Association between (De)Sorption, Surface Reconstruction, and Wettability Alteration in Carbonate Reservoirs

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Mechanisms controlling the native wettability of carbonate reservoirs and its alterations via Improved Oil Recovery (IOR) technologies remain poorly understood, because of the complex compositions and responses of interacting minerals, brines and crude oils (CROs) across multiple length scales. Here, we use a combination of contact angle goniometry (advancing & receding), atomic force microscopy (AFM), confocal Raman microscopy (CRM) as well as Fourier-transform infrared (FTIR) and nuclear magnetic resonance (NMR) spectroscopy to identify relevant interactions and physicochemical processes at the interfaces between these materials that ultimately control the efficiency of recovery.

First, we demonstrate how the initial equilibration of highly saline formation brine, CRO and mineral (calcite) upon aging at elevated temperatures (95°C) produces a starting condition that is characterized by a dynamic exchange of organic and inorganic material between all three phases. Mimicking the much slower process of diagenesis, we find a chemical and topographic restructuration of mineral surfaces that involves deposition of magnesium calcite adlayers as well as sorbed organic molecules [1]. Optical and force microscopies indicate that these modifications occur in a heterogeneous way, partially guided by initial topographical features of the solid surface. The organic adlayer, enriched in polyaromatic hydrocarbons and enveloping the mineral surface, give rise to more "oil wetting" contact angles [2].

Secondly, exposure of these 'oil-wet' aged carbonate surface to various brines of lower salinity, induces very significant additional topographical and chemical modifications of the surface, including the fractional removal of sorbed polyaromatic molecules and partial dissolution of the underlying mineral substrate. Macroscopic wettability measurements demonstrate that these microscopic surface modifications give rise to a reduction of the advancing contact angle of crude oil, implying more water-wet behavior. NMR and FTIR spectroscopy allow to establish a correlation between the applied brine compositions and the sorbent molecules eluted from pre-aged carbonate surfaces.

The results of our study address the knowledge gap of how the sorption of formation water and CRO derived organic molecules provide anchor points for adhering oil and how their removal by low salinity brines can improve oil recovery. Understanding the stability and mobilization of the organic deposits during fluid displacement in reservoirs can assist the development of novel IOR technologies.

References

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