Consortium for Processes in Porous Media
26th Annual Meeting

Rice University, Houston, TX
Dec 8th, 2022
Parking: North Annex
Enter with your own credit card; exist with parking pass (provided by the consortium)

Meeting Venue:
Duncan Hall 1064

Coffee and Lunch:
Duncan Hall 3092
Meeting Agenda: Morning Session
Thursday, Dec 8th

8:15 am — 8:30 am  Coffee

8:30 am — 8:45 am  Opening Speech  Dr. George Hirasaki

8:45 am — 9:30 am  Overview of NMR core-analysis projects  Dr. Philip Singer

9:30 am — 10:00 am  Permeability Anisotropy Estimation in Organic-Rich Chalk by NMR Restricted Diffusion  Dr. Xinglin Wang

10:00 am — 10:30 am  Separation of solid and liquid components in organic-rich chalks using NMR relaxation  Mr. Yunke Liu

10:30 am — 10:45 am  Coffee Break

10:45 am — 11:15 am  Contrasting NMR relaxation at high viscosity probed by atomistic simulations of glycerol and polymer (recorded)  Dr. Arjun Parambathu

11:15 am — 11:45 am  Formation Evaluation in the Energy Transition  Dr. George Hirasaki

11:45 am — 12:45 pm  Lunch
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Opening Speech

Thursday, Dec 8th: 8:30 am — 8:45 am

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

Abstract
Welcome to the 26th annual meeting of the Consortium on Processes in Porous Media. We had our first meeting in 1996. The goal of this consortium is to engage in collaborative research to advance the fundamental understanding of porous media processes. Our core research areas include the study of surfactant, CO₂ foam Enhanced Oil Recovery (EOR) processes, 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.

Notes
Overview of NMR core-analysis projects

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

Abstract
The current trend in $^1$H NMR core-analysis is to go to higher frequencies, i.e., above 2 MHz. In this presentation, we highlight some recent examples of 20 MHz $T_1$-$T_2$ data in low-permeability organic-rich chalk. The data demonstrate how 20 MHz instruments (with shorter dead times) can detect solid-like signals including kerogen, bitumen, and clay hydroxyls. Furthermore, 20 MHz provides better $T_1/T_2$ contrast for determining hydrocarbon saturation. Concurrently, the data also imply that 2 MHz core-analysis is required for calibrating the interpretation of NMR logs.

We then use the frequency dependence, temperature dependence, EPR (electron paramagnetic resonance), and MD (molecular dynamics) simulations to show that the dominant NMR relaxation mechanism for viscous fluids and fluids under nano-confinement is $^1$H-$^1$H dipole-dipole relaxation rather than paramagnetism.

We conclude that the best approach in NMR core-analysis is the synergy of 2 MHz and 20 MHz, and we provide some suggestions for best practices.

Notes
Permeability Anisotropy Estimation in Organic-Rich Chalk by NMR Restricted Diffusion

Dr. Xinglin Wang  
(xw51@rice.edu)

Abstract

We present a new method for studying permeability anisotropy using NMR restricted diffusion measurements. The NMR restricted diffusion measurements were made with a 2.3 MHz NMR core analyzer core plugs drilled parallel (horizontal) and perpendicular (vertical) to the bedding plane. The cores at connate water saturation were then saturated with methane at 1,200 psi and then saturated with decane for NMR measurements. Pore size and tortuosity were estimated based on the NMR-restricted diffusion versus diffusion length data, and then used in a modified Carman-Kozeny model to predict the permeability anisotropy.

The permeabilities, computed from a modified Carman-Kozeny model, shows that the tortuosity is the main factor in the anisotropy of the measured core permeabilities. The diffusive tortuosity is much greater in the vertical direction than the horizontal direction due to the additional diffusional restriction from the depositional laminations. We find that the $L_D$ at which the vertical core reaches its tortuosity limit is significantly shorter than in the horizontal direction.

We propose a new method to measure the permeability anisotropy using NMR restricted diffusion and Carman-Kozeny model. This method can reduce the diffusive coupling using hydrocarbon saturation on cores with connate water and make a more accurate permeability estimation.
Presentations

Thursday, Dec 8th: 10:00 am — 10:30 am

Separation of Solid and Liquid Components in Organic-Rich Chalks

Mr. Yunke Liu
PhD Graduate Student, 4th Year (yl179@rice.edu)

Abstract
Currently there is great interest in interpreting the $^1$H NMR $T_2$ relaxation (i.e., transverse relaxation) of porous geological media containing both liquid-like and solid-like signals. This has an impact on the interpretation of commercial NMR core and log analysis of organic-rich shales, such as shale oil and shale gas, where $T_1$-$T_2$ relaxation maps are routinely used to identify sweet spots and producibility of the hydrocarbon reservoir.

We report a novel method to separate liquid-like components with an exponential decay ($T_{2e}$) in transverse magnetization from solid-like components with a Gaussian decay ($T_{2G}$). The method uses novel pulse sequences together with a 20 MHz $^1$H NMR relaxometer optimized for reservoir core plugs. The method is applied to obtain 2D $T_1$-$T_2$ maps in organic-rich chalks saturated with water or heptane, as well as bitumen-extracted samples. The maps clearly distinguish liquid-like signals (including micro/meso-macro pore fluids, heptane dissolved in bitumen, and clay-bound water) from solid-like signals (including kerogen, bitumen, and clay hydroxyls) in the organic-rich chalks.

