Consortium for Processes in Porous Media
25th Annual Meeting

Rice University, Houston, TX
October 27th, 2021
## Meeting Agenda (CST)

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Introductio

Dr. George J. Hirasaki
A.J. Hartsook Emeritus Professor in Chemical Engineering (gjh@rice.edu)

Abstract
The goal of this consortium is to engaged in collaborative research to advance the fundamental understanding of porous media processes. Our core research areas include the study of surfactant and foam Enhanced Oil Recovery (EOR) processes, wettability alteration with smart water, and NMR & molecular simulation studies of unconventional formations. As the director of this research consortium, I thank you for your support of our research and welcome you to potential opportunities for collaboration and participation.
Synergy of 2 MHz and 20 MHz NMR Core-Analysis

Dr. Philip M. Singer
Assistant Research Professor
Rice University
(ps41@rice.edu)

Abstract
The current trend in NMR core-analysis is to go to higher NMR frequencies. In this presentation, we highlight some recent examples of 2 MHz versus 20 MHz $T_1$-$T_2$ data in hydrocarbon-saturated organic-rich shale, $T_1$ dispersion (i.e., NMR frequency dependence) of bitumen and polydisperse polymers, and $T_1$ dispersion of water in Gd$^{3+}$-aqua. The data demonstrate that 20 MHz instruments can detect shorter $T_2$'s because of shorter echo-spacings, 20 MHz is better than 2 MHz for fluid-typing in organic-rich shale, and $T_1$ dispersion measurements are the best way to validate MD simulations for elucidating the NMR relaxation mechanism. The data also imply that 2 MHz core-analysis is essential for calibrating NMR logs, and that internal gradients at 20 MHz can in certain cases complicate the interpretation of $T_2$. We conclude that the best approach in NMR core-analysis is the synergy of 2 MHz and 20 MHz.
Presentations

Wednesday, October 27th: 9:10 am — 9:30 am (CST)

Study of Bakken and Three Forks Formation Using NMR Core Analysis

Mr. Mohamed Awad
Visiting Student
University of North Dakota
(mohamed.awad91990@yahoo.com)

Abstract
In this study, we used NMR $T_1 - T_2$ measurements at 2.3 MHz and 22 MHz to provide key insights into the wettability, NMR wettability index, presence of bitumen, surface-relaxation mechanism, and internal gradient effects in cores from the Bakken and Three Forks formations. We used the temperature dependence (25 °C to 100 °C) of $T_2$ at 2.3 MHz to determine the origin of the NMR surface-relaxation mechanism in the saturated nanometer-sized pores. Finally, we vary the echo-spacing of the $T_2$ measurement to check for internal gradient effects, which (if present) would complicate the interpretation of wettability and surface-relaxation mechanism from $T_2$. 
Presentations

Wednesday, October 27th: 9:30 am — 9:50 am (CST)

Pore Size, Tortuosity, and Permeability from NMR Restricted Diffusion in Organic-Rich Chalks

Mr. Xinglin Wang
PhD Graduate Student, 4th Year
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(xw51@rice.edu)

Abstract

Permeability estimation is crucial for formation evaluation. However, the current NMR methods are not adequate in many unconventional formations. Here, we develop a new method to estimate permeability using a modified Carman-Kozeny model with pore size, tortuosity, and porosity information inferred from NMR restricted diffusion measurements. In this study, we focus on low-permeability organic-rich chalks with connate water present. The core samples are pressure-saturated with methane or decane, with connate water present. NMR measurements are conducted to obtain the restricted diffusivity of the fluid in hydrocarbon-bearing pore space. An optimum series of diffusion-encoding times are chosen for the unipolar stimulated echo pulse sequence to measure the restricted diffusivity. By applying the Padé fit to the restricted diffusivity, we can estimate the tortuosity and pore-body size of the hydrocarbon-filled pore space. The estimated parameters from NMR are used to predict permeability. A modified Carman-Kozeny model shows advantages over older methods like SDR and Timur-Coates models especially in complex pore structures. This new method can potentially be used for estimating permeability by well logging and core-log integration.
Presentations

