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An analytical model to predict the volume of sand during drilling and production

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ABSTRACT

Sand production is an undesired phenomenon occurring in unconsolidated formations due to shear failure and hydrodynamic forces. There have been many approaches developed to predict sand production and prevent it by changing drilling or production strategies. However, assumptions involved in these approaches have limited their applications to very specific scenarios. In this paper, an elliptical model based on the borehole shape is presented to predict the volume of sand produced during the drilling and depletion stages of oil and gas reservoirs. A shape factor parameter is introduced to estimate the changes in the geometry of the borehole as a result of shear failure. A carbonate reservoir from the south of Iran with a solid production history is used to show the application of the developed methodology. Deriving mathematical equations for determination of the shape factor based on different failure criteria indicate that the effect of the intermediate principal stress should be taken into account to achieve an accurate result. However, it should be noticed that the methodology presented can only be used when geomechanical parameters are accurately estimated prior to the production stage when using wells and field data.

1. Introduction

Up to 70% of oil and gas reservoirs worldwide are located in poorly consolidated formations (Nouri et al., 2003, 2007). In these reservoirs, when the pressure is depleted to a point where the maximum tangential stress exceeds the formation's strength, the formation fails and sand production is triggered. The sand production phenomenon is generally taking place through three stages: (1) loss of mechanical integrity of rocks surrounding the borehole, (2) separation of solid particles due to the hydrodynamic force, and (3) transportation of the particles to the surface by production. This phenomenon is particularly important when significant changes of in-situ stresses, high production rates, and collapses of cavities are observed (Wang and Dusseault, 1991; Kooijman et al., 1996; Abass et al., 2002). Solid production in non-granular rocks such as carbonates shares the same concept and is triggered when excessively broken rocks due to natural fractures are transported by production fluids (Papamichos and Furui, 2013).

Excessive sanding or solid production may damage the downhole and surface equipment, induce wellbore instability, and cause difficulties during completion and production phases. Sand production has, therefore, remained as an ongoing challenge in the reservoir management and field operations. A better understanding of the sanding mechanism should allow for prediction of the initiation of sanding more realistically. This is, however, a complex mechanism as sanding is impacted by various parameters, including geological, geomechanical and fluid characteristics of the formations as well as the initial state of stresses, pressure conditions, wellbore completions and boundary conditions (Papamichos and Malmanger, 1999; Vaziri et al., 2000; Palmer et al., 2000; van den Hoek et al., 2000). Considering the impact of these parameters in a simple model is not practical and assumptions are required to derive models for prediction of sanding. One of these assumptions is the one where shear failure is considered as the most likely mechanism in unconsolidated formations, causing sand/solid production to take place in the presence of the fluid flow (Wang and Papamichos, 2012).

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There have been many sand production risk assessments performed using geomechanical models where analytical approaches were proposed to predict either the initiation of sanding or the extent of rock failure around the borehole. For example, Bratli and Risnes (1981) and Risnes et al. (1982) developed analytical solutions for rock failure around the boreholes which was only suitable for a steady state flow condition. Bratli and Risnes (1981) introduced a cohesive failure model and calculated a critical bottomhole pressure for sanding in a uniformly stressed cylindrical borehole. Their model, however, could not be used for the prediction of sanding due to shear failure, which is more common than cohesive failure in unconsolidated formations. Morita et al. (1989) proposed the so-called equivalent plastic strain (EPS) criterion and stated that sanding occurs once a critical plastic strain is achieved. Their approach could not be validated completely later when it was used for a gas filed (Wang and Dusseault, 1991). McLellan and Wang (1994) developed an analytical approach to evaluate the failure of boreholes by assuming an exclusive elastic–brittle–plastic strain-softening behavior for the formations. Weingarten and Perkins (1995) developed a model to predict the sanding exclusively for the perforations made in loose formations based on the assumption of elastic-perfectly plastic materials, where the effect of the steady-state and compressible fluid flow was taken into account. Bradford et al. (1998) proposed analytical models for predicting the failure around the boreholes under an isotropic in-situ stress condition which could not be used for a tectonically active region with three independent principal stresses. Ewy et al. (2001) proposed a Lade model to enhance the accuracy of predictions previously provided by the Mohr–Coulomb criterion and/or Drucker–Prager criterion. Their model, however, did not find a wide application due to the limitation and complexity of the Lade equation. Vaziri et al. (2002) used different sand production criteria for predictions in a high temperature and high pressure well and indicated a high level of conservation in the predictions provided. Nouri et al. (2006) developed a new set of criteria for prediction of sanding using the conservative Mohr–Coulomb failure criterion through experimental and numerical analyses. Osisanya (2010) developed an approach based on the production, well logs and laboratory data to determine the initiation of sanding, but did not indicate the importance of predicting the volume of sand if it is initiated. Wang and Papamichos (2012) compared the shear, cohesive and effective plastic strain sanding criteria by doing calibration with the results obtained from a perforated test in sandstone. They suggested the plastic strain approach as the best method for the prediction of sanding, although the accuracy of results was questionable. Lamorde et al. (2014) developed an approach to determine the volume of sand produced based on the yield zone and fracture energy dissipation around the wellbore. However, their approach requires very complicated calculations and experimental studies to determine the energy dissipation.

