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Experimental investigation on permeability evolution law during sand production process of weak sandstone

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A B S T R A C T

Sand production is a crucial engineering problem in the process of reservoir development. In this work, a self-developed experimental platform was established as a reliable technique to study the permeability evolution law during sand production process. The core used in experiment was from Kingfisher (KF) oilfield, which is a typical weak sandstone reservoir. The pressure differences across the core were recorded continuously to further detail analysis. In the water injection process weak sandstone reservoirs, the permeability of weak sandstones is no longer constant, but belongs to nonlinear seepage due to the transport of rock particles. However, the traditional Darcy's law can not describe the nonlinear seepage, so a new concept of 'transient permeability' was presented to describe the nonlinear seepage of sand production process at first. Meanwhile, based on the new concept of 'transient permeability', we further proposed two new concepts of 'relative prevailing index' and 'stability index' for quantitative characterization the dynamic evolution process of sand production. A lot of data was got during the experiments, six typical stages have been screen out by careful data analysis, which can be well described the whole dynamic evolution process of sand production.

1. Introduction

Sand production is a serious problem in the process of reservoir development, especially for weak sandstone reservoirs (Isehunwa and Olanrewaju, 2010; Selby and Ali, 1988; Osisanya, 2010; Adeyanju and Oyekunle, 2010). There are a number of reasons caused sand production, such as drilling, well completion, production and workover. Sand production generates lots of negative impacts. At first, the sands deposit in well caused sand plugging which lead to oil production cuts. Secondly, it increases the workload of downhole operations. Meanwhile, the equipments are easily worn such as valve, piston, bushing and so on. Thirdly, it may cause borehole collapse and well shut down. All in all, it is very important to study mechanisms of sand production.

Lots of effective theoretical researches and experiment researches about sand production mechanism, sand production prediction technology and sand control method were studied (Morita et al., 1989a,b). It was found that lower well bottom pressures, influx, reservoir pressure loss, velocity increases and flow rate suddenly changing could lead to sand production based on observing and analyzing lots of wells with sand production. In order to explain the sand production phenomena, the borehole stability and sand production were studied quantitatively and qualitatively. In qualitative aspect, an analytical solution of a simplified elastoplastic strain hardening model was used (Morita et al., 1989a,b). In quantitative aspect, a three-dimensional (3-D) finite element (FE) method was used (Morita et al., 1989a,b). There were some complicated reasons leading to sand production, which was not only related to formation intensity and geostress, but also related to fluid property.

The relationships between water saturation and sand production were studied by combining experiments and computer simulations (Bruno et al., 1996). For different wells of the same reservoir, there were different conditions of sand production (Kessler et al., 1993). The pressure loss of North Sea oilfields was considered to be the main sand production reason (Addis et al., 1998; Venkitaraman et al., 2000). The sand production behaviors were studied by simulation experiments in laboratory by drilling hole in cores about the uniaxial compressive strength of sandstone formation in the range 2–25 MPa (Fahrenthold and Cheatham, 1986).

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For the weak cementation sandstone reservoirs, it easily forms sand arch by fluid drag force. Meanwhile, the stable sand arch is benefit for sand control. So far, many researches studied on the factors that affected the stability of sand arch by experiments based on artificial cores and computer simulations (Perkins and Weingarten, 1988; Kooijman et al., 1996; Bratli and Risnes, 1981; Antheunis et al., 1976a,b; Hall and Harrisberger, 1970; Fahrenthold, 1984; Fahrenthold and Cheatham, 1986). The stability of sand arch was studied by filling sands in a cylinder (Weingarten and Perkins, 1995).

Besides, scholars have done numerous researches about sand production of gas reservoirs (Antheunis et al., 1976a,b, 1979; Parton et al., 1987). Non-Darcy flow was considered as the main reason of sand production for high productive wells (Ong et al., 2000). The effects of flow rate were studied in laboratory (Tippie and Kohlhaas, 1973). In particular, the sand production was studied by an in situ perforation cavity on a 1:1 scale (Tronvoll and Fjaer, 1994). The effects of rock strength and perforation size were studied by an experimental investigation (Fattahpour et al., 2012). A cell was used to investigate the factors affecting the production, including slot size, gas injecting pressure, sand particle size and moisture content (Ranjith et al., 2013).