Wednesday, October 27th: 9:50 am — 10:10 am (CST)

Macro-Pore Hydrocarbon Saturation from NMR $T_1$-$T_2$ Maps in the Unconventional Point-Pleasant Formation

Mr. Yunke Liu
PhD Graduate Student, 3rd Year
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Abstract

Of particular interest in unconventional reservoir characterization is an NMR log of total porosity and macro-pore hydrocarbon saturation, where both quantities are independent of a mineralogy model. However, NMR logs in unconventional shale are challenging due to potential overlapping signal in the 1-dimensional (1-D) $T_2$ domain between micropore water and bound hydrocarbon (i.e., bitumen), and macro-pore water and hydrocarbons.

In response to this challenge, an example from the unconventional Point-Pleasant formation using NMR core analysis is shown where the traditional $T_1$-$T_2$ cutoff technique to determine macro-pore hydrocarbon saturation breaks down, which is remedied by measuring $T_1$-$T_2$ maps on mixed hydrocarbon-water saturated cores. The results show that the log-mean $T_1$ is much more sensitive to macro-pore hydrocarbon saturation than the log-mean $T_2$ or log-mean $T_1/T_2$ ratio for the Point-Pleasant organic-shale formation. The calibration of macro-pore hydrocarbon saturation from log-mean $T_1$ is found to be different above and below a para-sequence boundary (nonconformity) in the organic-shale interval, the results of which can be used to interpret NMR logs.
Predicting the Effects of Paramagnetics in 1H NMR Relaxation Using Molecular Simulation: The Case of Gd$^{3+}$-aqua

Mr. Arjun Valiya Parambathu  
PhD Graduate Student, 5th Year  
Rice University  
(av42@rice.edu)

Abstract
Atomistic molecular dynamics simulations are used to predict $^1$H NMR $T_1$ relaxation of water from paramagnetic Gd$^{3+}$ ions in solution at 25°C. Simulations of the $T_1$ relaxivity dispersion function computed from the Gd$^{3+}$-$^1$H dipole-dipole autocorrelation function agree within $\approx 8\%$ of measurements in the range $f_0 \approx 5\rightarrow 500$ MHz, without any adjustable parameters in the interpretation of the simulations, and without any relaxation models. The simulation results are discussed in the context of the Solomon-Bloembergen-Morgan inner-sphere relaxation model, and the Hwang-Freed outer-sphere relaxation model. Below $f_0 \leq 5$ MHz, the simulation overestimates compared to measurements, which is used to estimate the zero-field electron-spin relaxation time. The simulations show potential for predicting $r_1$ at high frequencies in chelated Gd$^{3+}$ contrast-agents used for clinical MRI.
Computing Solid-Liquid Interfacial Free Energy from a Thermodynamic Integration Perspective

Mr. Thiago J. Pinheiro dos Santos
PhD Graduate Student, 2nd Year
Rice University
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Abstract
We consider the problem of evaluating the interfacial energy between a non-elastic solid and a liquid (LJ-like systems) under different conditions using the well-known test area method. We then validate these results using an alternative Dupré-like approach. In the latter, a thermodynamic integration is used to split the interfacial energy into a non-interacting term (free energy due to repulsion) and an excess part (adhesion without repulsive contributions). The results show good agreement between these independent calculations and previous works. We show that the alternative approach provides good physical insights into the solid-liquid interfacial properties by allowing us to measure the free energy due to attractive forces at the interface. Finally, we conclude that the test area method captures all the necessary physics for computing interfacial energies of solid-liquid systems, with the advantage of not having to explicitly define the dividing interface as in approaches that use Gibbs formalism.
Effects of Velocity and Gas Type on Capillary Pressure and Rheology on Foam Flowing in Porous Media

