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Failure criterion effect on solid production prediction and selection of completion solution

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ABSTRACT

Production of fines together with reservoir fluid is called solid production. It varies from a few grams or less per ton of reservoir fluid posing only minor problems, to catastrophic amount possibly leading to erosion and complete filling of the borehole. This paper assesses solid production potential in a carbonate gas reservoir located in the south of Iran. Petrophysical logs obtained from the vertical well were employed to construct mechanical earth model. Then, two failure criteria, i.e. Mohr–Coulomb and Mogi–Coulomb, were used to investigate the potential of solid production of the well in the initial and depleted conditions of the reservoir. Using these two criteria, we estimated critical collapse pressure and compared them to the reservoir pressure. Solid production occurs if collapse pressure is greater than pore pressure. Results indicate that the two failure criteria show different estimations of solid production potential of the studied reservoir. Mohr–Coulomb failure criterion estimated solid production in both initial and depleted conditions, where Mogi–Coulomb criterion predicted no solid production in the initial condition of reservoir. Based on Mogi–Coulomb criterion, the well may not require completion solutions like perforated liner, until at least 60% of reservoir pressure was depleted which leads to decrease in operation cost and time.

1. Introduction

Solid production can cause a number of problems including wellbore instability, pipes erosion, plugging of production liners, subsidence of surface ground, and need for disposal of fines in an environmentally acceptable manner (Wan and Wang, 2004). However, it is also an acceptable issue if screens or perforated liners are used in an open hole completion (Aadnoy and Looyeh, 2011). There are extensive studies on sand production using laboratory experiments, theoretical modeling and field observations. Van den Hoek et al. (1996) performed laboratory experiments in which sand failure was assessed for near-cavity effective stresses above a certain threshold, independent of applied drawdown. The results led to the conclusion that cavity failure under compressive or tensile stress mainly depends on cavity size, and not on near-wellbore stress or drawdown. Sand production prediction methods based on field observations include those of Ghalambor et al. (1994). Studies based on theoretical modeling include the works of Risnes et al. (1982) and Papamichos and Malmanger (1999). In this study, we investigate the effect of intermediate in situ stress on onset of solid production in a well completed with perforated liner. The studied interval of the wellbore is located in reservoir section of a vertical well which is mainly composed of dolomite and limestone with some streaks of anhydrite and shale.

2. Solid production

Solid production may be initiated during drilling phase; however, it is typically a problem associated with production wells. The wellbore pressure decreases with increased flow rate; consequently, the same increases will occur in tangential stress on the borehole wall, resulting in wellbore collapse. According to Aadnoy

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and Looyeh (2011), solid production will initiate when the critical collapse pressure exceeds the pore pressure. In fact, wellbore collapse and solid production are the same type of failures; they just take place at different operational phases of well drilling and operation (Aadnoy and Looyeh, 2011). A stable borehole is given by the following condition:

$$P_{\mathrm{wc}} \leq P_0 \tag{1}$$

where P_{wc} and P_0 stand for the critical collapse pressure and pore pressure, respectively. In the case of wellbore collapse, when the wellbore pressure is higher than the pore pressure, a non-penetrating boundary condition is typically required. For underbalanced drilling and sand production, the wellbore pressure is equal to the pore pressure which leads to a penetrating boundary condition (Aadnoy and Looyeh, 2011). The effective minimum principal stress then becomes

$$\sigma_3' = P_{\mathrm{w}} - P_0 = 0 \tag{2}$$

where σ_3' and P_{w} are the effective minimum principal stress and well pressure or mud weight, respectively. Therefore, for solid production analysis, stress condition at the borehole wall is the key factor that should be considered in wellbore stability.

2.1. Stress distribution around wellbore

When drilling a well, stresses in the vicinity of the wellbore are redistributed where the balanced situation originally offered by the drilled-out rock is replaced by the mud hydraulic pressure (Nadimi, 2015; Kidambi and Kumar, 2016). This stress concentration is described by three principal stresses in a cylindrical coordinate system (Fig. 1): the radial stress (σ_r), circumferential stress (σ_z) (or hoop stress), and tangential shear stress (σ_θ) (Zimmerman and Al-Ajmi, 2006). The stress concentration around a vertical well drilled parallel to the vertical principal stress in an isotropic, elastic medium is described by the Kirsch equations (Kirsch, 1898; Jaeger and Cook, 1979):

