**Attachment A**

**Work Statement**

**Unconventional Reservoir Engineering Project**

**(UREP)**

**Phase 4**

**March 1, 2019 – April 30, 2021**

**Summary**

Phase 4 of the UREP Consortium will start on March 1, 2019 and span through April 30, 2021. The UREP Advisory Board (AB) meeting to be held on Nov. 9, 2018 in Golden, Colorado will serve as the final meeting of Phase 3 and kick-off meeting of Phase 4.

The general objective of UREP is to improve the understanding of tight unconventional reservoirs and develop more appropriate reservoir engineering tools and practices for these reservoirs. In Phase 4, we will build on the fundamentals established during the earlier phases of the consortium and focus on converting our research findings into technology to develop improved reservoirs models that honor the physics of flow in fractured nanoporous media, improve predictive capabilities of reservoir engineering tools, increase recovery factors from unconventional reservoirs, and propose EOR methods based on the understanding of mechanisms stranding hydrocarbons in unconventional reservoir. The membership fee for Phase 4 is $50,000/year, with two-year commitment. This work statement outlines the research objectives and time schedule of Phase 4.

**Background**

The UREP consortium was established in 2012 to focus on reservoir engineering aspects of tight, unconventional oil and natural gas reservoirs. Currently, the Consortium has completed its Phase 3 (each phase is two years) and is starting Phase 4. The general objective of UREP is to achieve a more complete reservoir engineering understanding and develop more appropriate reservoir engineering tools and practices for these reservoirs. This objective covers the entire spectrum of reservoir engineering research of nanoporous, fractured, unconventional formations. Under scrutiny are the discerning physical characteristics, phase-behavior, capillary-pressure and surface-forces in pore confinement, non-Darcy flow mechanisms and anomalous diffusion, and fluid exchange mechanisms between fractures and the rock matrix. Development of reservoir models, analysis techniques, and prediction tools are also part of the research spectrum. For management purposes, during the first three phases, the research focus of the Consortium was divided into five project areas outlined in Table 1. Because of the completion of some of the original tasks, emergence of new focus areas, and the shifts in the priorities of the Consortium members, the original project areas in Table 1 are no longer descriptive of the current research focus of the Consortium. Therefore, we redefine the focus areas of Phase 4 in the next section.

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| **TABLE 1 – UREP Projects and Objectives for Phases 1 – 3** | |
| **RESEARCH FOCUS** | **OBJECTIVES** |
| **PROJECT 1**  Flow and Transport of Hydrocarbon Fluids in Nano-Porous Reservoirs | Develop a more comprehensive understanding and perception of flow and transport in nanoporous reservoir rocks to form the basis of unconventional reservoir engineering tools and practices. Understand mechanisms associated with n-pore size environments |
| **PROJECT 2**  Fluid Transfer Between Nano-Porous Matrix and Multi-Scale Fractures | Define the interface conditions and fluid transfer mechanisms between nanoporous matrix and fractures to more realistically account for the contribution of ultra-tight, unconventional rock matrix |
| **PROJECT 3**  Production from Tight, Fractured Formations in Close Proximity of Source Rocks (Liquid-Rich Reservoirs) | Define and model the support of source rocks on production from contiguous fractured formations for the analysis and prediction of production from liquids-rich reservoirs |
| **PROJECT 4**  Simulation of Flow and Transport in Fractured Nano-Porous Reservoirs | Progressively incorporate the results of the UREP research projects and new findings into a numerical unconventional-reservoir simulator developed by NITEC |
| **PROJECT 5**  Analysis and Prediction of Well Performance in Unconventional Reservoirs | Develop and improve models and interpretation methods for pressure- and rate-transient data and long-term production performance to help reservoir management |

**Objectives and Scope**

The focus of Phases 1 and 2 was mainly conceptual and mathematical and experimental modeling were used to substantiate theoretical findings. While continuing the development of genuine physical concepts, fundamental constitutive relations and new flow models, Phase 3 also put emphasis on experimental modeling and verification, molecular modeling, understanding mechanisms that strand fluids in nanopores, potential of improving recovery from unconventional reservoirs, and converting research findings to engineering tools and guidelines. Phase 4 will continue on these tasks and focus on upscaling techniques, anomalous diffusion as a means of upscaling, DFIT modeling and analysis, hindered transport, and EOR technologies. Research tasks of Phase 4 are outlined in Table 2.

Tasks and deliverables of each project area will be reconsidered based on the level of funding (which is determined by the number of consortium members) at the AB meetings to be held bi-annually. Depending on the level of completion of the active projects and the volume of funding available, extensions of the active projects will be proposed and new projects will be initiated at the AB meetings.

