Joint Industry Project: Sustainable Hydrocarbon Recovery in Unconventional Reservoirs

Thrust Area 2: Hydraulic Fracturing of Shale Reservoirs

The University of Kansas’ (KU) Chemical and Petroleum Engineering (C&PE), Tertiary Oil Recovery Program (TORP) and Civil, Environmental, Architectural Engineering Department (CEAE), and the Kansas Geological Survey have started a collaborative work dedicated to developing novel hydraulic fracturing proppants, fluids, and propagation models. Part of this investigation will focus on reuse of produced water to prepare hydraulic fracturing fluids.

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Team: Graduate research assistant (1), undergraduate research assistant (1), field liaison engineer (1)

Projects

1. **Nano-proppants for hydraulic fracturing of hydrocarbon-bearing shale reservoirs**

Development of nano-proppants capable of packing micro-fractures and preventing fluid loss in order to improve both effective fracture length and productivity of fractured wells is the main objective of this focus area. Size, nano-hardness, reduced elastic modulus, fluid loss prevention capabilities as well as their induced fracture conductivity by a currently known waste product show potential for development of a novel nanopropellant system. KU researchers will collaborate with other JIP partners to improve this system to serve the needs of the industry.

2. **Effects of produced water composition on fracturing fluid efficacy**

Identifying the levels below which chemical contaminants need to be reduced in order for companies to reuse produced and flow-back water is the objective of this focus area. Effect of produced water composition on formulation, rheological properties, and fracture propagation and cleanup parameters is being investigated by KU researchers. Moreover, identifying regional fluid properties and chemical composition for formations of interest is an essential first step in understanding of fracturing fluid efficacy. Mapping of water compositions, understanding thermodynamic equilibrium conditions and saturations, etc. will help to identify resource base for a reuse of flow-back water.
3. **Hydraulic fracture cleanup improvement: modeling and experimental**

Productivity of induced hydraulic fractures is a function of fracture conductivity. Cleanup of fracturing fluids from hydraulic fractures has been improved using polyelectrolyte complex nanoparticle systems with dual applications of fluid loss prevention and delay release of enzyme breakers. Simulation studies have been applied and effects of fracture cleanup, water blockage, and fracture properties on productivity were studied. Further applications of this system for fracture cleanup applications are currently being studied.

4. **Fracture propagation in ultra-tight unconventional reservoirs**

The objective of this project is to optimize the production from shale reservoirs by characterizing the hydraulic fracture propagation using experimental and computer simulation techniques. Tri-axial compression tests will be applied to measured parameters like Young’s modulus, Poisson’s ratio, poro-elastic coefficient and friction angle for shale samples. Hydraulic fracture propagation simulation will be applied to generate hydraulic fractures connected to vertical and horizontal wells using the porosity, permeability, rock mechanics parameters and fluid loss results gathered in the previous phases of the project.

5. **Nanoparticle-stabilized CO₂-foam as fracturing fluid**

A nanoparticle system is applied to optimize the performance of fluid loss and fracture cleanup properties of CO₂-foam as fracturing fluid. Different charged polymers and nanoparticles will be used to optimize the performance of such fluids.

**Benefits to industry**

- Strong track record with industry-focused research.
- Access to faculty and researchers who are experts in their fields.
- Opportunity to meet students actively engaged in research, trained from a solid community of faculty that have industry training and value industry sponsored projects.
- Extensive experience working with Kansas-area producers to perform field tests.
- Fully equipped laboratories.

**Experience**

By bringing together C&PE and CEAE faculty members as well as TORP and KGS researchers, KU has created a cross-disciplinary team that understands the geology of unconventional reservoirs, water quality issues and the engineering needs of the oil and gas industry.

The project team includes C&PE, CEAE, TORP, and KGS researchers and faculty members with extensive experience in the areas of hydraulic fracturing fluids, fracture cleanup and fracture propagation. Specific areas of expertise include:

- Reservoir stimulation expertise in the areas of fracture conductivity, fluid loss, shear loop studies under wellbore and fracture conditions, HPHT rheology, foam rheology, acid fracturing and matrix acidizing.
• Regional, field, and reservoir scale characterization, including petrophysics, water and rock geochemistry, reservoir properties, geomechanics
• Characterization of reservoir structural elements, natural fractures, and geomechanical regional and local stress-field analysis
• Fracture cleanup and propagation
• Application of nanoparticles to improve conductivity of hydraulically-induced fractures

With an experienced crew in serving the needs of the oil and gas industry in Kansas and beyond, performing research in the lab with close ties to the field application is the main goal of our researchers. Our abilities in responding to the need of oil and gas industry have resulted in several successful field trials in the past.

