geoconvention
Virtual Event
September 13 - 15 2021

Microbially Enhanced Thermally Engineered Oil Recovery (METEOR) – proof of concept from post-steam cores, outcrops, and laboratory experiments

Milovan Fustic[1,2], Rudy Strobl[3], William D. L. Richardson[2], Emma Bell[2], Carmen Lee[2], Casey Hubert[1]
[1]University of Calgary, [2]Nazarbayev University, [3]Independent Consultant

Summary

Microbially Enhanced Thermally Engineered Oil Recovery (METEOR) is a recently patented technology (Hubert and Fustic, 2021) focused on improving oil recovery, lowering greenhouse gas emissions, and reducing operation costs per barrel of produced oil. Technology is based on promoting the activation of dormant microorganisms that produce gas to increasing pressure and oil production.

Previous studies show that during Steam Assisted Gravity Drainage (SAGD) operations, temperature observation wells and Residual Saturation Tool (RST) logging illustrate the top of the associated steam chamber and the occurrence of gas in conductively heated zones above the steam chamber. Steam chamber growth is commonly delayed or halted at the base of mudstone-dominated inclined heterolithic strata (IHS) where thin low-permeable fine-grained (mudstone) layers of IHS act as barriers for steam growth. Post steam core studies shows that (i) low permeable layers remain active seals for upward migration of the steam over the life cycle of the SAGD production (8-10 years; (Fig. 1); and (ii) bitumen is produced from conductively heated zone via a different production mechanism than emulsion from an expanding steam chamber. While reservoir properties and connectivity remains relatively constant, the production from conductively heated zone can be attributed to:

- Reduced viscosity and associated increased mobility (by conductive heating)
- Additional increase of mobility by occurrence of gas
- Increased pore pressures (by gas and thermal expansion) that provides drive to push mobilized bitumen along inclined mudstone (IHS) surfaces down to an amalgamated steam chamber.

In addition to previous theories about the origin of gas in SAGD reservoirs including gas which is liberated from solution, gas generated by thermal cracking of bitumen, and/or produced by aquathermolysis, decarboxylation, or in-situ coke gasification, we demonstrate that microbially generated gas may make significant contributions.

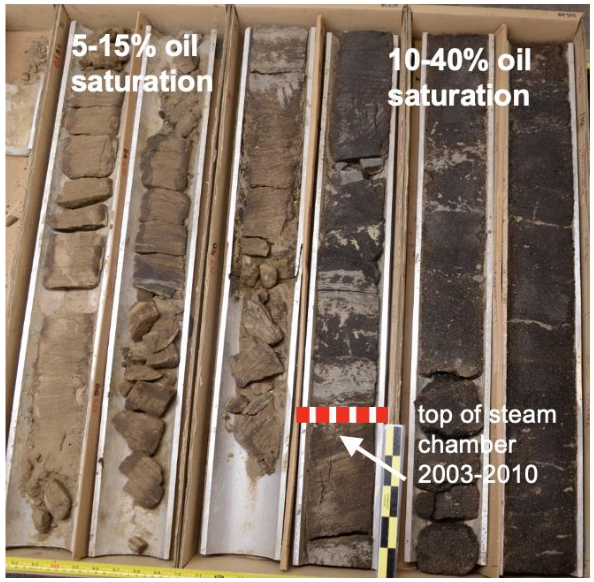

Figure 1. *Post steam core sections from a 4.5 m interval of oil sands spanning the steam chamber (left) and IHS (right). This core corresponds to the conductive heating and logging shown in Fig. 2B, C, for the Christina Lake oil sands SAGD site. The top of the steam chamber is indicated by the red dashed line directly below a grey mudstone barrier above which conductive heating warms the IHS.*

Post steam core studies (Figs. 1-2) shows that gas is present within most if not all IHS bed-sets within the conductively heated zone (30-100C) and that gas occupies the upper most parts of individual sandy intervals (0.1-0.3m thick) immediately below an upper mudstone barrier (muddy IHS laminae), while lower parts of the bed-set remain occupied by bitumen (referred as "shadow effect"). This pattern resembles reservoir configurations with gas at the top and oil below, as observed at the bed-scale (0.1-0.3m thick). Considering that described pattern is reoccurring in stacked IHS bed-sets (up to 15m thick), the most logical interpretation is that gas is formed in-situ, within each bed-set.

The new evidence from post-steam cores (Fig. 2) and Hangingstone River outcrop (Fig. 3) coupled by laboratory experiments and calculations shows that increased temperature activates dormant thermophilic microbes in oil sands reservoirs, which in return produces potentially significant amount of various biogenic gasses that may contribute to total volume of in reservoir occurring free gas. This is also confirmed by mass balance calculations obtained by comparing Dean-Stark results between closely spaced pre-steam and post-steam (i.e. after 8 years of production) cores. The biogenic gas production rates are controlled by temperature, quality of substrate (bitumen) and availability of nutrients. Results of microbiological studies on oil sand samples show strong evidence of increased microbial activities at 50C. These rates can be further increased by additional nutrients that might be injected via a range of different well configurations including conversion of vertical wells and drilling additional horizontal wells (Fig. 2).

Additionally, technology shall allow for developing currently uneconomical thin-pay heavy oil reservoirs worldwide.