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| **TABLE 2 – UREP Projects and Objectives in Phase 4** | | | | |
| **RESEARCH FOCUS** | **OBJECTIVES** | **RESEARCH ITEMS (ALL POSSIBILITIES)** | **PHASE 4 TASKS** | **FUTURE** |
| **PROJECT 1**  **State of Hydrocarbon Fluids in Nano-Porous Reservoirs** | Develop comprehensive understanding and perception of state of hydrocarbon fluids in nanoporous reservoir rocks. Form the basis of predicting fluid saturations and estimating unconventional reservoir recovery factors | * Molecular dynamics (MD) simulation of state of gases and liquids – adsorption, density distribution, composition distribution, etc. * Modeling of MD results – averaged over single pores and over multiple pores * Experimental verification? We have a device that can measure gas-in-place. * MD simulation of phase behavior in nanopores * Modeling of phase behavior * Measurement of phase behavior * Multiphase (≥3) flash calculations | * Review the state of knowledge * MD simulation of gas (pure and mixture) in single pore and in multiple pores * Measure gas-in-place for comparison * Multiphase flash models of vapor-liquid-adsorption equilibrium (equilibrium data obtained through molecular simulations) * Multiphase flash models for pore networks of different sizes | * Review the state of knowledge * MD simulation of phase transition (pure and mixture) * Modeling of phase transition * Experimental verification * Measurement of liquid-in-place |
| **PROJECT 2**  **Flow and Transport of Hydrocarbon Fluids in Nano-Porous Reservoirs** | Develop comprehensive understanding and perception of flow and transport in fractured nanoporous reservoir rocks. Form the basis of unconventional reservoir engineering | * Compositional changes during gas / liquid transport through nanopores * Supporting MD simulations * Supporting (continuum-scale) models * Characterization of diffusion * Anomalous-diffusion in tight, fractured, unconventional reservoirs | * Measure component separation during liquid transport * Measure component separation during gas transport * Numerical 2D and 3D modeling of multi-phase anomalous diffusion * MD simulations to predict anomalous diffusion coefficient | * Support observations with MD simulations? * Develop continuum-scale models * Characterization of diffusion * Relate anomalous diffusion parameters to petrophysical characteristics |

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| **TABLE 2 (Continued-1) – UREP Projects and Objectives in Phase 4** | | | | |
| **RESEARCH FOCUS** | **OBJECTIVES** | **RESEARCH ITEMS (ALL POSSIBILITIES)** | **PHASE 4 TASKS** | **FUTURE** |
| **PROJECT 3**  **Enhancing Flow and Transport in Nano-Porous Reservoirs** | Develop understanding of mechanisms stranding fluids in nanoporous reservoir rocks. Form the basis of EOR technologies in unconventional reservoirs | * Fluid entrapment mechanisms in unconventional reservoirs * Hindered transport in nanoporous formations * Selective adsorption * Mechanical entrapment, steric hindrance, filtration * Wettability, capillary effects, surface forces, and osmotic pressure * Effects of pore size heterogeneity * Gas injection EOR * EOR screening for unconventional reservoirs | * Hindered transport model for tight unconventional reservoirs * Experiments to measure filtration efficiency & verification of theoretical calculations * Detection of compositional differences across mini-cores / filters * Gas injection EOR to reduce filtration in tight unconventional reservoirs * MD simulations of CO2 EOR | * Compositional model of hindered transport in fractured nano-porous reservoirs * Simulation of gas injection EOR * Screening criteria for EOR applications in unconventional reservoirs * Well spacing and optimization of injection and soaking periods * CO2 sequestration and EOR |
| **PROJECT 4**  **Upscaling and Integration with Simulations** | Progressively incorporate the results of the UREP research projects and new findings into the numerical unconventional-reservoir simulator (COZSim-UREP). Form the basis of upscaling pore-scale physical understanding to field scale production | * Multiphase flash models * Hindered transport * Anomalous diffusion | * Multiphase flash models | * Hindered transport * Anomalous diffusion |

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| **TABLE 2 (Continued-2) – UREP Projects and Objectives in Phase 4** | | | | |
| **RESEARCH FOCUS** | **OBJECTIVES** | **RESEARCH ITEMS (ALL POSSIBILITIES)** | **PHASE 4 TASKS** | **FUTURE** |
| **PROJECT 5**  **Analysis and Prediction of Well Performance in Unconventional Reservoirs** | Develop and improve models and interpretation methods for pressure- and rate-transient data and long-term production performance to help reservoir management | * Anomalous-diffusion models * Multi-well interference * DFIT * Applications of machine learning and big data | * Anomalous diffusion models for variable bottomhole pressure and rate conditions * Multi-well interference model for fractured horizontal wells under variable rate-variable pressure production * Improved DFIT model & analysis * Applications of big data analytics | * Effect of finite-conductivity and skin on interference test * Applications of machine learning |

**Experimental Program**

Our experimental program is intended to grow in Phase 3 to support the characterization, measurement, and tool-development objectives of the project. Three groups of experimental studies are planned: PVT experiments, core measurements, and filtration experiments

**PVT Experiments:**

The expansion of the nanofluidics laboratory established during Phases 1, 2, and 3 will continue in Phase 4. The objective of the experimental study in the previous phases was to make direct observations of phase change of confined hydrocarbon fluids inside nano-fluidic chips. In the experiments, 99.99% pure propane gas was pumped into the micro/nano-fluidic chips and condensation sequence was observed (first in the nano-channels and then in the micro channels) as a proof of concept. The objective of Phase 4 PVT studies is to accurately measure the condensation pressure and temperature to compare with the theoretical results, such as Kelvin’s equation and the correlations developed in the previous phases based on equilibrium thermodynamics. However, because the measurement of pressures in nano-channels is currently not possible, a new approach utilizing the reflection of laser beam will be developed and a new measurement system will be set up. Improved accuracy of pressure and temperature readings will also help us switch our focus from the parallel orientation to more-realistic, random patterns of nano-channels as condensation happens first at the intersections of the nano-channels at lower pressures.