It was clearly that the permeability was improved over time due to continuous sand production (Chalmers et al., 2014). However, this literature only presented the site data, which was lack of theoretical analysis and experimental validation. Meanwhile, this paper did not analyze the entire period of sand production. The factors impacting on the permeability, such as rock types (Mudstone and sandstone), confining pressures and temperatures were studied (Yasuhara et al., 2012). In the sand production process, the permeability of weak sandstones is no longer constant. It belongs to nonlinear seepage due to rock particles transportation. The permeability is looked as a vital parameter used as describing the sand production process in this work.

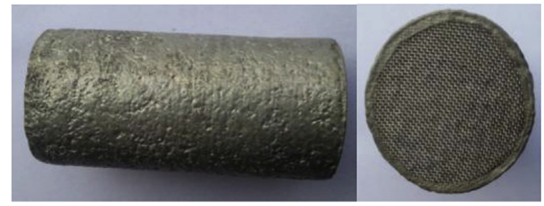
2. Experiment

2.1. Core sample and displacing fluid

The core samples were taken from Kingfisher (KF) field located at Albert basin, Uganda. To get proper cores sample suitable for the experiment, we followed the following method. At first, we examined the core which was seen that some sections were too friable. Therefore, we cut core samples in the more friable sections using liquid nitrogen as the bit lubricant. Then, the core samples were mounted prior to cleaning. The procedures for mounting were described as following: Samples were mounted with 0.04 mm thick aluminum foil. Two mesh screens, sizes 20 and 200, were placed on each face of the samples and held in place by folding over the ends of the aluminum foil. The screens provided strength to the samples and allow porosity and permeability measurements to be performed. The samples were loaded into a hydrostatic core holder at 50 psi confining pressure. After 15 min the pressure was increased slowly to 500 psi for a further 10 min before reducing the pressure and gently removing the samples. At last, the core samples were fully cleaning until there were no hydrocarbons and salts. By following the above steps, the proper core samples suitable for experiments were finished, seen as Fig. 1a. In this experiment, the aluminum foil and mesh screens were removed to avoid preventing sand particles freely flowing (Fig. 1b).

The properties of core sample used in the experiment are shown in Table 1.

The simulating formation water with the same ion concentration as the fluid in the oilfield is used as displacing fluid. The data are shown in Table 2.



(a)

(b)

Fig. 1. Core.

Table 1
Properties of core sample.

Length (cm)	Diameter (cm)	Grain density (g/cm^3)	Rock density (g/cm^3)	Porosity (%)	K_{air} ($10^{-3}\mu m^2$)
6.562	2.50	2.67	1.84	31	2182.3

2.2. Experimental platform

In this paper, a self-developed experimental platform was established. The schematic diagram of the experimental flow system is shown in Fig. 2, consists mainly of the following devices: (1) A high pressure stainless-steel cylinders (0–70 MPa; ≤150 °C; 1000 mL; Huaan, China) was used to store and deliver simulating formation water. (2) A pressure acquisition system was used to get the pressure date for real-time. The time intervals of data acquisition can be set. (3) A pressure/flowing system was used to determined the injection pressure and injection speed automatically. (4) An injection pump (ISCO, flow range, 0.001–60 mL/min; flow accuracy, 0.5%; pressure range, 0–10,000 psi; pressure accuracy, 0.1%) was used to displace samples. (5) A core holder (0–100 MPa; ≤150 °C; Huaan, China) was used to realize the core which can be compressed same as reservoir conditions. (6) A confining pressure pump was used to maintain the pre-specified pressure inside the cell during the tests (Huaan, China; pressure range, 0–5800 psi; pressure accuracy, 0.1%). (7) A sand filter and flow meter was composed by filter paper and tube. The filter paper was used to filter sand.

2.3. Experimental procedures

The experiments were performed by the following procedures:

(1) Vacuumize the core sample and saturate it with stimulant formation water.
(2) The core sample was put into core holder. A constant flow rate of 1.0 cm^3/min (no sand production) by flooding control system was applied to attain the absolute permeability calculated by Darcy's law.
(3) A larger flow rate (3.0 cm^3/min) was set by flooding control system with an obvious sand production observed in sand filter. The pressure differences across the core sample were recorded by pressure acquisition system.