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Changes in the structures of mixed-layer illite–smectite during flooding of terrigenous oil reservoirs

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Abstract

A difference-spectrum method is proposed for the qualitative assessment of changes of illite–smectite structures accompanying the flooding of oil reservoirs. The method permits one to get an open system and reduce the application of procedures based on Markov's chain formalism. A computer simulation is made to obtain spectra by subtracting the spectrum of an ethylene glycol-saturated sample from the spectrum of an air-dried preparation throughout the entire range of concentrations of illite and smectite components with a short-range order factor $R = 0$ or $R = 3$.

It has been established that only in the presence of filtration are the maximum and minimum of the spectra in the range of 12.5–9.4 Å complicated by a number of local extrema, whose position is specified by the structure of intermediate phases. The flooding process first involves mixed-layer phases with $R = 0$, leading to a partial segregation of the structures into phase with one and two networks of interlayer H_2O. When the secondary mica particles break, phases with $R = 3$ appear along the boundaries of nanoblocks, first only with 1 H_2O and then only with 2 H_2O in labile interspaces. Their coexistence with the phases $R = 0$ in the sample proves the existence of percolation effects due to two-phase filtration in the porous medium. The fully flooded reservoir is always dominated by a mechanical mixture of illite–smectite phases of different nature with $R = 0$ and with different ratios of components. Transformation of mica that can drastically reduce oil production begins long before the appearance of flooding zones, which are revealed by standard logging methods.

Keywords: oil production; mixed-layer illite-smectite; micas, X-ray diffraction; computer simulation

Introduction

Long-term oil-field development in Tatarstan and other regions has revealed a number of phenomena not explainable by the conventional concepts of fluid dynamics. Injection of fresh water from near-surface sources into a reservoir usually leads to a reduction in the filtration capacity of terrigenous reservoirs, especially those of high shaliness. In the producing Devonian horizon of Tatarstan, this process can have disastrous effects. It has been found that as the density of reservoir water reduces to 1.09 g/cm^3, the oil-bearing reservoir of shaliness > 5% sometimes stops producing oil (Muslimov, 2003). Similar phenomena are observed in a number of locations in West Siberia. It has been found that the dominant factor responsible for the reduction of oil extraction is not the swelling effect but the counter electroosmotic flow produced by mica nanoblocks fixed in the pore space and having a high surface charge which cannot be compensated for in the absence of K^{1+}. Such blocks are formed during the inverse transformation of secondary micas to the initial smectite with decreasing concentration of the reservoir solution under the influence of micflora, accompanied by the formation of mixed-layer illite–smectite phases (Krinari and Khramchenkov, 2008a,b, 2011). Of greatest interest for applications is to identify the earliest stages of water flooding of reservoirs based on mineralogical criteria, and this was the main objective of the study. However, the kinetics of the process remains largely unexplored since no methods have been developed to analyze the real structure of the products of the inverse transformations of secondary micas. A number of methods have been proposed to prevent the reduction of filtration, but, without considering the specificity of man-made changes in the composition of the clay component, they are difficult to optimize for the development of particular locations; this requires different approaches and techniques for analyzing the structure of newly formed phases.

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