**Core Measurements:**

Our results so far and the published literature on the subject clearly indicate that phase behavior in nanoporous media is a function of pore-size distribution, or in general, petrophysical heterogeneity at nano-scale. Adding the influence of the forces exerted by the complex mineralogical composition of the pore surfaces, need for making the phase behavior measurements in actual core samples comes out as a necessity. Core characterization of phase behavior may also serve as a first approximation to the upscaling of nano-pore phase behavior data for flow equations. In Phase 3, we presented a new experimental method that measures gas-core interactions from changes in frequencies of oscillations. Our results demonstrated that the gas-in-place could be successfully measured over a conventional Berea core, and phase change inside a nanoporous core could be detected. This experimental study will continue into Phase 4, and the focus will be to measure gas-core interactions in nanoporous media.

**Filtration Experiments:**

In Phases 1 and 2, we have noted the membrane properties of nanoporous media and defined the filtration efficiency theoretically (by the analogy to osmosis and using equilibrium thermodynamics). This concept indicates that if two pores are connected by a nano-size throat and a pressure gradient is applied, the molecules which can easily pass through these pores will be the smallest ones and the larger ones will be obscured. This steric hindrance of larger molecules explains why we produce light fluids at the surface from unconventional reservoirs.

We have been working on the definition and computation of filtration efficiency as a function of pressure and temperature. In Phase 3, we have developed two sets of tools / procedures; one for miniaturized cores and another for membranes, to experimentally determine the compositional changes in hydrocarbon fluids as they pass the “filters”. In both core experiments and membrane experiments, compositional changes were noted. These studies will be continued and extended in Phase 4. First, we will collect more data to better understand the mechanisms that lead to compositional separation, paving way to the development of a compositional flow model. Second, we will use these experiments to explore thermal and chemical procedures to improve rate of flow so that field production can be enhanced or optimized.

**Modeling Studies**

Our efforts to incorporate the research findings of UREP into COZSim will continue in Phase 4. Most of the phase behavior results obtained so far have been included in COZSim together with n-porosity capability, which enhances our ability to study realistic heterogeneities (such as layers and regions of varying properties). However, the interface lacks some of the capabilities to print and plot the results of some complex cases. We will focus on making the interface more user friendly while continuing the improvement of COZSim by including the new research finding.

Another modeling study will concentrate on the demonstration of filtration in nanoporous media. This will be a 1D, two-phase, compositional model including the effects of pressure and concentration driven fluxes coupled with filtration. The model will serve as a testing medium for the effects of pressure, temperature, and chemicals on the recovery from nanoporous media.

In Phase 2, we developed a one dimensional, two-phase, numerical anomalous diffusion model for heterogeneous, nanoporous media. In this model, a fractional form of Darcy’s law, which incorporates the non-local and hereditary nature of flow, was coupled with the classical mass conservation equation to derive a fractional diffusion equation in space and time. We will enhance this model to be used in the upscaling studies as it provides a means of transferring petrophysical heterogeneity to velocity-field heterogeneity.

In Phase 3, we continued developments of complex phase behavior models. These models considered capillary forces, pore size distributions, and wettability heterogeneities, and they can be used effectively as a single-cell reservoir simulator to describe changes in fluid properties and saturations in pressure depletion. We also developed phase behavior models that are capable of solving the equilibriums of multiple (≥3) phases. Such models are valuable for nanoporous media, because 1) there is often an adsorbed phase, the composition of which is different from vapor and liquid phases, and 2) fluids stored in pores of different sizes often have different compositions, and heavier components have preference toward pores of smaller sizes. The n-porosity capability of COZSim may be used to describe these phenomena. In Phase 4, we will continue to develop our multiphase flash models, and our activities will focus on 1) using molecular simulation data to establish equilibrium ratios; and 2) integration of n-phase flash with n-porosity simulator.

**Advisory Board Meetings**

There will be bi-annual AB meetings in the spring and the fall. The AB meetings for Phase 4 of UREP have been tentatively scheduled on

Fall 2018 AB Meeting: Nov. 9, 2018

Spring 2019 AB Meeting: May 3, 2019

Fall 2019 AB Meeting: Nov. 8, 2019

Spring 2020 AB Meeting: May 1, 2020

Fall 2020 AB Meeting: Nov. 6, 2020.

**Membership Fee**

The membership fee is $50,000/year with two-year commitment. The payment schedule for the membership fee is as follows:

Payment for Year 1: Due by March 15, 2019

Payment for Year 2: Due by March 13, 2020