The aim of this paper is to present a new methodology based on changes in the geometry of boreholes for predicting the volume of sand produced during drilling and depletion phases. The application of this approach will be initially at the reservoir assessment stage, where the risk of sand production must be quantified to develop a management strategy or to satisfy regulatory authorities.

2. Sand prediction models

Predicting the onset of sanding is a long standing geomechanical issue which has been the subject of many studies such as those presented earlier in the Introduction section. According to these studies, approaches developed to predict sand production can be divided into three main categories of empirical correlations, analytical models and numerical analysis.

Through the use of empirical correlations, the relationships between the onset of sanding and effective parameters, causing the sanding to take place, are established (Veeken et al., 1991). These correlations are, however, developed based on particular field data and their results may not be generalized to any other fields.

Analytical models are used to predict the sanding when critical conditions for the initiation of sanding are determined by the analysis of the stress state near the wellbore or perforations (Cerasi et al., 2005; Detournay et al., 2006). Simplifying the geometry of the problem and rock's mechanical properties, analytical equations are used to estimate the onset of sanding. These models are easy to be used and widely acceptable for the sand production evaluation (Addis et al., 2008). Although analytical models suffer from limitations due to simplified assumptions, they are still commonly used in complex well geometries and subsurface environments.

Numerical models are perhaps the best approach for the analysis of a combination of effective parameters contributing to the onset of sanding. Finite element (Watson and Jones, 2009) and finite difference (Detournay et al., 2006; Nouri et al., 2007) numerical models have been used to assess the variation of the stress state when the fluid flow is presented. They can be used for the quantitative evaluation of the sand volume, but require a large data acquisition.

In this section, a new analytical solution for determination of the volume of sand produced during drilling and production is presented based on the changes in the shape of the borehole. The approach can be used in conjunction with different failure criteria to estimate the sanding onset in the presence of formation strengths and principal stresses.

2.1. A new elliptical model for prediction of sanding

Boreholes are expected to have a circular shape, but in practice, due to stress concentrations around the borehole, the borehole tends to change its geometry to reach a new state of stability. Generally speaking, the optimal shape (i.e. circular shape) of the borehole changes during the life of a well and may become elliptical due to shear failure. This concept is depicted in Fig. 1.

One of the approaches conventionally used for determination of the maximum and minimum tangential stresses in the elliptical

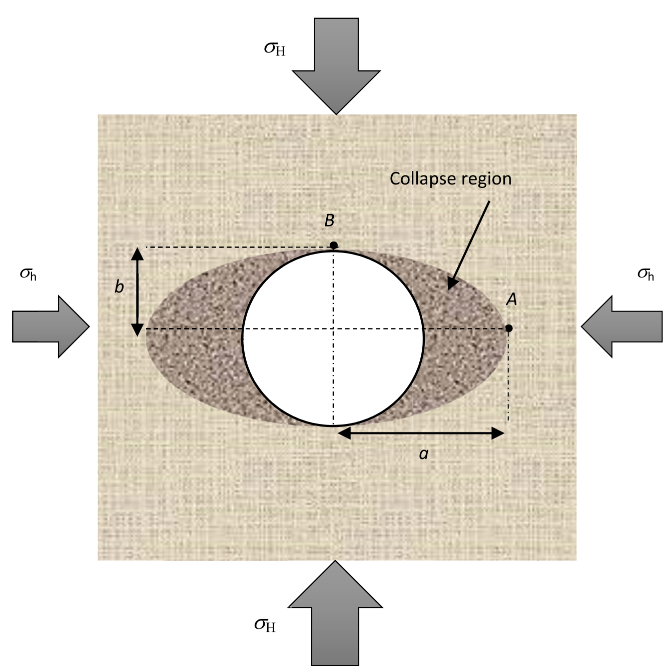

Fig. 1. Changes in the shape of the borehole as a result of shear failure.