IN DEVELOPMENT

Principal Investigators:

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Investment per Sponsor
Module 1 $60K (USD)

Module 2 $45k (USD)

Duration
9 months

Project I 01285

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Beyond Digital Rock Physics

Printing your Rock Type (*Rock on Chip*) to Conduct Improved Stimulation (*Lab on Chip*) for Increased Hydrocarbon Recovery

VALUE

- Developing new constitutive transport laws for shales by performing flow through experiments on Rock on Chip at nano-scale
- Understanding the effect of wettability by tailoring the wettability of Rock on Chip
- Understanding the effect of channel shape and dimensions on relative permeability
- Understanding the effect of confinement on PVT properties of hydrocarbon fluids

KEY DELIVERABLES

For conventional and unconventional liquid and/or gas rich reservoir rocks:

1. Report on ranges of organic and inorganic porosity from digital rock model and 3-D visualization of organic and inorganic facies
2. Experimental measurements of relative permeabilities for multi-phase fluids in rocks of in-situ wettability
3. Evaluation of recovery factor after secondary and tertiary recovery treatment of choice
4. Selection of most effective fracturing fluid and proppant for a particular reservoir
5. Report on bubble points of nano-confined oil

Rationale & Significance

Rock on Chip (**ROC**) is a new technology that allows engineers and geologists to perform experiments to test and refine properties, new materials, and methods for enhanced recovery in conventional and unconventional reservoirs. The *Rock on Chip* technology goes a step beyond traditional digital rock physics where computer models of rocks are generated by imaging rocks. The *Rock on Chip* technology uses the pore or fracture geometry derived from digital rock model and fabricates it onto a custom-coated silicon chip. Whether it is for enhanced recovery through new surfactant, reduced water usage in hydrocarbon recovery, use of new proppants or fracturing fluid, use of CO_2/N_2 for huff & puff, water or steam flooding, one of the greatest difficulties is the necessity to test and refine these type of projects at a field scale. Testing and refining materials and processes are expensive, time-consuming and often in-conclusive. The *Rock on Chip* technology provides a rapid, small scale, conclusive method to test and refine materials and processes to experimentally and effectively stimulate reservoir before field scale testing.

The experiments are performed in the ***Lab on Chip*** (**LOC**) that consists of nanofluidic setup with a high resolution imaging system, a highly sensitive flow controller and flow sensing system with femtoliter resolution in order to measure key properties related to transport of fluids at nano-scale. The *Rock on Chip* will supplement and transform traditional reservoir characterization methods by performing experiments at nano-scale in *Lab on Chip* to refine computer simulations that only modestly represent the true subsurface environment and physical processes, particularly in case of the shale reservoirs. The conventional simulators that use physics based on Darcy's law for permeability and conventional EOS for PVT properties, fail to add the complexity of pore-wall–fluids interaction in calculating transport and thermodynamic properties of hydrocarbon fluids in shales. The customized *Rock on Chip* that replicates the actual geology of the relevant formation provides useful insights into transport and thermodynamic properties in nanoporous rocks such as shales. Flow through tests are carried out using actual oil which will advance the evaluation along with defining new processes, new additives, new proppants, new treating fluids, and new surfactants for an enhanced recovery of hydrocarbons.

Scope of Work

The *Rock on Chip* technology fills the major gaps in digital rock physics technology. The advantages of rock on a chip technology over digital rock physics technology is shown in Figure 1. The *Rock on Chip* technology makes use of a pore or fracture network model extracted from a digital rock model of oil/gas reservoir (hence the geology of the reservoir is accounted) and uses representative sub-surface fluids to design improved stimulation to increase hydrocarbon recovery. The deliverables from *Rock on Chip* also include the traditional deliverables (porosity, permeability and 3-D visualization) from digital rock physics technology but are based on experiments instead of simulations.