Notes
Contrasting NMR relaxation at high viscosity probed by atomistic simulations of glycerol and polymer (recorded)

Dr. Arjun Valiya Parambathu  
Postdoctoral Researcher at the University of Delaware (arjunvp@udel.edu)

Abstract
The traditional Bloembergen, Purcell, and Pound (BPP) model is the cornerstone in interpreting NMR relaxation times of fluids. However, measurements of NMR relaxation in crude oil and polymer-alkane mixtures showed significant deviation from BPP theory at high viscosity. Our recent molecular simulation results show this is a consequence of assumptions made in BPP theory. But, it is intriguing that BPP theory was compared to glycerol measurements that were a satisfactory match. In this regard, we utilize atomistic simulations to compute NMR relaxation in the two contrasting cases: glycerol and poly(isobutene). We simulated over five decades of viscosity over temperature: glycerol by varying temperature and poly(isobutene) by varying molecular weight. We find that dipole-dipole relaxation alone explains the measurements for both cases. Both cases showed significant deviation from the BPP theory for intramolecular relaxation. Rather than the mono-exponential decay of auto-correlation (assumed in BPP theory), we observe a multimodal distribution of exponential correlation times. The modes indicate that the difference in relaxation behavior is primarily due to the hydrogen bonding network in glycerol, causing the glycerol to be more rigid than poly(isobutene).
Dr. George J. Hirasaki
A.J. Hartsook Emeritus Professor in Chemical Engineering (gjh@rice.edu)

Abstract
Our society has a dual need for fossil energy but yet reduce the emission of carbon dioxide. These dual needs can be met with carbon capture, utilization, and storage (CCUS). Our industry has been practicing CO₂ EOR for over 50 years. Earlier sources of CO₂ were natural sources but now the US has pipelines and infrastructure for distributing natural and industrial CO₂ to locations where they can be utilized and/or stored. Also, NMR formation evaluation technology is being developed to quantitively measure the distribution of hydrocarbon in the organic and inorganic porosity of unconventional formations. This has promise for evaluating for CO₂ “Huff-n-Puff” EOR in unconventional formations.

Notes
How Foam Develops Apparent Viscosity in CO₂ EOR

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

Abstract
CO₂ is widely used enhanced oil recovery but the low viscosity and density of CO₂ often results in poor sweep efficiency and recycling of the CO₂. This problem can be improved by in situ dispersing the CO₂ with brine to generate a foam. This process has been applied since the 1970s for steam, natural gas, and CO₂. This presentation summaries the mechanisms by which foam develops apparent viscosity, how the experiential data is fitted to empirical models, and used in reservoir simulation.
**Presentations**

**Thursday Dec 8th: 1:15 pm — 1:45 pm**

**Characterization of N\textsubscript{2} Foam Flow with in-situ Capillary Pressure Measurements in a High-Permeability Homogeneous Sandpack: Effect of Surfactant Concentration Concentration and Flowrate**

**Mr. Chutian Bai**

PhD Graduate Student, 5\textsuperscript{th} Year (cb51@rice.edu)

**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 surfactant concentration and flowrate on capillary pressure and apparent viscosity of a foam flowing through porous media. We designed and constructed a custom capillary-pressure probe to characterize foam flow in a 140-Darcy homogeneous sandpack in our results. Foam quality scan experiments were conducted at a fixed gas velocity. The effects of surfactant concentration and flowrate on foam flow through porous media under ambient conditions were studied.

By comparing the test results collected under different flowrates and surfactant concentrations, the apparent viscosity and the capillary pressure decrease above the transition foam quality (at peak apparent viscosity). The transition foam quality increases with increasing surfactant concentration and flow rate. For the slowest velocity, a minimum surfactant concentration is required to generate strong foam. While above this minimum surfactant concentration, foam apparent viscosity is similar for different surfactant concentrations at the same velocity.

**Notes**
Presentations
Thursday, Dec 8\textsuperscript{th}: 1:45 pm — 2:15 pm

Qualitatively Comparing the Effect of Gas Types on Foam Texture and Foam Dynamics

Ms. Yiwei (Mavis) Wang
PhD Graduate Student, 4\textsuperscript{th} Year (yw87@rice.edu)

Abstract
Foam applications range from enhanced oil recovery in production wells to carbon sequestration in hydraulic fracking sites. To better predict foam flow in these natural porous media, researchers need to understand the fundamental physicochemical processes involved. Microfluidics have been proven effective in visualizing small-scale events and processes that would otherwise be difficult to observe in confined systems. In this study, we utilized a microfluidic device that mimics heterogeneous sandstone porous media to investigate the effects of gas type on foam dynamics, foam stability, foam generation, and phase mobility. Real-time imaging and image processing techniques were employed to obtain an in-depth picture of foam texture and morphology in relation to foam quality and apparent viscosity.

Notes
Inhibiting Asphaltene Deposition Using Polymer Functionalized Nanoparticles (recorded)

Ms. Thao Vy Nguyen
PhD Graduate Student, 4th Year (tvn3@rice.edu)

Abstract
Asphaltenes constitute the heaviest and most polarizable fraction of crude oil. They are usually referred to as the “cholesterol of petroleum” because of their tendency to aggregate and precipitate, causing clogging problems not only in the wellbore and near wellbore regions, but also in pipelines and production equipment and facilities. In this study, we investigate the effectiveness of polymer functionalized nanoparticles in asphaltene mitigation. The nanoparticle has an iron (II, III) oxide core, whose surface is functionalized with AA-AMPS copolymers, which increase the nanoparticle’s colloidal stability at high temperature, high salinity conditions. Approaching from a microfluidic perspective, we design a dual permeability porous micro-device, where we study asphaltene deposition of four different crude oils, with and without the presence of nanoparticles coating. Our results demonstrate that our functionalized nanoparticles are effective in mitigating asphaltene deposition in different crude oils. With further tuning of nanoparticles, mitigation effects can be improved, and application can be expanded to different surfaces (stainless steel, chromium, etc.).

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