Key Personnel

Dr. Reza Barati, the Principal Investigator, is a Petroleum Engineering Assistant Professor in the Department of Chemical and Petroleum Engineering (C&PE) at the University of Kansas (KU). Reza is experienced in managing successful research projects that have been conducted in conjunction with industry and the Society of Petroleum Engineers (SPE). He managed two industry projects in the area of core characterization and chemical flooding of the Minnelusa formation while working at the Enhanced Oil Recovery Institute (EORI) in Wyoming as a member of the Minnelusa Consortium. He has been the PI of several projects funded by SPE, Kansas Interdisciplinary Consortium (KICC), and independent operators since he started his new position at KU.

Dr. Anil Misra, a Co-Principal Investigator, is an environmental engineering professor in the Department of Civil, Environmental, and Architectural Engineering at KU. He has more than 25 years of experience researching geomaterials. Dr. Misra has co-edited three books; guest edited two journal special issues, and authored more than 200 papers in journals, edited books and conference proceedings. He has made more than 100 presentations of his research results at national and international forums. His research has been funded by a variety of sources including governmental agencies and private industry and received 29 research grants from different institutions. Dr. Misra is well recognized for his work on the micromechanics of granular geomaterials and discrete bodies with interfaces. He has developed the granular micromechanics approaches to bridge the discrete and continuum scales for geomaterials.

Dr. Jyun-Syung Tsau, a Co-Principal Investigator, is an Associate Scientist and Director of CO2 Flooding & Sequestration/Reservoir Management & Simulation for the Tertiary Oil Recovery Program at the University of Kansas (KU). He has twenty-plus years of experience in conducting research on oil recovery techniques and has worked on projects related to CO2 miscible/near miscible injection, CO2 foam for mobility control, and reservoir simulation. He has a record of successfully conducting research projects for the Department of Energy and other agencies. His research interests are in carbon dioxide application for IOR in conventional and unconventional plays, phase behavior, foam mobility control/stimulation and numerical simulation.
Dr. Tandis Bidgoli, has contributed to a number of industry projects as a structural geologist for ExxonMobil. She has also participated in several externally funded research projects focused on faults in Nevada. She recently joined the KGS (January 2014), but brings significant petroleum geology and structural analysis expertise to the project. Tandis serves as a Co-Investigator for several DOE sponsored projects at KGS.

Mr. Mark Ballard, a Co-Investigator, is currently the Field Liaison at the Tertiary Oil Recovery Program (TORP) at the University of Kansas. He acts to move the research performed at TORP out into the field to benefit the independent crude oil producers. He has 12 years of experience as a Petroleum Engineer with field experience in crude oil production, design & implementation of waterflood projects, and economic analysis of oil producing properties. Mr. Ballard also has over 25 years of business management experience. He has a B.S. in Petroleum Engineering and an MBA.

Mr. Yevhen Holubnyak, a Co-Investigator, is a Petroleum Engineer at Kansas Geological Survey (KGS) at the University of Kansas (KU). Yevhen managed and worked on numerous projects which were performed in conjunction with Department of Energy (DOE) and industry partners, for instance, he managed Sourcing of Bakken Reservoirs study and performed reservoir modeling and characterization on several CO2 Enhanced Oil Recovery projects while working at Energy and Environmental Research Center in North Dakota. Currently, Yevhen is a Co-Investigator for several DOE sponsored projects at KGS.

Facilities

Barati (PI)’s lab (800 sq. ft, 4101A Learned Hall) is equipped with a high pressure, high temperature (HPHT) CO2 flooding setup designated for temperature of up to 100 °C and pressures of up to 3000 psi. Moreover, this lab is equipped with a core-flooding setup that is designed for temperatures up to 50 °C temperature and 2500 psi pressure that has been used for both steady state and unsteady state relative permeability measurements as well as for other applications. The PI’s lab is also equipped with a HPHT IFT and contact angle measurement setup, a HPHT rheometer (300 °C and 5800 psi) used for both fracturing fluids and CO2 foam rheological measurements, a Dean-Stark core cleaning setup, a high performance computer that is equipped with 12 cores, 48 GB of RAM and high performance graphics card for simulation of large scale reservoirs, a hydraulic fracture and acid fracture conductivity setup, and a hydraulic press and a core holder are available for stress-strain relation measurements. A fully equipped Dynamic Fluid Loss setup was recently donated to the Unconventional Resources Lab. This setup includes a fluid preparation unit, two shear loops, an oil bath, and three fluid loss cells. Schlumberger donated five licenses of Ocean, PetroMod, PipeSim, Techlog, Eclipse and Petrel software with all their modules and maintenance packages to his lab (worth approximately 27 million dollars). Barati’s lab is closely collaborating with other research groups both on campus and in other domestic and international universities.