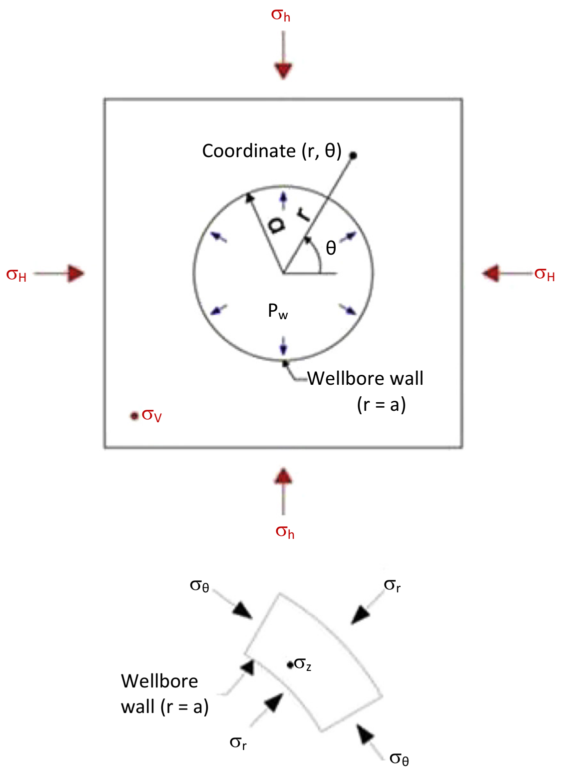

Fig. 1. Stresses around a wellbore at depth (Song, 2012).

$$\left.\begin{aligned}\sigma_r &= P_{\mathrm{w}}\\ \sigma_\theta &= (\sigma_{\mathrm{H}}+\sigma_{\mathrm{h}}) - 2(\sigma_{\mathrm{H}}-\sigma_{\mathrm{h}})\cos(2\theta) - P_{\mathrm{w}}\\ \sigma_z &= \sigma_{\mathrm{V}} - 2\nu(\sigma_{\mathrm{H}}-\sigma_{\mathrm{h}})\cos(2\theta)\end{aligned}\right\} \tag{3}$$

where σ_{H} and σ_{h} are the maximum and minimum horizontal stresses, respectively; θ is the angle measured counter-clockwise from the σ_{H} direction; σ_{V} is the vertical stress; and ν is the Poisson's ratio. In general, failure will occur when the concentrated stress exceeds the strength of the rock. The tangential and radial stresses (σ_θ and σ_r) are functions of the well pressure, but the circumferential stress (σ_z) is not. Therefore, any change in the well pressure will only influence σ_r and σ_θ. Inspection of these two equations reveals that the shear failure, known as breakout, is expected to occur at the point of maximum tangential stress ($\theta = \pm 90^\circ$), where the rock is under the maximum compression stress. On the other hand, tensile failure, known as drilling induced fracture, is expected to occur at the point where the minimum tangential stress is applied to the rock ($\theta = 0^\circ$ or 180°) (Gholami et al., 2014; Nadimi et al., 2016). The magnitudes of stresses around the wellbore are estimated as

$$\left.\begin{aligned}\sigma_r &= P_{\mathrm{w}}\\ \sigma_\theta^{\max} &= 3\sigma_{\mathrm{H}} - \sigma_{\mathrm{h}} - P_{\mathrm{w}}\\ \sigma_z &= \sigma_{\mathrm{V}} + 2\nu(\sigma_{\mathrm{H}}-\sigma_{\mathrm{h}})\end{aligned}\right\} \tag{4}$$

Solid production is also a shear-type wellbore failure that occurs when the tangential stress exceeds wellbore pressures (i.e. onset of solid production is the same as breakout and wellbore collapse) (Aadnoy and Looyeh, 2011).

2.2. Effect of depletion

In porous rock, pore fluid carries part of the load, so pore pressure is the failure controlling parameter (Al-Awad and Al-Misned, 1997). During the life of a reservoir, in situ stresses change as the reservoir pressure is depleted (Khamehchi and Reisi, 2015). The change of in situ stresses due to the decrease in formation pressure is the key factor in analysis of solid production (Rubing, 2014). Generally, the overburden stress remains constant; however, as the pore pressure changes, the effective overburden stress must change. In addition, due to Poisson's ratio effect, the effective horizontal stresses change as well (Aadnoy and Looyeh, 2011). According to Aadnoy (1991) and Aadnoy and Angell-Olsen (1996), changes in horizontal stresses due to pore pressure depletion can be written as

$$\sigma_{\mathrm{h}}^* = \sigma_{\mathrm{h}} - \frac{1-2\nu}{1-\nu}\left(P_0 - P_0^*\right) \tag{5}$$

$$\sigma_{\mathrm{H}}^* = \sigma_{\mathrm{H}} - \frac{1-2\nu}{1-\nu}\left(P_0 - P_0^*\right) \tag{6}$$

where the asterisk denotes the depletion condition. Solid production will not occur if the corresponding depleted collapse pressure is lower than depleted pore pressure.

2.3. Failure criteria

In this study, two commonly used failure criteria in oilfield were deployed for estimation of critical collapse pressure during production to assess the likelihood of solid production in a

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