PRF No. 58746-ND9

A New Approach to Quantifying Adsorption/Diffusion Characteristics of Shale Formations

PI: Dr. Hadi Jabbari, Petroleum Engineering Department, University of North Dakota

Co-PI: Dr. Minou Rabiei, Petroleum Engineering Department, University of North Dakota

Introduction

Complexity associated with the characterization of shale formations and their rock/fluid interactions is multifold. One of the main challenges is the understanding of storage capacity and the mass transport of hydrocarbon and injected fluids in these unconventional reservoirs. Also, sorption/adsorption characterization for rock compositions and minerals in shale formations with relatively high amount of illite, kaolinite, quartz, dolomite, and kerogen are challenging and thus requires further investigations. In this research, such challenges are tackled through innovative methods of reservoir characterization and fluid flow experiments in the lab as well as simulation and modeling of fluid transport at the nano/micro-scale of tight shale formations.

We acquired two rock samples, a Berea core plug and one rock core plug from the Bakken Fm. Williston Basin, ND. We started with characterizing these rock samples from the perspectives of pore structure, mineralogy, rock/fluid interactions, and fluid flow. Our laboratory experiments along with simulation and modeling have produced these results: a) permeability (through steady-state, Aspike & Multipulse method), geomechanical properties (through seismic velocities), and storage capacity (**Fig. 1**; *Assady et al.* 2019; *Badrouchi & Jabbari* 2019), b) anatomical configuration and pore structure of Berea and the Bakken samples through CT, micro-CT scanning, and proper image processing (**Fig. 2**; *Al-Metwally & Jabbari*, 2019a,b), c) characterizing the lithofacies of the Bakken Fm. using nuclear magnetic resonance (NMR) and scanning electron microscope (SEM) for the estimation of porosity and permeability (**Fig. 3**; Tomomewo et al. 2019), d) the adsorption and diffusion of CO_2 in the Bakken Fm. CO_2-EOR process. The changes in formation permeability and porosity, under different conditions, were studied to better correlate molecular diffusion/adsorption with stress/strain changes in a typical huff-n-puff process in the Bakken shale play of Mountrail County, Williston Basin, ND. This was performed through ca two-way coupling of geomechanics and fluid flow (*Ellafi & Jabbari*, 2019).

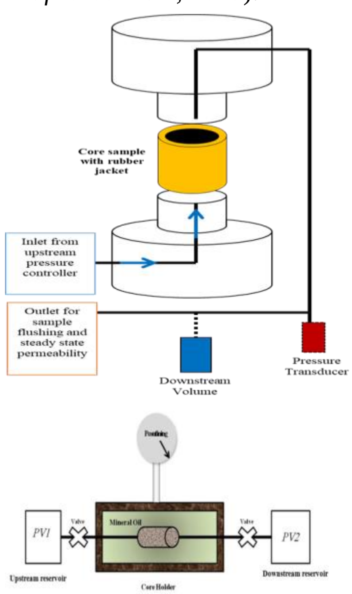

Figure 1. pulse-decay method for permeability measurement (*Assady et al.* 2019)

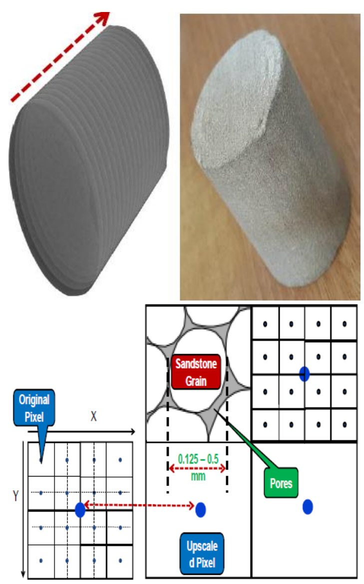

Figure 2. CT-scan analysis of core plugs to obtain pore structure (*Al-Metwally & Jabbari*. 2019a,b)

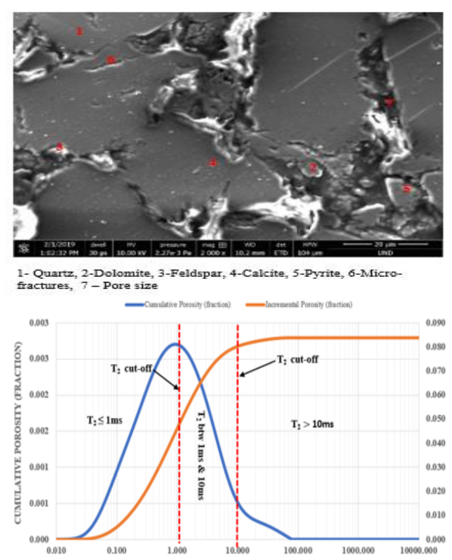

Figure 3. (Top) SEM image showing pores and grains of a Bakken core sample, (Bottom) T_2-relaxation NMR and porosity from experimental results (*Tomomewo et al*. 2019)

Development of Proper Workflow for Synthetic Core Plugs & 3D Printing Replicas

We have developed a robust workflow to create synthetic core plug samples which are porous and permeable that can properly replicate the pore network and thus the transport properties (*Al-Metwally & Jabbari*, 2019a,b). We have produced novel algorithms to simulate/model fluid flow which is of paramount interest within the reservoir engineering community. A 3D printer does the reverse of what we do when preparing a surface mesh file (i.e. STL file). The process starts to slice the generated continuous volumetric surface to layers. Then, it uses the printing material (plastics, sandstone, etc.) to follow the solid intersections between the horizontal plane and the input volumetric geometry and repeat layer by layer from bottom to top. In this work, we have tested the proposed workflow of generating representative 3D-printed core plugs with print materials, such as common plastic (PLA), polylactic acid, acrylonitrile butadiene styrene (ABS), and colored sandstone as shown in **Fig. 4**. In order to test the reliability of our proposed method and to see if the printed samples can represent the original cores, the petrophysical properties of the synthetic plugs were measured (using porosimeter & gas permeameter) and compared to the original cores which were found in close agreement (*Al-Metwally & Jabbari*, 2019a,b).

