Implications of free phase gas production on enhanced oil recovery

Yuan Zhang[1], Navreet Suri[2], and M. Cathryn Ryan[1]
[1]Department of Geosciences, University of Calgary
[2]Department of Renewable Resources, University of Alberta

Summary

Free phase gas (FPG) i.e., gas bubbles usually forms when the total dissolved gas pressure (P_{TDG}) reaches bubbling pressure. Natural in situ biochemical gas production to the point of FPG production can potentially lead to various implications in the subsurface such as over-pressurization, faulting, well blow-outs, and other geomechanical phenomena (Kelly et al., 1985; Michael and Bachu, 2001; Lei et al., 2017; Li et al 2022). Previous studies reported the potential role of microbial gas production on oil recovery (Marshall, 2008; Sen, 2008; Youssef et al., 2009). 3% oil recovery was achieved in sand pack column within 48 hours incubation with denitrifying bacteria and has shown 200 kPa pressure increase (Nuryadi et al., 2011). Formation of N_2, H_2 and CO_2 by a mixed microbial culture increased the pressure at the top of the well by 150kpa in an oilfield in Russia (Belyaev et al., 2004). This mechanism can induce effective oil recovery, but there is limited study on the impact of increased P_{TDG} and FPG production on oil recovery and many related parameters are yet to be investigated.

This study seeks to demonstrate the impact of in situ biochemical FPG production on enhanced oil recovery by facilitating microbial activities in laboratory microcosms. Further measurements of surface tension, interfacial tension, and zeta potential were studied to understand other impact factors on oil recovery. Atomic Force Microscopy (AFM) analysis was conducted to study the interaction forces between gas bubbles and oil droplets.

Method

Experiments were conducted in customized laboratory testing columns that were packed with 50-70 mesh silica sand and injected with light or heavy oil (Figure 1). These cells were first flooded with CSBK nutrient broth and then inoculated with a mixed solution of denitrifiers (Gassara et al., 2017), acetate and nitrate as substrates to stimulate gas production through denitrification. Total dissolved gas and water pressure (P_{TDG} and P_W; Roy and Ryan, 2013) were monitored in the columns for 21-30 days to evaluate the rate of dissolved gas production, and the point at which bubbling pressure was exceeded, and FPG production was expected. Helium filled serum bottles were attached to the top of the columns via three-way valves and were connected to the columns periodically during incubation.

The supernatant of the microbial culture mixture was separated by centrifuge after incubation. Surface tension and interfacial tension of culture supernatant were measured. CSBK medium was used as a control sample. Zeta potential of gas bubble and oil droplet was measured in CSBK medium and culture supernatant. Interactions forces between gas bubbles and oil droplet were studied through AFM analysis. Oil-coated AFM cantilever tip was driven first approach the gas bubble in the culture supernatant solution and then retracted from the bubble until they are no longer in contact. The movement of cantilever and the corresponding interaction forces were recorded as a function of time.

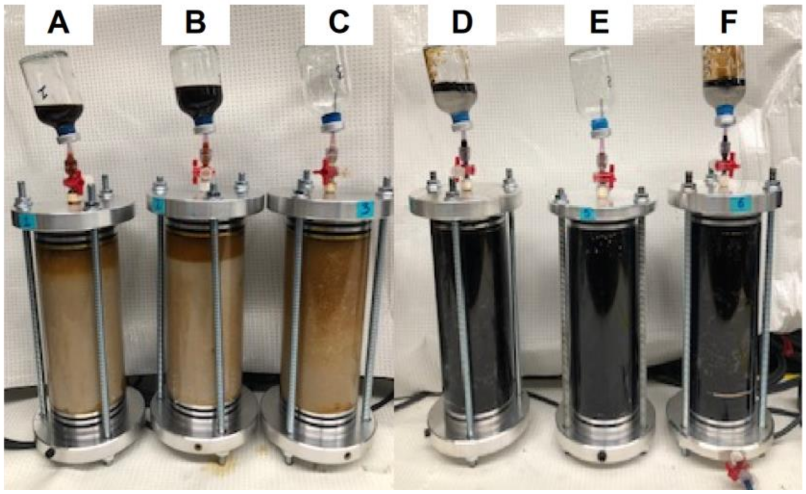

Figure 1 MEOR customized laboratory testing cells. Columns A, B, C were filled with light oil while D, E, F were filled with heavy oil. C and E were the control columns in each category. Effective oil recovery was observed in A, B, D, and F cells.