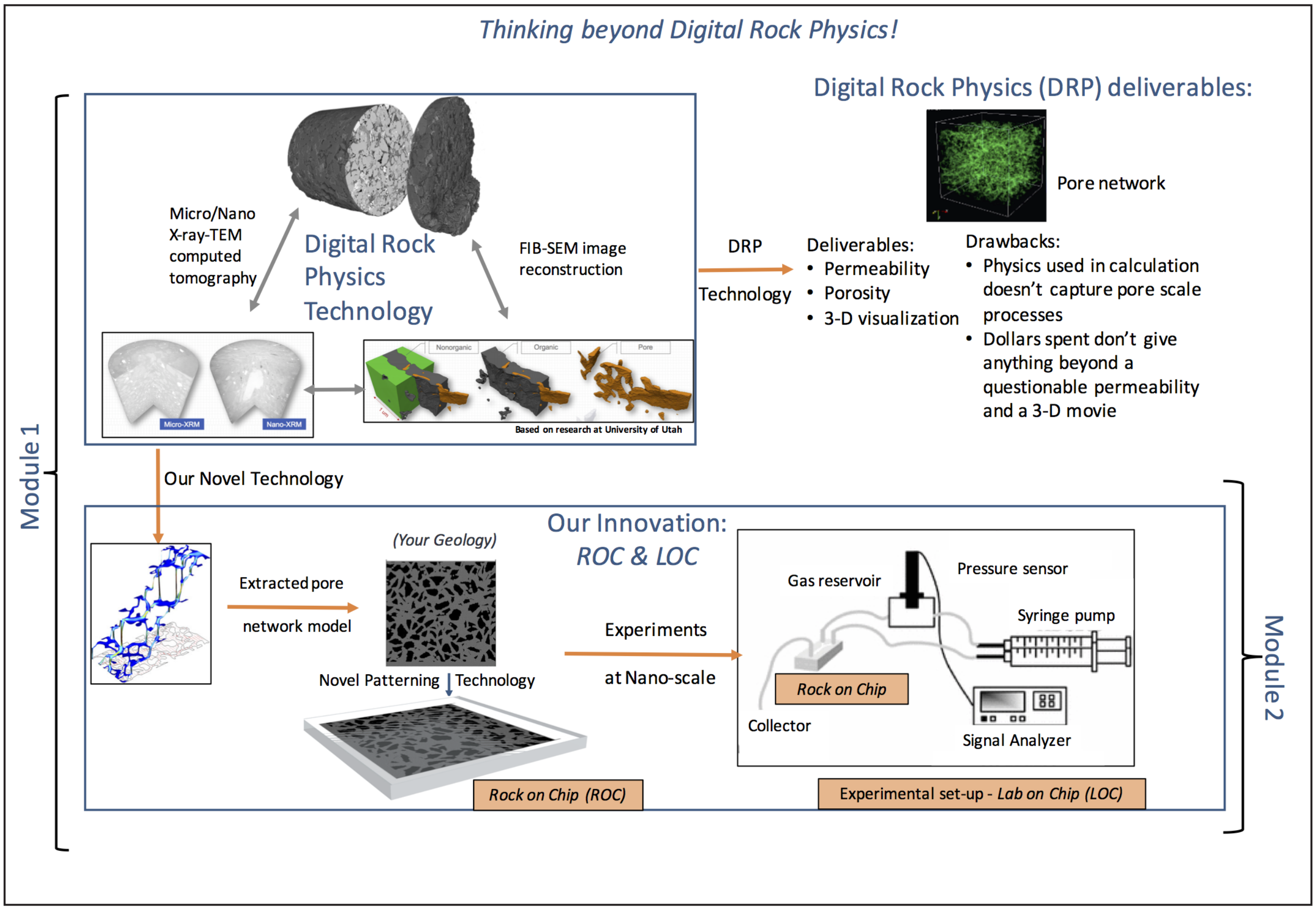

*Figure 1: Advantages of **Rock on Chip** technology over established digital rock physics technology. The deliverables form **Rock on Chip** not only includes deliverables of digital rock physics but goes a step beyond in terms of reliability and offers a laboratory (**Lab on Chip**) to test and refine new methods, materials, and processes for your reservoir. Module 1 and 2 are discussed in the following section.*

