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An experimental investigation on the effect of rock strength and perforation size on sand production

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ABSTRACT

Sand production is one of the major research subjects in petroleum industry. This is usually studied either by experimental or numerical methods. Experimental tests are usually focused on thick-walled hollow cylinder samples. In the current study, an experimental setup is introduced which is capable of performing test on large scale cylindrical samples with 15 cm in diameter and 30 cm in height. Fluid flow and confining stress can be applied to the samples. During test all the data including produced sand is recorded continuously. An innovative method is used to continuously measure the produced sand. Eight tests with similar grain size distribution are performed and the results are discussed. In order to investigate the effect of rock strength and perforation size, samples are made with 2 different hole diameters (10 and 20 mm) and 4 different rock strengths. Diagrams obtained from tests are analyzed and changes in sanding regime for different confining stress levels are discussed. The results show a direct relation between sand production and hole size while it is reversely correlated with sample strength. Produced sand at different stress levels show direct power law and exponential relation.

A scenario is proposed for sanding process based on test observations. In order to combine results for different hole size and rock strengths, produced sand and stress levels are scaled according to the proposed method. This combination shows a meaningful trend for the present group of tests with similar grain size distribution.
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1. Introduction

Approximately 70% of the world's oil and gas reserves are found in poorly/weakly-consolidated reservoirs (Penberthy and Shaughnessy, 1992). Several oil and gas reservoirs including sandstone formations are among those poorly consolidated reservoirs.

A sandstone formation before drilling is in hydro mechanical equilibrium. In other words in-situ stresses and pore pressure are in a static equilibrium. Drilling and completion activities, like creating perforations and oil production, redistribute stresses and pore pressure around the production cavity. When hydrocarbons are produced from a sandstone reservoir, under special circumstances, sand particles move from the reservoir into the well along with the hydrocarbon flow. This unintended byproduct of the hydrocarbon production is called "sand production". The amount of produced solids can vary from a few grams per cubic meter of reservoir fluid, which usually represents a minor problem, to catastrophic amounts possibly leading to complete filling of the borehole and eventually the loss of the well (Fjær et al., 2008).

Depletion during production increases the effective stress. Redistribution of in situ stresses and increasing the effective stress due to the drawdown are among the main hydro mechanical factors, which trigger the sand production.

Sand production can cause serious damages on surface production facilities. The damages are mainly erosion of valves and pipelines and sand deposits in the separators. In addition to the damages of sand production on production facilities another main problem is the instability of the production cavities and wellbore itself, which may in extreme cases result in a complete filling of the borehole.

In high flow rate oil and gas wells, sand influx from formation erosion is considered negative, though this view is slowly changing (Dusseault et al., 2000). Although sand particles cause different types of problems, but recently, limited amount of sand production has been considered acceptable and even considered a positive factor in production increase (Fjær et al., 2004). Dusseault (2004) discussed this new trend and stated that devices, which are installed, for controlling little amount of sanding decrease the production and it seems better to tolerate that small amount of sanding instead of installation of those devices. During the last decades, it became apparent that in some cases sand influx leads to better oil production

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rates (Dusseault and El-Sayed, 2000; Dusseault and Santarelli, 1989). The awareness among hydrocarbon producers that limited amount of sand production can lead to increase in production grows the need to determine the amount of produced sand after sand occurrence (Fjær et al., 2004). As a result, researches have focused on sanding behavior after sand initiation. To study this, a lot of numerical, analytical and experimental investigations have been done. This has resulted in new features for experimental setups. One of the main features is continuous recording of the produced sand. This feature enables continuous production record, which can be used to show the effect of different factors on the production continuously.

Different methods have been used for sand production measurement; from sonic and acoustic sand detection system (Tronvoll and Fjær, 1994) to the apparatus, which was made, based on direct measurement of precipitated sand grains by submerged scale (Cerasi et al., 2005). There are also some discontinuous methods for produced sand measurement such as the method, which was used by Nouri et al. (2005). A new apparatus is introduced in this paper for continuous measurement of produced sand based on precipitation.

According to Fjær et al. (2008), observations of sand production are classified in three types:

1. *Transient sand production*, where a burst of sand is followed by a continuous production of sand with declining rate under constant conditions. Transient sand production is frequently observed right after a perforation job, after a change in the production conditions (usually a reduction in the well pressure), and after water breakthrough.
2. *Continuous sand production*, where sand is continuously produced at a relatively constant rate.
3. *Catastrophic sand production*, where sand is produced at such a high rate that the well is choked.