Dr. Eric Vavra
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Abstract
Classically, strength of a foam flowing in porous media is thought to be governed by the stability of liquid lamellae that separate individual gas bubbles and by the “limiting” capillary pressure above which these foam lamellae rupture. In this work, a custom probe was designed and constructed for directly measuring in-situ capillary pressures of foam in porous media. Foam quality scan experiments were conducted primarily in a 143-Darcy sand pack with AOS14-16-stabilized N₂ foam at ambient lab conditions and constant gas flow rates. Capillary pressure was observed to increase with increasing foam quality before plateauing over a range of qualities in the low-quality regime. Then, in contrast to the classical view, capillary pressure decreased with increasing foam quality in the high-quality regime. The measured capillary pressure decreases were correlated with in-situ observations of increasing bubble size. These general trends occurred regardless of gas velocity over the range of velocities that were tested. Increasing velocity led to increasing transition foam qualities and plateau capillary pressures.
Presentations

Wednesday, October 27th: 11:30 am — 11:50 am (CST)

Effects of Pressure and Temperature on Foam Flow in Porous Media

Mr. Chutian Bai
PhD Graduate Student, 4th Year
Rice University
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Abstract
The capillary pressure is important in foam flow in porous media because bubbles are thought to coalesce by lamella rupture as the "limiting capillary pressure" is approached. Here, we will describe the role of system pressure and temperature on capillary pressure and apparent viscosity of a foam flowing through porous media. We designed and constructed a custom high-pressure capillary-pressure probe to characterize foam flow in a 140-Darcy homogenous sandpack in our previous results. Foam quality scan experiments were conducted at a fixed gas velocity. The effects of pressure and temperature on foam flow through porous media at 500 psi and various temperatures were studied.

By comparing the test results collected at 500 psi to the results under ambient conditions, the transition foam quality (at peak apparent viscosity) for a 500-psi experiment was found to be higher than that at ambient conditions ($f_g = 0.83$ and $f_g = 0.65$ respectively). The apparent viscosities at 500 psi are larger by up to a factor of 2.2. Also, an increase in temperature from 20°C to 50°C resulted in a weaker foam due to reduced viscosity of the liquid phase at the elevated temperatures. The effect of pressure is more complicated to explain. Several hypotheses related to pressure fluctuations and density effects are discussed.
Presentations

Wednesday, October 27th: 11:50 am — 12:10 pm (CST)

Results of a CO₂ Foam Pilot in East Seminole Field

Dr. Zachary Paul Alcorn

Research Scientist

University of Bergen

(Zachary.alcorn@uib.no)

Abstract

A CO₂ foam pilot was conducted in a mature heterogeneous carbonate reservoir in East Seminole Field, Permian Basin USA. The main objective was to achieve in-depth CO₂ mobility control to increase CO₂ sweep efficiency and improve the CO₂ utilization factor. The pilot program implemented a laboratory to field upscaling approach which included extensive foam formulation screening, numerical modeling, and field monitoring to verify foam generation. The monitoring campaign obtained a baseline before the pilot and monitored reservoir response to foam injection. A rapid surfactant-alternating-gas (SAG) injection strategy began in May 2019 in an inverted 40 acre 5-spot pattern. Eleven complete SAG cycles were injected at the completion of the pilot injection phase in August 2020. Pilot results revealed reduced CO₂ mobility, increased oil recovery, and an improved CO₂ utilization factor, compared to conventional CO₂ or WAG injection. This work presents the analysis and field results from the successful implementation of CO₂ foam mobility control for enhanced oil recovery (EOR).
Demulsification of Nonionic Surfactant Stabilized Emulsions With Magnetic Nanoparticles

Dr. Sibani Lisa Biswal
William M. McCardell Professor in Chemical Engineering
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Abstract
Stable water-crude-oil (W/O) emulsification with a nonionic surfactant that after six months of gravity separation, phase separates into a neat oil (top), viscous W/O emulsion (middle), and mainly water contaminated with crude oil (bottom). Phases like that are expected to be produced in the field. Production of crude oil heavily emulsified with water or water contaminated with crude oil is challenging for downstream refining processes. I will describe the application of functionalized magnetic nanoparticles (MNPs) that adsorb to the oil-water interface via intermolecular interactions. The advantage of MNPs is that they are responsive to an external magnetic field. The application of an external magnetic field gradients immediately disrupts the oil-water interface and have been shown to successfully separate produced W/O emulsions.