Project Activities

The proposal is divided into two Modules:

Module 1: EGI will create a digital rock model (using FIB-SEM image stack reconstruction) and extract a precise pore or fracture network model. This pore/fracture network model is etched onto a chip in order to make the *Rock on Chip*. This lab on a chip set up is used to experimentally measure fluid dependent permeabilities in rocks. It provides a reusable/fundamentally robust platform to test and refine new materials, processes and methods to increase hydrocarbon recovery and reduce water usage and carbon footprint. Sponsors will have to provide rock sample(s) for this module. Oil samples for flow through experiments are optional.

Module 2: Sponsor will provide the digital rock model or FIB-SEM image stack that they may have received from digital rock physics service companies. EGI will fabricate *Rock on Chip* based on provided digital rock model or FIB-SEM image stack and provide similar deliverables as Module 1. Oil samples for flow through experiments are optional.

The results generated from the data donated by the sponsors would be incorporated in the final report while keeping the original data confidential. For each Module, cost of participation increases by $5,000 (USD) if sponsors don't provide data.

Up to three fluids may be included to determine EOR. For sponsors who would like to test more than three, the cost would be decided on a case by cases basis.

Project Timeline, Report & Investment

The duration of the project is 9 months. Updates and interim data uploads will be announced during the project cycle and provided to all sponsors. A final report will be prepared and delivered following the final meeting.

The investment per sponsor for Module 1 is $60,000 (USD).
The investment per sponsor for only Module 2 is $45,000 (USD).

Project duration: 9 months

Research Team

Staff	Expertise/ Affiliation
Milind Deo, Ph.D. Chair, Department of Chemical Engineering University of Utah	Principal Investigator Reservoir Simulation & Engineering, Enhanced Oil Recovery
Manas Pathak, EGI Fellow & PhD Candidate Department of Chemical Engineering, University of Utah	Reservoir Characterization, Thermodynamics & Nano-technology
Raymond Levey, Ph.D., Director & Research Professor	EGI Director & Project Advisor
	Additional EGI staff & expertise will be added as needed

EGI Technical Contacts

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Research Interests

- Production of fluids from shales
- Reservoir engineering
- Enhanced oil recovery

Milind Deo, PhD

Professor Chemical Engineering

Milind Deo is a Professor and Chairman of the Department of Chemical Engineering at the University of Utah and Director of the Petroleum Research Center where he has supervised over 20 Ph.D. students and six Masters students.

He received his B.S. from the Indian Institute of Technology in Chennai, India and his Ph.D. from the University of Houston in Houston, TX, in Chemical Engineering. His Ph.D. research concentrated on the development of methods for determining residual fluid saturations after a carbon dioxide flood.

After a short stay at the Schlumberger Perforating Center in Houston where he worked on under-balanced perforating technology, followed by two years of post-doctoral work at Stanford University, he joined the University of Utah in December 1989. At Stanford, his main areas of interest included detailed petroleum characterization and phase behavior of oil, gas, and carbon dioxide mixtures. His main areas of research at the University of Utah have been reservoir engineering and enhanced oil recovery. He is widely published in the field with numerous papers and articles, and has authored several EGI reports.

Research Highlights

Dr. Deo's research group was involved in two highly successful U.S. Department of Energy (DOE) Class I and Class III Reservoir Projects. The Class I Reservoir Project with Lomax Exploration Company led to the revitalization of waterfloods in the Uinta Basin, while the Class III Project reactivated an idle lease in the Midway Sunset Field, resulting in over two million barrels of additional oil produced.

