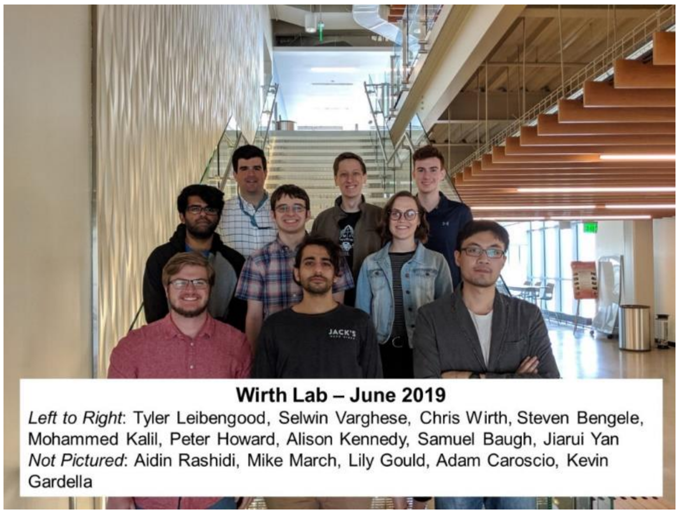
PRF#: *58038-DNI5*

Project Title: *ACS PRF DNI: Microstructure and Transport of Nanoparticle Laden Foams in Porous Media*

P.I. Name, Affiliation: *Christopher Wirth, Chemical and Biomedical Engineering, Cleveland State University*



Wirth Lab – June 2019
Left to Right: Tyler Leibengood, Selwin Varghese, Chris Wirth, Steven Bengele, Mohammed Kalil, Peter Howard, Alison Kennedy, Samuel Baugh, Jiarui Yan
Not Pictured: Aidin Rashidi, Mike March, Lily Gould, Adam Caroscio, Kevin Gardella

Summary: Multiphase fluids are important to many applications found in the petroleum industry. Two timely examples are the use of foams in the areas of shale fracturing and enhanced oil recovery (EOR). Greater efficacy of foam fracking fluids would substantially reduce the volume of water required for unconventional natural gas drilling, while foams have been used in EOR as effective displacing fluids, as well as sweeping fluids for environmental remediation. Nanoparticle stabilized foams have many of the properties that make them desirable for these two applications, including strong stability in the presence of oil and also favorable rheological and mechanical properties. Yet, there has been very little work on how particle properties and interfacial microstructure influences the transport of nanoparticle stabilized foams in porous media. Funds from the ACS PRF DNI program are helping our group fill this gap in knowledge by predicting particle microstructure and interfacial properties, and subsequently applying these predictions to the transport of foam in porous media.

Impact on participating students and on my career and participating students: Funds provided via the ACS PRF DNI program had a significant positive impact. Four graduate and two undergraduate students have been involved in the project thus far, in either major or minor roles. Three graduate students completed their MS degrees, while another PhD student is working towards finishing his degree. Of the graduated students, one entered the PhD program at Cleveland State University working in my lab, the second obtained employment at a local engineering company, and the third is employed at the Sherwin-Williams company. I expect the PhD student to finish his degree in spring 2020. The undergraduate students involved in the project reported having a positive experience, with both continuing on in my laboratory past their initial commitment. Both senior undergraduate students are considering their career options, expressing interest in either entering the workforce or pursuing PhD studies after graduation in spring 2020. Initial work on this project has also had a positive impact on my career by providing much needed personnel and supplies support to push this and related projects forward. I received an NSF CAREER award for a complementary project, focused on measuring interactions of complex particles near interfaces.

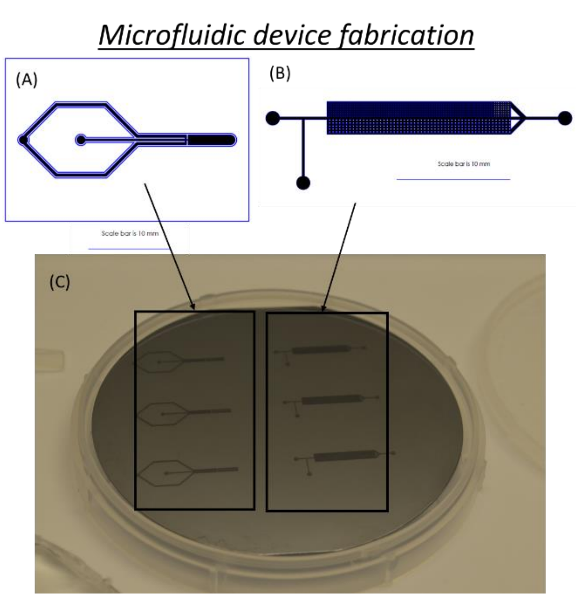


Figure 1: Microfluidic mold for fabricating PDMS devices for studying foams in porous media. (A) Tip streaming device design for generating foam, (B) Porous media design, and (C) mold for microfluidic device fabrication.

Activities during the budget period 2018 – 2019: Our research activities over the past year have focused primarily in two areas: (1) further development and testing of the microfluidic device used to generate bubbles and (2) microstructure measurement of particles at fluid/fluid interfaces.