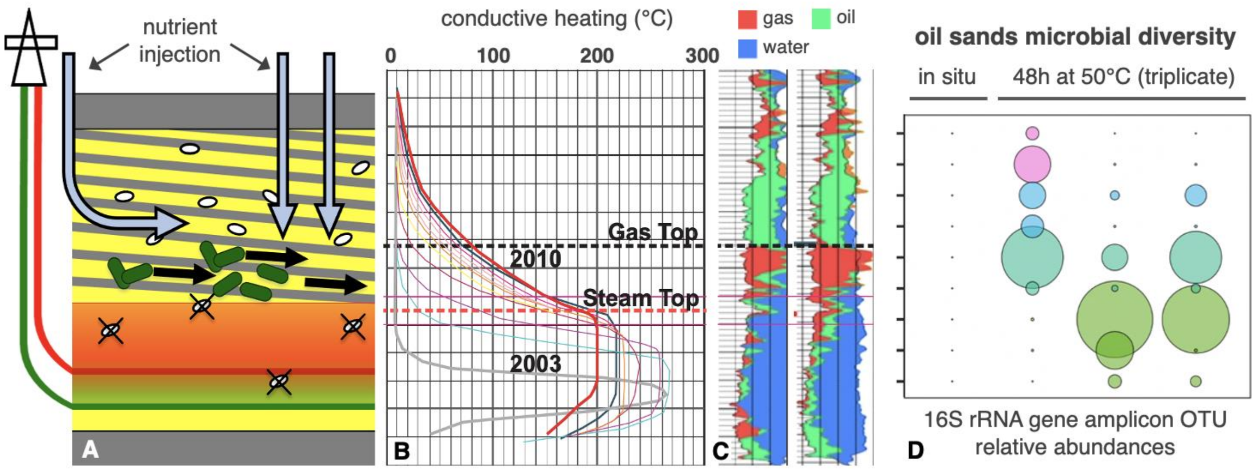

Figure 2. *Oil sands reservoir architecture (A) depicting horizontal wells for steam injection (red) and oil production (green) situated where the steam chamber (bottom shaded area) establishes at the base of the reservoir. SAGD usually consists of 6-8 of these well pairs at each of several well pads in a 1-2 km^2 area (Strobl et al, 2014). IHS of interbedded oil sands (yellow) and mudstone (grey) contain dormant bacterial endospores (white ovals) that are killed by 200°C steam but can germinate into active cells (green rods) during conductive heating. (B) Temperature data from Christina Lake (Cenovus, 2010) collected by thermocouples installed in vertical wells originally drilled for exploration (vertical wells can be repurposed for nutrient addition as shown in A). Comparing 2003 with 2010 demonstrates an enlarging habitable zone for thermophiles during conductive heating of IHS. Dormant thermophiles in oil sands include Geobacillus thermodenitrificans (D: lower left, green circles in 2 out of 3 replicates of oil sands outcrop incubations), which increases from below detection to 60-90% after 48 h at 50°C, showing thermophilic spores are plentiful in oil sands and can be stimulated to germinate. Activating dormant thermophiles to produce biogas (black arrows in A) is proposed to facilitate additional drainage without additional steam injection. Thermophile activation may in fact already contribute to drainage from IHS, given the gas build-up during conductive heating at temperatures <100°C during the first few years of SAGD (panel C shows data collected in 2007 and 2009 from the same Christina Lake site shown in B).*

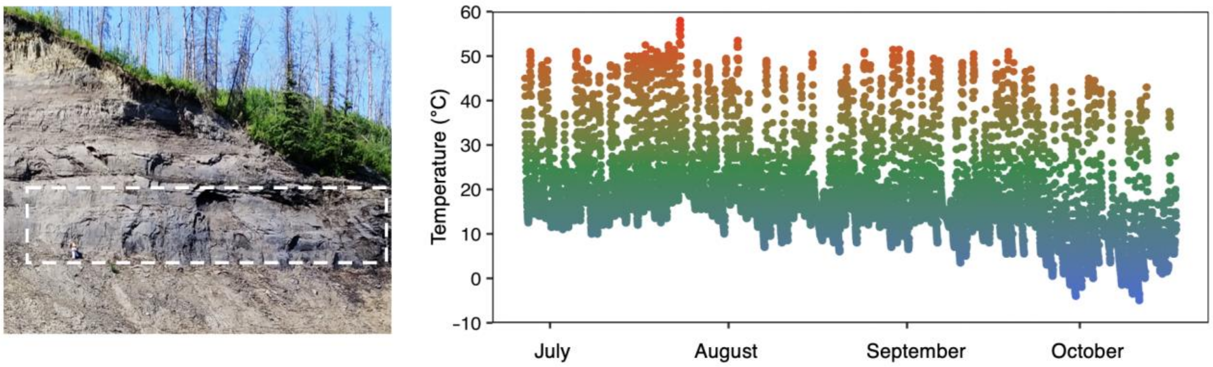

Figure 3. *Oil sands outcrops are easily accessible for large volume sampling. The Hangingstone River outcrop shown here was sampled in 2019, enabling temperature measurements using dataloggers embedded in the outcrop (white dashed line at left) and retrieved 4 months later (Bell, unpublished). Outcrops are tectonically uplifted reservoir intervals. These samples therefore enable proof of concept testing on large-volume reservoir samples. Outcrop surface temperatures close to 60°C correspond with the detection of putative thermophiles like Mahella spp. (Salinas et al, 2004), which exhibits 0.4% relative abundance in 16S rRNA gene amplicon libraries. NovaSeq metagenomics revealed a Mahella genome (96.1% completeness, 1.2% contamination) indicative of thermophilic fermentative metabolism present in 0.1 to 0.7% relative abundance based on CheckM and phyloFlash, respectively (Bell, unpublished).*

Acknowledgements

We thank many colleagues and friends from industry and academia who discussed with us heavy oil reservoir and production issues and provided useful directions for our ongoing research activities.

References

Hubert, C., & Fustic, M. (2021). *U.S. Patent No. 10,920,550*. Washington, DC: U.S. Patent and Trademark Office.