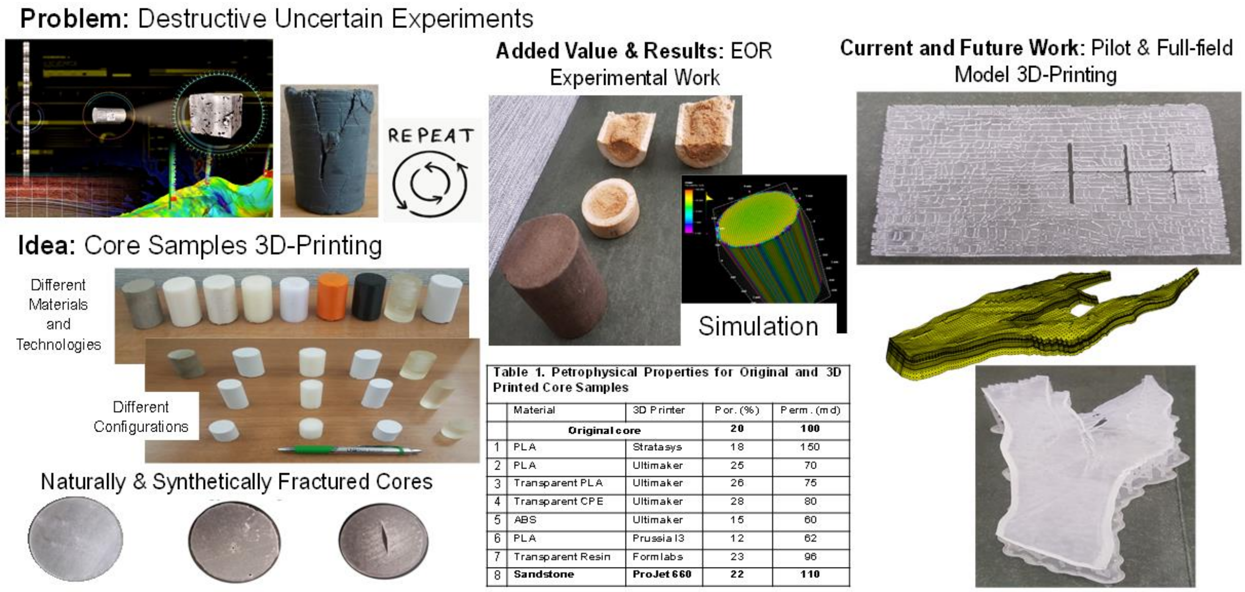

Table 1. Petrophysical Properties for Original and 3D Printed Core Samples

	Material	3D Printer	Por. (%)	Perm. (md)
	Original core		**20**	**100**
1	PLA	Stratasys	18	150
2	PLA	Ultimaker	25	70
3	Transparent PLA	Ultimaker	26	75
4	Transparent CPE	Ultimaker	28	80
5	ABS	Ultimaker	15	60
6	PLA	Prussia I3	12	62
7	Transparent Resin	Formlabs	23	96
8	**Sandstone**	**ProJet 660**	**22**	**110**

Figure 4. Using 3D-printing replicas to simplify the physics of fluid flow (*Al-Metwally & Jabbari*, 2019a,b)

Impact of the research

This ACS grant has had a substantial impact on the success and growth of my research group at UND, Petroleum Engineering Department. Five PhD students have been funded partially/fully on this grant. There were a few other students who partly contributed and altogether we have published six papers so far (listed below), and a few more are under review.

This grant has also impacted my career through establishing solid connections with industry and other research institutions. Through this grant and the novelties pursued, we will publish more results within the second year which can contribute into a better understanding of fluid flow and EOR in the unconventional (liquid-rich shale) reservoirs of North America.

Publications

Al-Metwally, A. and Jabbari, H. (2019a). *Development of Novel Workflow to Replicate Pore Networks Through 3D Printing Technology*, presented at the 53rd US Rock Mechanics/Geomechanics Symposium, NY, USA.

Al-Metwally, A. and Jabbari, H. (2019b). *CT-Scan Image Processing for Accurate Pore Network Modeling and Core Samples 3D Printing,* presented at the 53rd US Rock Mechanics/Geomechanics Symposium, NY, USA.

Assady, A., Ellafi, A., Goudarzi, B., and Jabbari, H. (2019). *On the Characterization of Bakken Formation: Oscillating-Pulse, Pulse-Decay & Geomeachanics*, presented at the 53rd US Rock Mechanics/Geomechanics Symposium, NY, USA.

Badrouchi, N., Jabbari, H. Badrouchi, F., Tomomewo, O. (2019). *Comparison of unsteady-state permeability measurement methods for Middle-Bakken core samples*, presented at the 53rd US ARMA Symposium, NY, USA.

Ellafi, A. and Jabbari, H. (2019). *Coupling of geomechanics properties and transport/diffusion mechanisms: Case study of CO2-EOR in the Bakken Formation*, presented at the 53rd US Rock Mechanics/Geomechanics Symposium, NY, USA.

Tomomewo O.S., H. Jabbari, N. Badrouchi, and C. Onwumelu. (2019). *Characterization of lithofacies and geomechanics parameters in the middle Bakken: Comparison of NMR and pressure pulse decay.* Paper presented at the 53rd US Rock Mechanics/Geomechanics Symposium, NY, USA.