His research group has also developed a new generation of reactive-transport, multiphase reservoir simulators that are also capable of modeling fractures as discrete networks. He is conducting a comprehensive multifaceted study on Liquids from Shales that includes production analysis, development of rapid analysis and forecasting tools, material and geologic characterization, reservoir simulation, and geomechanics.

Currently, he and his students are engaged in research related to production of oil from oil shale, carbon dioxide enhanced oil recovery and sequestration, heavy oil production, and flow assurance apart from unconventional gas production.

Dr. Deo has developed a strong oil and gas enhanced oil recovery and reservoir engineering research program at the University of Utah. An important milestone in this program was the establishment of the Petroleum Research Center as one of the State Centers of Excellence. He has also established a computational component with focus on fractured reservoirs and discrete-fracture models, including a series of multi-phase, finite element discrete-fracture models as an alternative to dual-porosity models to help better understand and manage fractured reservoirs.

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Research Interests

- Effect of the presence of kerogen and confinement on PVT properties of liquids in shales
- Thermodynamic modeling of fractionation of oil through kerogen-absorbed and free oil
- Enhanced recovery through CO_2 sequestration in shales
- Reservoir characterization and simulations
- Basin and petroleum systems modeling
- Big data and data-driven modeling

Manas Pathak spent three years as a Graduate Research Assistant and EGI Fellowship recipient working closely with EGI Affiliate Scientist and Professor and Chair of the Department of Chemical Engineering at the University of Utah, Dr. Milind Deo, before beginning a career at Hewlett Packaard in California in 2017. At EGI Manas examined the interaction between kerogen and formation fluids and its importance in predicting the Pressure-Volume-Temperature properties of oils. His research established the presence of two phases of oil in shales, absorbed and free oil. His thermodynamic models predicted the retention of oil in the matured kerogen within the shales. He also investigated enhanced recovery through CO_2 sequestration in shales. His regional and basin expertise includes major US shale play basins, onshore Netherlands and the North Sea, and onshore and offshore Myanmar.

Manas receivedthe prestigious STAR scholarship from the Society of Petroleum Engineers and the INSPIRE Scholarship awarded by the government of India. He received his Master of Science and Technology (Applied Geology) in 2013 from the Indian School of Mines and completed a Ph.D. in Chemical Engineering at the University of Utah. Manas has delivered several well accepted talks in different conferences hosted by SPE, AAPG, SEG and EAGE. He has served as vice president for the student chapter of SPE and president for student chapter of A&WMA at the University of Utah. He is member of Society of Petroleum Engineers, American Association of Petroleum Geologist, European Association of Geoscientists and Engineers.

Selected Publications

- Pathak M., Panja P., Huang H., Deo M.D., Enhanced Recovery in Shales: Molecular investigation of CO2 energized fluid for re-fracturing shale formation in URTeC 2016
- Panja P., Pathak M., Guachalla R.V., Deo M.D., Least Square Support Vector Machine: An Emerging Tool for Data Analysis in SPE Low Permeability Symposium, 2016
- Pathak, M., Pawar, G., Huang, H., & Deo, M. D. Carbon Dioxide Sequestration and Hydrocarbons Recovery in the Gas Rich Shales: An Insight from the Molecular Dynamics Simulations. Carbon Management Technology Conference. (2015, November 17), Woodlands TX. doi:10.7122/439481-MS
- Pathak, M., Deo, M. D., Panja, P., & Levey, R. A., The Effect of Kerogen-Hydrocarbons Interaction on the PVT Properties in Liquid Rich Shale Plays. Society of Petroleum Engineers Unconventional Resources Conference, Calgary, Canada (2015, October 20), doi:10.2118/175905-MS
- Pathak M., Deo M., Levey R., Examination of the Generation of Overpressure in Eagle Ford. 65th Annual Convention Gulf Coast Association of Geological Societies,September 20-22, 2015, Houston, USA

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