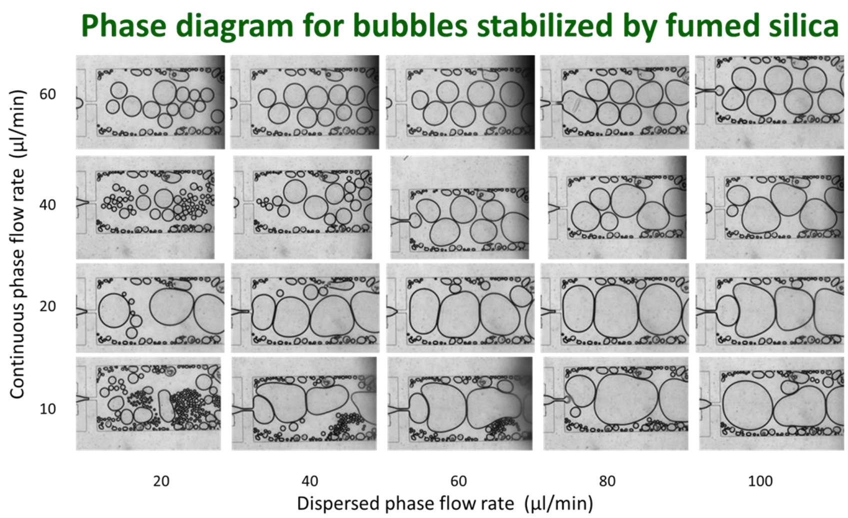


Figure 2: Structure map for variations in dispersed and continuous phase flow rate for bubbles stabilized by fumed silica. This is proof-of-concept that we can generate 'wet' foams stabilized by silica nanoparticles.

(1) Development and testing of microfluidic device for bubble generation: We designed and had fabricated the mold for a microfluidic device for micromodel experiments of foams in porous media (see **Fig. 1**). The SU-8 mold consists of a flow focusing "foam generator" (see **Fig. 1(A)**) and also a porous media micromodel (see **Fig. 1(B)**). The molds were initially designed with SolidWorks and then fabricated at the University of Louisville Micro/Nano Technology Center. Over the past year, we began making and benchmarking the PDMS microfluidic devices fabricated with the mold (see **Fig. 2**).

Figure 2 summarizes results from these initial benchmarking experiments. The essence of this work was varying the liquid and continuous phase flow rates along with variation of some standard stabilizing agents, including surfactant and nanoparticles. We found that fumed silica was able to stabilize bubbles at a wide variety of flow rates. We found that smaller bubbles were generated at smaller dispersed flow rates for all continuous flow rates.

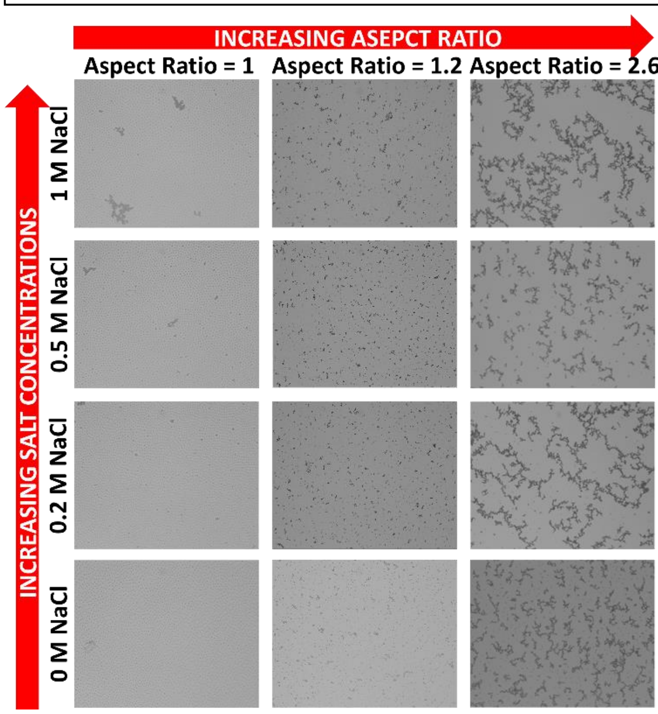


Figure 3: Nominally 5 μm diameter polystyrene spheres were used to prepare ellipsoids of aspect ratio = 1.2 and = 2.6. Particles were imaged after reaching a pseudo-equilibrium structure in response to 0 M, 0.2 M, 0.5 M, and 1 M NaCl Solutions.

(2) Microstructure measurement of particles at fluid/fluid interfaces: The second major piece of work of the past year was more extensive measurement of the microstructural evolution of particles at a fluid/fluid interface (see **Fig. 3**). The primary motivation for these measurements is to elucidate the influence of electrostatics on the flocculation of non-spherical particles at a fluid/fluid interface. These systems (particles near water/oil interfaces) are regularly found in the oil and gas industry. Of particular interest to us is determining at what aspect ratio capillary attraction dominates electrostatic repulsion. Our data from the past year suggests that ellipsoids have a 'critical aspect ratio' of ~ 1.2, which balanced electrostatic repulsion with capillary attraction. We are currently preparing a publication summarizing these data.

Nest steps: The key accomplishments from 2018-2019 consisted primarily of developing and benchmarking our microfluidic devices and further exploring via measurement the microstructural evolution of anisotropic particles at a liquid/liquid interface in the presence of salt. Next steps in the upcoming year are focused on one driving question: How does a particle laden foam structure in porous media and what role particle shape and surface chemistry plays in foam structure in porous media?