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RESEARCH PAPER

Effects of oil recovery rate on water-flooding of homogeneous reservoirs of different oil viscosity

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Abstract: Based on physical simulation of water-flooding homogeneous reservoirs, the water-flooding characteristics of homogeneous reservoirs with different oil viscosity are examined at different oil recovery rate. Reservoirs with low-viscosity (<5 mPa·s) oil can be evenly swept, with thick streamline. With increasing oil recovery rate, water rush weakens along the reservoir bottom and sweeps the reservoir more evenly in the vertical direction; and the sweep efficiency difference between top and bottom of the reservoir decreases. In high-rate development of the low-viscosity oil reservoir, the water-free recovery percent is significantly higher than that in low-rate development, and the rising velocity of water cut is lower than that under low-rate development, which proved that such reservoirs are suitable for high-recovery-rate development. For reservoirs with medium-high viscosity (5–50 mPa·s) oil, the injected water fingers significantly in the water-flooding process, with thin streamline, the coverage is not swept completely, especially in area between streamlines, the sweep efficiency difference between top and bottom is great. As the oil recovery rate increases, the streamline becomes thinner, the coverage becomes more incomplete, and the sweep efficiency of top and bottom both decreases. Medium to high-viscosity oil reservoirs developed at high rate have a short water breakthrough time, and the recovery percent in the water-free period is much lower than that in low rate development, and the rising velocity of water cut is higher than that under low-rate development, so high-rate development is not adaptable for medium-high viscosity reservoirs.

Key words: water-flooding experiment; homogeneous reservoir; oil viscosity; oil recovery rate; water-flooding law; injected water sweep characteristics; high-rate development adaptability

Introduction

Crude oil has mainly been recovered from sandstone reservoirs around the world with different oil recovery rate, which may be low to less than 1% or high to above 8%[1–3]. This recovery rate would be dependent on many factors, e.g. reservoir geology, and management and strategies of oilfield development[4–7], among which reservoir geology is the most essential factor. For reservoirs with similar geologic conditions (permeability, heterogeneity, etc.), the oil recovery rate would mainly be dependent on crude viscosity[8–10]. This paper deals with the impact of oil recovery rates on water flooding in homogeneous reservoirs with different viscosities based on physical simulations[11–12] and discusses the relationship between water drive velocity and the efficiency of development for the feasibility of high-rate recovery of oil reservoirs with different viscosities.

1. Experimental devices and workflow

The model is 50 cm long, 50 cm wide and 3 cm thick, as shown in Fig. 1. The top and bottom of the device was equipped with two organic glasses for the convenience of observing fluid motions in the whole process of experiment. The internal was filled with quartz sands of 0.093–0.250 mm with the porosity of 30% and permeability of 2 000×10^{-3} μm^2.

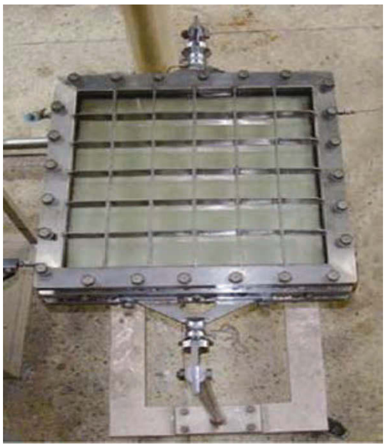

Fig. 1. Experimental device for physical simulation.

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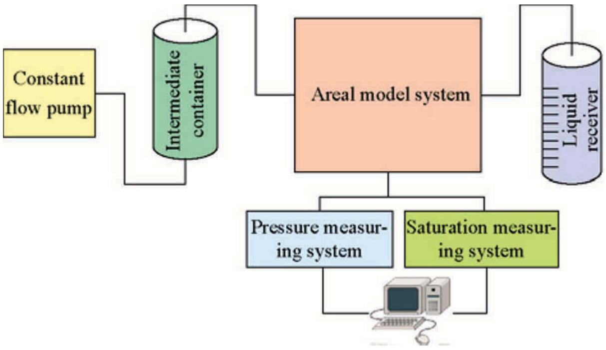

Fig. 2. Workflow of physical simulation.

The water injected has a viscosity of 0.5 mPa·s (25 °C). In view of the impact of oil-water viscosity ratio on water flooding, two crude oil samples were prepared with the kerosene of 0.5 mPa·s (low viscosity) and of 10 mPa·s (medium to high viscosity), respectively. Before sands filling, the kerosene and water were completely mixed with quartz sands in a proper proportion (which was estimated based on the porosity needed for quartz sands) so that the kerosene would scatter homogeneously in the model. One artificial injector and three production wells were designed at four corners of the model to simulate a quarter of an inversed 9-point pattern. The water injected was colored with naphthalene red for the observation of water displacing oil. Oil recovery would be simulated with constant pressure. The workflow of experiment is shown in Fig. 2.