Results

Both P_W and P_{TDG} started to increase shortly after the inoculation. After 24 hours, P_W and P_{TDG} increased to 154 and 150 kPa respectively from atmospheric pressure (~87 kPa). When the serum bottles connected to the column, there was significant drop of column P_W and P_{TDG} and fluid and free phase gas production in the serum bottles. Gas dissolution reduced oil viscosity, leading to increase of oil mobility (Holm and Josendal, 1974) and creating favorable conditions for subsequent oil recovery. Microbial activities increase the system pressure, leading to the repressurization of the columns. When the pressure was released, the dissolved gas will exsolve to free phase gas based on Henry's Law and induce the oil recovery flow. On average, 56.2 ± 14.2 % residual oil in place (ROIP) was produced from light oil columns A and B and 10.9 ± 1.3 % ROIP was produced in heavy oil columns D and E.

Both surface tension and interfacial tension in culture supernatant were lower than those in CSBK media which indicates the biosurfactant production in the solution and the potential for oil emulsification. The existence of biosurfactant aids to break oil droplets into smaller sizes and increase the wettability of the pathway, contributing to the enhanced oil recovery (Youssef et al., 2009). There was emulsion formation between the culture supernatant and oil as compared to no emulsion formation between CSBK and oil. However, the emulsions were not very stable. Zeta potential of both gas bubble and oil droplets was lower in the culture supernatant comparing to CBSK, which is likely due to the presence of biosurfactant.

In AFM analysis, while the cantilever was approaching gas bubble, weak to strong repulsion was recorded. During retraction, the range of the adhesion force between heavy oil and gas bubbles (1.91nN) was recorded to be wider than that between light oil and gas bubbles (0.21nN). Overall, there was no strong attachment observed during this approach-retraction cycle for both heavy and light oil samples.

Conclusions

This study demonstrated successful enhanced oil recovery through microbial gas production (N_2 and CO_2) in both heavy and light oil samples. The results of the FPG gas drive tests show a difference in recovery efficiency, which is higher in light oil columns comparing to heavy oil columns. The extensive microbial gas production increased P_{TDG} during incubation and FPG production during pressure depletion, serving as a driving force for oil recovery. Moderate biosurfactants were produced contributing to the oil emulsification and enhanced oil recovery.

References

Belyaev, S. S., Borzenkov, I. A., Nazina, T. N., Rozanova, E. P., Glumov, I. F., Ibatullin, R. R., & Ivanov, M. V. (2004). Use of microorganisms in the biotechnology for the enhancement of oil recovery. Microbiology, 73(5), 590-598.

Gassara, F., Suri, N., & Voordouw, G. (2017). Nitrate-mediated microbially enhanced oil recovery (N-MEOR) from model upflow bioreactors. Journal of hazardous materials, 324, 94-99.

Holm, L.W., Josendal, V.A., 1974. Mechanisms of oil displacement by carbon dioxide. Journal of Petroleum Technology 26,1427–1438.

Kelly, W. R., Matisoff, G., & Fisher, J. B. (1985). The effects of a gas well blow out on groundwater chemistry. Environmental Geology and Water Sciences, 7(4), 205-213.

Lei, X., Ma, S., Wang, X., & Su, J. (2017). Fault-valve behaviour and episodic gas flow in overpressured aquifers-evidence from the 2010 MS5. 1 isolated shallow earthquake in Sichuan Basin, China. Progress in Computational Fluid Dynamics, an International Journal, 17(1), 2-12.

Li, C., Zhan, L., & Lu, H. (2022). Mechanisms for Overpressure Development in Marine Sediments. Journal of Marine Science and Engineering, 10(4), 490.

Marshall, S. L. (2008). Fundamental aspects of microbial enhanced oil recovery: A literature survey. National Research Flagships wealth from Oceans.

Michael, K., & Bachu, S. (2001). Fluids and pressure distributions in the foreland-basin succession in the west-central part of the Alberta Basin, Canada: Evidence for permeability barriers and hydrocarbon generation and migration. AAPG bulletin, 85(7), 1231-1252.

Nuryadi, A., Kishita, A., Watanabe, N., Vilcaez, J., & Kawai, N. (2011, September). EOR simulation by in situ nitrogen production via denitrifying bacteria and performance improvement by nitrogen alternating surfactant injection. In SPE Asia Pacific Oil and Gas Conference and Exhibition. OnePetro.

Roy, J. W., & Ryan, M. C. (2013). Effects of unconventional gas development on groundwater: a call for total dissolved gas pressure field measurements. Groundwater, 51(4), 480-482.

Sen, R. (2008). Biotechnology in petroleum recovery: the microbial EOR. Progress in energy and combustion Science, 34(6), 714-724.

Youssef, N., Elshahed, M. S., & McInerney, M. J. (2009). Microbial processes in oil fields: culprits, problems, and opportunities. Advances in applied microbiology, 66, 141-251.