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Organic Shale Wettability and Its Relationship to Other Petrophysical Properties: A Duvernay Case Study

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Abstract

In this study, we conduct spontaneous imbibition tests and measure air-oil and air-brine contact angles of nine twin core plugs from five wells drilled in the Duvernay Formation, which is a source rock located in the Western Canadian Sedimentary Basin (WCSB). We investigate wettability of the shale samples with a wide range of TOC (2.2-6.6 wt%), effective porosity (2.0-6.2% BV), and kerogen maturity (wet-gas, dry-gas, and over-mature). We characterize the samples by measuring the effective porosity, pressure-decay permeability, oil saturation, bulk density, matrix density, mineralogy, total organic carbon (TOC) content, and conducting rock-eval pyrolysis tests. To investigate the effects of pore connectivity, we also measure spontaneous imbibition and contact angles of oil and water on crushed shale packs and compare the results with those of similar tests on the core plugs. We also investigate the crossplots of effective porosity, pressure-decay permeability, bulk density, matrix density, oil saturation, and TOC content, by using 130 data points from samples of the five wells.

Analysis of the data reveals a positive correlation of TOC content with effective porosity, pressure-decay permeability, and oil saturation of the samples. Bulk density and matrix density of the core samples decrease with increasing the TOC content. The crossplots indicate that the majority of pores exist in the organic matter of the samples and these organic pores have high affinity towards oil. Scanning Electron Microscope (SEM) and energy-dispersive x-ray spectroscopy (EDS) analyses also demonstrate an abundant number of small nanopores within the organic matter. These hydrophobic small nanopores with diameters less than 100 nm may explain high imbibed volume of oil compared with that of brine, and also late equilibrium of oil imbibition. SEM and EDS analysis also show large micropores bordered by inorganic minerals. According to Handy's model, these hydrophilic micropores with diameters larger than 1000 nm may explain early equilibrium of brine in spontaneous imbibition experiments. We define pore-wettability index of oil (PWI_o) and brine (PWI_w) based on the imbibition rate of oil and brine, respectively. PWI_o is greater than PWI_w in all spontaneous imbibition tests. Higher PWI_o compared with PWI_w indicates that oil preferentially flows through smaller pores while brine prefers to flow through larger pores. We also define oil wettability index (WI_o) based on the equilibrium imbibed volume of oil and brine. The results of spontaneous imbibition experiments show that the samples with higher TOC content and effective porosity have higher WI_o. Positive correlation of WI_o with TOC content and effective porosity suggests that the majority of hydrophobic connected pores exist in the organic part of the rock. In addition, we observe negative correlation of WI_o with bulk density and oxygen index (OI). The higher number of organic nanopores in samples with higher kerogen maturity (lower OI), and also higher oil wetting affinity in kerogens with lower OI may explain the negative correlation between WI_o and OI.

Keywords

Wettability – Imbibition – Organic pores – Total organic carbon

1. Introduction

Organic-rich shales have been considered as potential reserves across the world (Gonzalez, 2013). Extraction of hydrocarbon from shale rocks in the United States is considered as one of the landmark events in this century (Wang et al., 2014). These unconventional resources with ultra-low permeability can produce hydrocarbon at economic rates by hydraulically-fractured horizontal wells. However, successful hydrocarbon recovery from such reservoirs requires characterization of rock/fluid properties such as wettability, relative permeability, and capillary pressure. Wettability affects other rock/fluid properties including capillary pressure, water flood behavior, relative permeability, and electrical characteristics of rock. (Anderson, 1986). Evaluation of shale wettability is significant for 1) mitigating low fracturing fluid recovery after fracturing operations (Cheng, 2012; Ghanbari and Dehghanpour, 2015 and 2016), 2) investigating water blockage in shale matrix followed by rapid decline in production rate (Bertoncello et al., 2014), 3) selecting the type of fracturing fluid (water-based or oil-based) and its additives