The workflow is described as follows. (1) Saturate quartz sands with crude oil, which would then be filled into the model. (2) Inject water into the simulated injector, accompanied by constant pressure recovery from 3 simulated oil wells. (3) Record oil output and liquid output from the injector and 3 oil wells, respectively. End the experiment when the water cut reaches 100%.

Crude oils with the viscosities of 0.5 and 10.0 mPa·s, respectively were used for water injection rates of 0.9 and 3.5 mL/min, respectively (to simulate production rates of 1% and 4%, respectively). Each experiment with a portfolio of predefined parameters was repeatedly for several times to get similar results and trends, which were then processed and interpreted to establish the pattern of water flooding in a certain injection rate in the oil reservoir with a certain viscosity.

2. Water displacing low-viscosity oil

Crude viscosity is 0.5 mPa·s, similar to the viscosity of injected water; so oil-water mobility ratio is equal to 1. The process of water displacing oil is close to piston-driven displacement of oil with relatively thick flow lines and homogeneous waterflood fronts (Fig. 3). Almost all the area among these wells would be swept by water and remaining oil mainly concentrates in the region unaffected.

For the production rate of 1%, injected water would first displace oil at the bottom, leading to different geometries of displacement at the top and bottom (Fig. 3). At the early and middle stages of development, the sweep efficiencies (SE) at the top and bottom would all increase with the degree of reserve recovery and the difference between them also increases from 9% at the recovery degree of 6% to 54% at the recovery degree of 29%. At the later stage of development with high degree of recovery and high water cut, the top-bottom SE difference would decrease to 19% for the recovery degree of 61% (Fig. 4).

When the production rate increases to 4%, the top-bottom SE difference is obviously smaller than that for the production

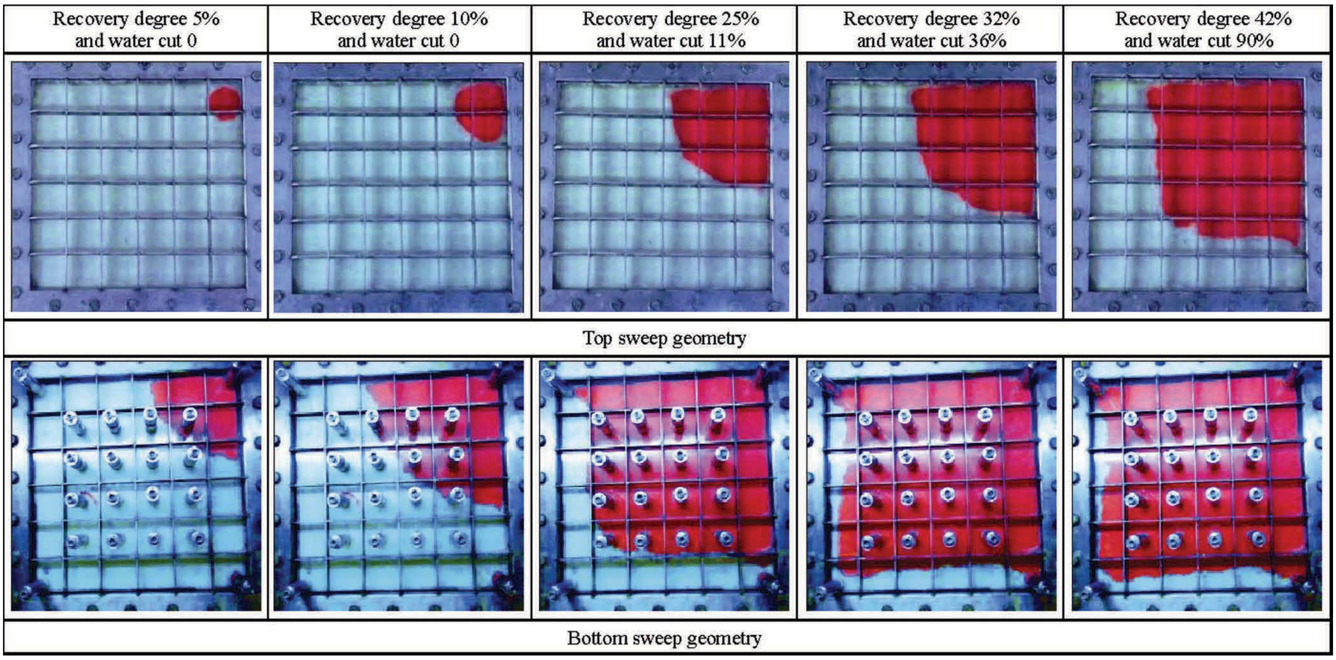

Fig. 3. Sweep geometries at the top and bottom of the low-viscosity homogeneous model with different degrees of recovery. The production rate is set to be 1%.