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Project Title: Mechanistic Modeling of Wetting Behavior of Complex Rock/Oil/Water Systems for Estimating Rupture Disjoining Pressure

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Narrative Progress Report – Year 2

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Research Findings:

The present study reports on a comparison of measured ambient condition (atmospheric pressure and laboratory temperature) values of adhesion energy per unit volume ($\Delta E_{adhesion}$), which can be mechanistically correlatable to rupture disjoining pressure, with the maximum values of disjoining pressure [$\Pi(h)$] derived from theoretical disjoining pressure curves for certain rock/oil/water systems that have been reported in the published literature (Jalili and Tabrizy, 2014). The rock/oil/water systems compared here showed varied degrees of wetting characteristics, as inferred from the sessile oil drop volume alteration experiments that were performed in order to collect the necessary dynamic water-receding and water-advancing contact angle (θ_r, θ_a) data.

Rock/Oil/Water System	**Theoretically-derived (Jalili and Tabrizy, 2014) Aqueous Phase Thickness, h (nm)**	**Theoretically-derived (Jalili and Tabrizy, 2014) Maximum Disjoining Pressure, Π(h) (atm)**	**Measured (This Study) Adhesion Energy/Volume $\Delta E_{adhesion}$ (atm)**	**Ratio of Measured Adhesion Energy per Unit Volume to Theoretically-derived Maximum Disjoining Pressure**	**Remarks**
Quartz modified with 0.35 wt % Asphaltene/ n-Decane/ Distilled Water	0.6	200 (attractive)	1394 (Trial 1) to 1258 (Trial 2) (attractive)	7.0 (Trial 1) to 6.3 (Trial 2)	Strongly Oil-wet System
Quartz modified with 0.35 wt % Asphaltene/ n-Decane/ 0.1M NaCl	0.9	200 (attractive)	645 (Trial 1) to 775 (Trial 2) (attractive)	3.2 (Trial 1) to 3.9 (Trial 2)	Strongly Oil-wet System
Calcite modified with 0.35 wt % Asphaltene/ n-Decane/ Distilled Water	0.9	200 (attractive)	556 (Trial 1) to 1060 (Trial 2) (attractive)	2.8 (Trial 1) to 5.3 (Trial 2)	Weakly to Moderately Oil-wet System
Calcite modified with 0.35 wt % Asphaltene/ n-Decane/ 0.1M NaCl	1.8	200 (attractive)	154 (Trial 1) to 275 (Trial 2) (attractive)	0.8 (Trial 1) to 1.4 (Trial 2)	Weakly Water-wet to Intermediately-Wet System

The results presented in Table 1 indicate that experimentally-measured $\Delta E_{adhesion}$ values are significantly higher than the theoretically-derived Π(h) values. This observed difference may be attributed either to the uncertainty associated with the theoretically-derived aqueous phase thickness (h) value that was used in the calculations of $\Delta E_{adhesion}$ using Eq. 1, or possibly to the inability of theoretical models to calculate Π(h) beyond certain values. As can be seen from Eq. 1, any uncertainty in the h value—which is the only non-measurable quantity in Eq.1—will result in significant variation in the measured $\Delta E_{adhesion}$ values. However, as can be seen Table 1, theoretically-derived Π(h) for all of the rock/oil/water systems that were evaluated in the present study terminate at the same maximum value, which in turn, indicates the potential difficulty of theoretical determination of Π(h) beyond a certain maximum value.

$$\Delta E_{adhesion} = \frac{\gamma_{ow}(Cos\,\theta_r - Cos\,\theta_a)}{h} \quad \text{…… Eq. 1}$$

Impact of the Research Findings on the Development of Disjoining Pressure Models for Complex Rock/Oil/Water Systems:

As can be seen in Table 1, for weakly water-wet to intermediately-wet systems, both the theoretical (disjoining pressure curve) and the experimental (adhesion energy/volume) approaches reasonably agreed. However, in the case of oil-wet systems, each approach results in significantly different values. Thus, the experimental results obtained in the present study can be used to further refine the existing theoretical models or to develop new disjoining pressure models for the complex rock/oil/water systems that exhibit oil-wet wetting behaviors.

Impact of the Research on My Career:

This research has provided me with an opportunity to build necessary experimental capabilities and to leverage financial support from local petroleum industry to develop experimental infrastructure. In the near future, this will enable me to further study the phenomenon of rock/oil adhesion, its impact of oil recovery, and the multiple variables (e.g. brine chemistry, oil composition) affecting the extent of rock/oil adhesion in petroleum reservoirs at actual conditions of elevated pressures and temperatures by using representative reservoir fluids (live oil and reservoir brine) and representative rock mineral crystals. A high-pressure and high-temperature optical cell capable of measuring oil/water interfacial tension and contact angles up to 680 atm (10,000 psi) and 150°C (302°F) has already been procured and it is ready to be used for future experimental research to experimentally characterize phenomena of rock/oil adhesion, wettability, oil/water interfacial tension, and gas/oil interfacial tension in petroleum reservoirs. I expect that the dissemination of these research findings at appropriate technical conference(s) and scientific journal(s) will further help me in terms of soliciting competitive research grant(s) in the near future that are aimed at developing effective and efficient ways in which to maximize oil recoveries in depleted oil and gas reservoirs.

Impact of the Research on the Student Participants:

To date, this research project has provided an opportunity for a total of eight undergraduate engineering (engineering sciences) and science (chemistry, physics, and computer science) students—including two female students—to acquire necessary research skills and to subsequently use them in assisting me, either in my current or other sponsored research activities. The majority of the students who had or have participated in the research—or are currently contributing to it—are either first-generation college students or students who belong to underrepresented minority communities. Some of the students who have already graduated are either already part of the local workforce (e.g. the local petroleum industry, pre-K-to-12 education, and the Exploratorium) or are actively seeking entry-level engineering positions.

Additionally, this research project attracted four local high school students who spent four weeks in my laboratory during the summer (June 2018) in order to perform independent research on the topic of the crude oil adhesion phenomena that have been observed in petroleum reservoirs. At the conclusion of their summer project, they presented their research at an event open to both the campus community and local public. The partial support provided by the American Chemical Society Petroleum Research Fund upon the successful completion of their research and the presentation of their research findings was duly acknowledged.

References:

Jalili, Z.; Tabrizy V.A. Mechanistic Study of the Wettability Modification in Carbonate and Sandstone Reservoirs during Water/Low Salinity Water Flooding. Energy and Environment Research 2014, 4(3).