Sand is usually produced from perforations generated by guns in the wells. To resemble this in the laboratory experiments, a cylindrical sample with a central hole is subjected to radial and axial stresses and is subjected to fluid flow (Nouri et al., 2005; Papamichos, 2006; Tronvoll and Fjær, 1994; Tronvoll et al., 1993, 1997) and sand production is recorded (Fig. 1). Although these kinds of tests are usually done by injection of fluid, some experimental setups were developed to simulate sand production during gas production (Wu and Tan, 2002). These experimental tests are basically designed for one phase flow and for studying the effect of some parameters like water-cut, setups should modified to inject two different phases (Papamichos et al., 2010; Wu and Chee, 2005).

A test procedure usually includes radial stress to be increased in different steps and for each step fluid is injected at different pressure, which causes different fluid flow rate through the sample. The produced sand is then recorded for each stage. Experimental setup, which is used for the present research, is based on the same principals, with some modifications. A new continuous sand measurement unit was designed for current study. A triaxial cell was also designed, which was able to apply radial and axial stress independently and to inject the fluid axially and radially. Before assembly of current large scale setup a small-scale lab test has been done in the Rock Mechanics Laboratory of the University of Tehran and the results are simulated successfully by numerical methods (Bodaghabadi et al., 2007). This research is part of a continuous research on sand production and current experimental setup is used by the authors for a range of researches on the effect of different parameters on sand production (Fattahpour et al., 2011a,b).

Modeling the process of sand production is one of the major trends in petroleum related rock mechanics topics. Those studies can be classified in two main categories of analytical (Cerasi et al., 2005; Papamichos, 2002; Papamichos and Stavropoulou, 1998) and numerical studies (Detournay, 2008; Li et al., 2006; Volonte et al., 2010). These models are usually compared with those of experimental tests.

In current study a model is proposed based on trend lines of sanding for different radial stresses. Rather than analytical or numerical modeling results from experimental tests are used to combine the results related to different hole sizes and rock strengths. Papamichos et al. (2008) has also introduced an empirical approach based on a variety of test data. They tried to found an average trendline for three categories of results related to different sandstones, including brittle, ductile and compactive.

2. Experimental test setup and procedure

In order to perform experimental tests on large-scale samples and covering the required features for continuous recording of applied stresses, injected fluid flow and produced sand, a new experimental setup was designed.

The new experimental setup can test hollow cylinder samples with 15 cm in diameter and 30 cm in height. Radial and axial stresses can be applied up to 400 bars and fluid flow can be injected up to 70 bars at 5 l/min. The setup includes the following parts:

(1) Triaxial cell
(2) Radial and axial pressure pumps
(3) Data acquisition system
(4) Injecting fluid tank and pump
(5) Regulator of injecting pressure
(6) Produced sand measurement unit
(7) Injected fluid flow measurement unit.

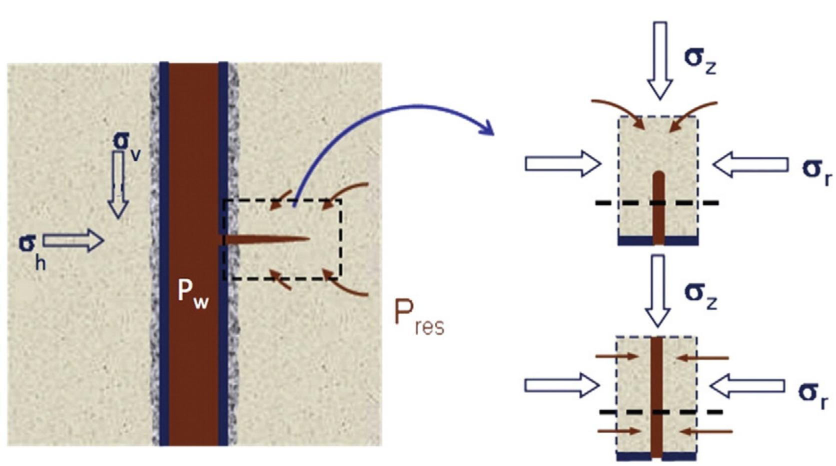

Fig. 1. Hollow cylinder test representing a part of perforation (Papamichos, 2006).

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