Misra’s Research Group is equipped with the following instrument and software capabilities:

The major equipment relevant to this thrust area are listed below. This equipment identified as 1-7 is available in
the Bioengineering Research Center:

(1) CHEMICAL IMAGING AND ANALYSIS - Perkin Elmer Spectrum 400 FTIR spectrometer and Spotlight 400 FTIR microscope equipped with two temperature stabilized fast-recovery deuterated triglycine sulphate detectors (optimized for Mid-IR and NIR) and Pike Heated Diamond GladiATR accessory with the capability of transmission, reflectance and ATR imaging using array detector with pixel resolution at 1.56 micron. Jobin Yvon LabRam ARAMIS Micro-Raman microscope – an integrated fully automated confocal Raman imaging system equipped with 2 sources of internal laser excitation (HeNe: 632.8nm Diode: 785nm), a full range of objectives (dry lens 10x, 20x, 50x, 100x; long-working distance lens 20x, 50x, water immersion lens 60x and 100x), polarization analyzer and a computer-controlled heating/cooling stage (temperature range -196 oC to 600 oC). Also available are high sensitivity UV/vis spectrophotometer (Agilent 8453), a Viscotek SEC system with static laser light scattering, and micro- and nanoparticle characterization equipment including a Multisizer III (Beckman Coulter).

(2) ACOUSTIC/ULTRASONIC - C-SAM Gen 5 system Scanning Acoustic Microscopes (SAM) – with a set of 4 high precision acoustic lenses: 15, 30, 100 and 230 MHz providing a resolution of ~2 micron. The acoustics lab is also equipped with Tektronix TDS5104 Digital Oscilloscope (1 GHz, 4 Channel), GE-Panametrics 5900 Pulser Receiver (200 MHz) and several paired sets of transducers.

(3) NANOMECHANICAL/STRUCTURE - Digital Instruments Multimode V Atomic Force Microscope/with Hysitron TS 75 TriboScope – includes HarmoniX™ nanoscale material property mapping, fluid imaging cells for contact mode and TappingMode AFM imaging in fluid environments, nanoindentation with property mapping, nanoDMA™ and scratch testing. Veeco Wyko NT 1100 Optical Profiler – non- contact surface metrology for sub-nanometer roughness to millimeter- high steps

(4) THERMAL ANALYSIS - TA Instruments Q200 Differential Scanning Calorimeter (DSC) – for differentiating the heat flow from the heat capacity(reversible) effect that usually comes from glass transition relaxation or crystal melting; and the heat flow from the non-heat capacity(non-reversible) effect that usually comes from enthalpic relaxation or cold crystallization. TA Instruments Q5000 Sorption Analyzer (SA) – for sorption analysis of materials under controlled conditions of temperature and relative humidity (RH). PekinElmer PYRIS 1 Thermogravimetric Analyzer (TGA) – can work on a large range of temperature: from sub ambient to 1000 °C for the detection of phenomena at room temperature.

(5) MECHANICAL ANALYSIS - TA Instruments Q800 Dynamic Mechanical Analyzer (DMA) – for tensile, compressive, and bending tests in both dry and wet (submerged) controlled temperature conditions. Bose ElestroForce 3300 Mechanical Analyzer – for tensile, compressive, bending and torsion testing under dynamic and static load over large frequency range in dry and submerged conditions. Q-sense E4-Auto Quartz Crystal Microbalance with Dissipation monitoring (QCM-D) – for real-time studies of molecular events as the mass and viscoelastic properties of molecular layers change on the sensor surface.

(6) MORPHOLOGY/STRUCTURE - Xradia MicroXCT Tomographic X-Ray Microscope – with a pixel resolution of about 0.3 mm has the highest performance of any commercially available x-ray detector. Optical Digital Image Capture System - Nikon LV100DU brightfield, darkfield episcopic/diascopic microscope equipped with CFI LU Plan Fluor EPI objectives and Plan Apo 100x Oil objectives.

(7) SPECIMEN PRAPARATION FACILITY – includes Leica SM2500 heavy duty sectioning microtome IsoMet 1000 Precision Saw, EcoMet 3000 Grinder/Polisher, and Leica CM1950 Cryostat. Additionally, area for histology is equipped with a basic microscope, a cryostat (Microm HM550 OMP), a precision diamond saw (Buehler Isomet 1000) and a microtome (Microm HM 355).

In addition to the above equipment, the following is available through central facilities:

(1) NMR facilities in the KU NMR Laboratory includes Bruker Avance 800 MHz instrument with a cold probe (cryoprobe) and a 4-channel Varian Inova 600 MHz system suitable for 2-, 3- and 4-dimensional experiments for ligand and protein-detected solution structure analysis.

(2) KU Microscopy and Electronic Imaging Laboratory has LEO 1550 field emission scanning electron microscope with EDAX and backscatter capability and 200 kV HRTEM system that includes cryo-imaging capabilities, STEM, EDAX and HAADF.

(3) Abaqus FE software and capabilities of developing our own Geomechanical analyses are also available.

TORP’s research facilities occupy approximately 4,000 sq. ft. TORP’s laboratories are equipped to perform many aspects of oil recovery research, including analytical instruments specific to oil and gas research and anaerobic chambers for oxygen-free studies. Combined, these labs are equipped with the following instrumentation:

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