	0.855

As can be seen in Table 2, for the minimum underbalanced pressure of the drilling mud, these values are between 0.514 to 0.733 and for the maximum underbalanced pressure of the drilling mud, these values are between 0.855 to 0.95. Then, by taking the average of the obtained ratios, two equations were obtained separately to estimate the minimum and maximum underbalanced pressure of the drilling mud, which are presented as a coefficient of pore pressure in the form of equations (1) and (2).

$$Pmud_{UBDmin} = 0.65\ P_P \qquad (1)$$
$$Pmud_{UBDmax} = 0.92\ P_P \qquad (2)$$

In these equations $Pmud_{UBDmin}$ and $Pmud_{UBDmax}$ respectively, the minimum and maximum underbalanced pressure of drilling mud in MPa and P_p pore pressure of the formations in MPa, respectively.

4. Conclusion

This study aimed to estimate the minimum and maximum underbalanced pressure of the drilling mud at in oil wells. To this end, data was collected from carbonate formations of oil wells of Iranian South Oil Company. The results are as follows:

- Equation 1 is a linear relationship that estimates minimum underbalanced pressure using pore pressure of the formations.
- Equation 2 is a linear relationship that estimates maximum underbalanced pressure using pore pressure of the formations.

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