

Report

Project title: Beneficial use of petroleum produced water to convert crude oil to methane gas in depleted oil reservoirs

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Sponsor: Oklahoma Water Resources Center and Oklahoma State University VPR Office (FY2019 annual program)

Reporting period: March 1, 2019 to February 29, 2020

Synopsis: This research project was to prove the feasibility of enhancing the recovery of residual crude oil from depleted oil reservoirs by stimulating the in-situ microbial conversion of crude oil and carbon dioxide to methane gas. The proposed method to stimulate the in-situ microbial conversion of crude oil and carbon dioxide to methane gas consisted of the alternate injection of petroleum produced water supplied with protein-rich matter and carbon dioxide emitted from power plants. This research project included both experimental and computational work. Experimental work was to prove that the availability of protein-rich matter and carbon dioxide stimulates the activity of indigenous methanogenic microbial communities. Experiments were conducted at both ambient and reservoir pressure conditions using petroleum produced waters and crude oil collected from the Stillwater and Cushing oil fields in Oklahoma. Computational work was to develop a new TOUGHREACT multiphase reactive transport module we called CO2Bio. TOUGHREACT-CO2Bio can simulate physical, chemical, and microbiological fate of carbon dioxide in depleted oil reservoirs under biotic conditions. The intended use of TOUGHREACT-CO2Bio is to design of injection schemes of petroleum produced water supplied with protein-rich matter and carbon dioxide into depleted oil reservoirs to optimize the recovery of residual crude oil in the form of methane gas.

Primary findings and impact: Most relevant findings from the conducted experimental work are: 1) the availability of protein-rich matter along with a reduction of pH due to the dissolution of carbon dioxide into the formation water stimulates the production of hydrogen from the degradation of crude oil (mostly n-alkanes) by fermentative microbial communities, 2) the availability of carbon dioxide enables the production of methane gas via the reduction pathway of carbon dioxide with hydrogen produced from the degradation of crude oil, and 3) methanogenic degradation of crude oil by the proposed stimulation method results in the biogenic recycling of carbon dioxide to methane gas. Most relevant findings from the conducted computational work are: 1) the alternate injection of petroleum produced water and carbon dioxide results in higher conversion levels of residual oil and carbon dioxide conversion to methane than the simultaneous injection of petroleum produced water and carbon dioxide into a depleted oil reservoir, and 2) the dissolution of carbonate rocks (calcite and dolomite) plays a key role in buffering the acidifying effect of carbon dioxide dissolution into the formation water. The findings of this research will lead to the establishment of an alternative way to make a beneficial use of not only petroleum produced water, but also carbon dioxide emitted from power plants in Oklahoma.

Products: The products of this research project within March 1, 2019 and February 29, 2020 include the following PhD thesis, peer reviewed journal publications, and conference presentations:

PhD Thesis

Beneficial Use of Produced Water and Carbon Dioxide in Depleted Oil Reservoirs: In-Situ Microbial Conversion of Crude Oil to Methane. 2019. <https://shareok.org/handle/11244/321577>

Papers in peer-reviewed journals (*Denotes corresponding author, **Denotes student)

**B. Shabani, J. Pashin, *J. Vilcáez. TOUGHREACT-CO2Bio – A new module to simulate geological carbon storage under biotic conditions (Part 2): The bio-geochemical reactive transport of CO₂-CH₄-H₂-H₂S gas mixtures. Journal of Natural Gas Science and Engineering, Vol. 76, 2020, Article 103190. doi.org/10.1016/j.jngse.2020.103190. (IF 3.859).

**B. Shabani, *J. Vilcáez. TOUGHREACT-CO2Bio – a new module to simulate GCS under biotic conditions (Part 1): the multiphase flow of CO₂-CH₄-H₂-H₂S gas mixtures. Journal of Natural Gas Science and Engineering, Vol. 63, 2019, pp. 85-94. doi.org/10.1016/j.jngse.2019.01.013. (IF 3.859).

Abstracts in conference proceedings (*Denotes corresponding author, ** Denotes student)

*J. Vilcáez, **B. Shabani. Beneficial use of produced water in depleted oil reservoirs: in situ crude oil conversion to methane gas. Geological Society of America (GSA) Annual Meeting 2019. Phoenix, Arizona, USA. September 22-25, 2019. Oral presentation.

*J. Vilcáez, **B. Shabani. Beneficial use of produced water in depleted oil reservoirs: in situ crude oil conversion to methane gas. Geological Society of America (GSA) Annual Meeting 2019. Phoenix, Arizona, USA. September 22-25, 2019. Oral presentation.

Student support: This research grant supported the research of 2 graduate students. One of them successfully defended his PhD dissertation in 2019. He is now a Research Scientist at the Indiana Geological & Water Survey of Indiana University Bloomington.

Notable achievements and awards:

Graduate student: Oklahoma State University Holistic Science Prize