Available online at www.sciencedirect.com
ScienceDirect
Journal of Petroleum Science and Engineering 58 (2007) 227–244
Journal of Petroleum Science & Engineering
www.elsevier.com/locate/petrol

Alteration of permeability by drilling fluid invasion and flow reversal

A. Gurkan Iscan [a,*], Faruk Civan [b], Mustafa V. Kok [a]

[a] Middle East Technical University Department of Petroleum and Natural Gas Engineering Inonu Bulvari 06531 Ankara, Turkey
[b] Mewbourne School of Petroleum and Geological Engineering, the University of Oklahoma, Norman, OK 73019, USA

Received 19 May 2005; received in revised form 3 January 2007; accepted 8 January 2007

Abstract

Permeability impairment caused by drilling fluids and subsequent cleaning and permeability enhancement by backflow are investigated by means of experimental and simulation studies. Damage caused by two different drilling fluids is measured experimentally by core tests as a function of the filtration pressure and analyzed using a simulator describing the fines migration and retention in porous media. Simulations were run both with experimental and synthetic data in forward and backward directions along the core samples. Permeability was correlated with respect to drilling filtration pressure in terms of the deposited particle volume fraction. The clean-up time was determined after back-flush with fresh water and improvement was observed both in porosity and permeability. Simulation results accurately match the experimental data, indicating that this simulator can be used for the estimation of permeability reduction and the permeability and porosity variation along the core samples at various filtration pressures. It was also determined that a polymer-added drilling fluid characterized with 65% permeability damage ratio may be the optimum drilling fluid causing less formation damage than the water-based bentonite mud.

Keywords: Drilling fluid; Permeability; Porosity; Damage ratio; Backflow; Impairment; Enhancement; Fines migration; Porous media; Simulation

1. Introduction

Many petroleum engineering operations, such as drilling, well completions, and workover, may cause an alteration in the properties of hydrocarbon-bearing formations, including porosity and permeability. Circumventing permeability alteration by fines migration is a very important task in petroleum engineering applications. Clay particles intrude the reservoir formations during drilling operations with water-based drilling fluids. Particle intrusion causes plugging and bridging across the pore throats within the pore spaces, reducing the permeability. However, many hydrocarbon reservoirs have aquifer boundaries. Water influx takes place in many cases. The cleaning effect of aquifers can be simulated by injecting water into mud-invaded core samples. In this study, the cleaning effect of the aquifers and the change in permeability are investigated both experimentally and numerically in terms of the damage ratio.

Krueger et al. (1967) studied the permeability reduction in sandstone samples exposed to drilling fluids and the clean-up with oil at elevated pressures. It was aimed to break the particle bridges through back-flush process. A drilling mud circulating system to was constructed to expose the cores to drilling mud under wellbore conditions. The experimental system consists of a one-barrel reserve pit and a conventional mud pump

* Corresponding author. Tel.: +90 312 2104884; fax: +90 312 2104883.
E-mail address: iscan@ou.edu (A.G. Iscan).

0920-4105/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.petrol.2007.01.002

used to circulate the drilling fluid through a high-pressure cell. This high-pressure test cell is a container having 12 ports that is used for exposing the core specimens to flowing drilling fluid conditions. Mounted cores are clamped in the ports, and burettes are connected to measure the volume of filtrate discharged during the experiments. Cylindrical Berea sandstone samples of 1.0-in. in diameter were used in the experiments. The air permeability of the core samples ranged between 300 and 600 mD. The specimens in brass tubes were sealed with a non-penetrating epoxy resin. The core samples were vacuumed and saturated with 3% brine, and then the connate water state of the saturated core sample was attained with 42° API oil and the final permeability to oil was established at a pressure drop of 600 psi. The drilling mud was circulated across the core sample at a rate of 130 ft/min at a temperature of 77 °C and the core samples were subjected continuously to the drilling fluid for 5 days under these conditions. The cumulative fluid loss was recorded at certain time intervals. After the circulation has been completed, the core samples were removed without disturbing the filter cake and placed into the backflow equipment. The backflow pressure was varied in different experiments to determine the recovery of permeability to oil in Berea cores. The oil backflow was started at 10 psi. After the stabilization of the permeability at this pressure, the pressure was increased from 10 psi to 30, 60, 100 and, 600 psi. Krueger et al. (1967) reported the permeability recovery at these pressures by a chart. The percent permeability recovery data are presented in Table 1, expressed as the backflow permeability divided by the original permeability. A significant increase occurred in the permeability recovery at lower backflow pressures when the core samples were exposed to a water-based mud. 38% of the original permeability of the core samples to oil was regained at the 600 psi backflow pressure. Using an oil back-flush was partially successful followed by a low rate reverse oil flow. It was concluded that low rate clean-up is better than high rate clean-up in Miocene and Pliocene producing zones. Oil back flush simulation reduced the wellbore damage caused by silt migration. The production rate declined gradually as the solid content increased in the produced oil.

Table 1
Percentage permeability recovery through back flow (after Krueger et al., 1967)

Backflow pressure (psi)	Drilling fluid, percentage recovery (%)	
	Oil-based drilling fluid-1	Oil-based drilling fluid-2
10	–	–
20	–	–
80	–	78
100	–	–
800	80	–
Backflow pressure (psi)	**Drilling fluid, percentage recovery (%)**	
	Water-based drilling fluid-1	Water-based drilling fluid-2
10	–	80
20	–	80
80	70	80
100	–	80
800	–	80

Vitthal et al. (1988) proposed a model that simulates the permeability impairment in radial geometry. It was noted that permeability impairment by fines migration produces a positive skin in the near wellbore. An idealized geometry porous medium and clay particles were considered. The clays were assumed spherical shape, single size, and constant density. Pore blockage occurs gradually by smooth pore surface deposition of particles. The porous medium is considered as a bundle of uniform-sized capillary tubes. The pressure drop across the porous medium is obtained by a relationship correlating the permeability to the mass of solid particles deposited in porous media. The rate of particle release is considered as an important phenomenon controlling the permeability impairment. The particle release from the pore walls is related with the electrostatic, van der Waals, hydration, and hydrodynamic forces, as well as the size of clay particles. The particle motion is assumed Brownian when the particle radius $r<2$ mm under the effect of diffusion and double-layer forces, and non-Brownian in the presence of the hydrodynamic effects. The rate of release coefficient is given as:

$$k_{\mathrm{rel}}^{i} = X_{\mathrm{k}} N_{\mathrm{p}} q_{\mathrm{s}} \quad (1)$$

where k_{rel}^{i} (m^2) is the rate of particle release coefficient, X_{k} (m^2) is the rate constant, N is the number of pore throats per unit bulk volume, and q_{s} is the superficial velocity (m/s). The particle and pore sizes were normalized with respect to their means. The numerical solution scheme is based on a low-order upwind finite-difference scheme. This method was chosen because of simplicity. In their study, a wide range of parameters effecting the fines migration in porous media were analyzed. The effect of the mean particle size, standard deviation of particle size distribution, clay concentration, rate of release coefficient, trapping length, and network connectivity were analyzed. Permeability damage increased with the mean particle size. Small particles were able to migrate to the front of the invaded