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Editorial

The relevance of microbial processes in geo-energy applications

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The subsurface is a vast reservoir which we exploit in various ways. We extract energy in the form of oil/gas or heat from it. We use it for the storage of energy, e.g., in shallow geothermal applications or for the underground storage of natural gas. A lot of recent research has studied the potential for storing hydrogen (H_2) in the subsurface. We also use the subsurface to dispose of energy-related waste, e.g., radioactive materials, carbon dioxide (CO_2), and acid gas.

For a long time, the subsurface was considered sterile below a few metres, probably stemming from work carried out in the 1950s which suggested that bacteria in Pacific sediments most likely disappeared somewhere just below 8m (Morita and ZoBell, 1955). This observation seems to have been extrapolated to the subsurface in general, but over time, as methods developed and microbiologists probed harder, this view changed, and it is now recognised that microbial communities exist at depths where the subsurface is exploited for most types of geo-energy. This raises questions about what sort of microbial community exists, how active it is, what limits and drives that activity and how this might impact geo-energy operations.

Microorganisms exist down to several kilometres below the surface and are ultimately likely to be limited by temperature or by available pore space. Temperatures of 80-90 °C are considered sufficient to "palaeopasteurise" a reservoir (though the absolute upper limit of microbial life is higher than this temperature). While rocks such as sandstones can have ample porosity and permeability to provide a habitat and supply a flow of nutrients for microorganisms, there is less pore space in shales and clays for microorganisms to exist, and in many non-sedimentary rocks, space for microorganisms is restricted to fractures. A picture is emerging that even in subsurface environments with limited nutrient availability, a low-biomass microbial ecosystem can develop, driven by autotrophic organisms capable of combining CO_2 and H_2 to produce methane (CH_4) and acetate, along with organisms that can use that acetate, CH_4, and H_2 to drive sulphate, iron, and nitrate reduction. The metabolic products of these microorganisms and breakdown of dead microbial cells are able to support a more diverse microbial community, including heterotrophic organisms, which maintains a low-activity and low-biomass status. Such ecosystems are thought to exist in clays and granites suitable for radioactive waste storage and saline aquifers suitable for carbon capture and storage (CCS). Precisely because these environments have little biomass and the microbial processes are slow, they are often overlooked in geo-energy projects. However, the injection of fluids (e.g., water/brine, CO_2, natural gas, or H_2) into the subsurface can stimulate native microbial communities. The injected water itself can contain microorganisms which may then accumulate and grow near the injection well, or the injected fluid may contain microbial growth substrates (e.g., components of drilling fluids) which would spark microbial activity. In both cases, the microbial processes can, over time, have a non-negligible effect on the geo-energy project. Such effects may be beneficial for the project, in which case, they may be intentionally triggered, or detrimental, in which case, one may have to take steps to prevent or control them.

Microbial processes that affect geo-energy applications. The impact that microorganisms can have varies depending

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on the geo-energy industry in question and environmental factors such as geology and groundwater conditions. Some microorganisms can produce biosurfactants which reduce the interfacial tension between two immiscible fluids. This process is harnessed in microbially enhanced oil recovery (Wood, 2019). Here, water is injected to displace partially trapped oil. The microbially induced lowering of interfacial tension tends to mobilise the oil, improving production.

The mere presence of biomass in the pores of the rock/soil is obstructive for fluid flow and leads to a reduction of permeability. This can be an issue in enhanced oil recovery if the injected water contains biomass or microbial nutrients; biomass accumulation in injection-well vicinity leads to a loss of injectivity. In unconventional gas recovery, biomass can plug up the cracks in the gas-bearing rock created by hydraulic fracturing. To prevent this, fracking fluids usually contain a biocide.

Microbial activity can lead to mineral scaling, i.e. precipitation of minerals. Sulphide precipitation can occur due to the activity of sulphate-reducing bacteria (SRB) near geothermal injection wells, which can lead to clogging around the well. In the case of a CO_2 injection pilot project at the Hellisheidi geothermal power plant in Iceland, a combination of biomass accumulation and iron sulphide precipitation in response to CO_2 injection led to a drop in injection-well transmissivity (Trias et al., 2017). There has been a lot of research in the recent years on how to make beneficial use of microbially induced carbonate precipitation to prevent the leakage of stored CO_2 through the caprock (Cunningham et al., 2013). This is achieved by stimulating bacteria to increase pH and eventually cause carbonate precipitation at the location of the leakage pathway, essentially blocking it. In radioactive waste disposal, another positive impact of microbially induced precipitation is the immobilisation of radionuclides (as phosphate, sulphide, carbonate minerals) through microbial reduction reactions (Brookshaw et al., 2012). In their reduced form, radionuclides are often less soluble and hence less mobile. Microorganisms also interact with radionuclides in other ways (such as biosorption, intracellular accumulation) which alter the mobility of the nuclides (Simonoff et al., 2007).

Some microorganisms can consume CH_4 (as part of natural gas) or H_2 in the subsurface (Gniese et al., 2014). The prevalent conversion mechanisms, and hence reaction products, depend on the availability of certain substances necessary for the microbial reactions. These substances could be part of the stored gas, e.g., CO_2, or a component of the formation water or the host rock, e.g., sulphates. In the case of natural gas storage, the composition of the stored gas can change over the storage period, yielding less CH_4 and more CO_2 and hydrogen sulphide (H_2S). For H_2 storage, one of the challenges the technology faces is quantifying how much H_2 will be lost due to microbial conversion. In some cases, the conversion of H_2 and CO_2 to CH_4 might be actively encouraged to create huge underground bioreactors to supply energy to households (Strobel et al., 2020).

Sulphate-reducing bacteria often come at the top of the list of troublesome microorganisms in geo-energy projects because of their ability to produce sulphides, either as gaseous H_2S or solid precipitates (e.g., iron sulphides). The potential for precipitation to reduce flow in CCS and geothermal energy has already been mentioned, and SRB can also be responsible for souring of hydrocarbon reservoirs and corrosion of infrastructure. Microbially influenced corrosion (MIC) is by no means limited to SRB but, rightly or wrongly, they are often considered to be the main culprits. Corrosion occurs through interactions of microorganisms in biofilms with the metals they are in contact with. In addition, H_2S (produced by SRB) can corrode materials at a distance from the site of microbial activity as H_2S migrates and accumulates. MIC affects most industries and whether this is the corrosion of canisters containing radioactive waste or the corrosion of infrastructure in the subsurface or at the surface (e.g., geothermal plants receiving SRB-containing water), it can represent a significant economic cost.

Challenges. Identifying, quantifying, and influencing these microbial processes in the context of geo-energy systems is notably difficult. An obvious problem is the tremendous degree of interdisciplinarity involved. Experts in the fields of microbiology, geochemistry, geology, fluid mechanics, reservoir engineering, and computer science are routinely tasked with collaborating on joint research questions or project goals. Learning to share a common language and common approaches is challenging.

The large range of spatial scales one has to deal with is a problem well known to anyone dealing with flow in the subsurface. Fluids flow through pores that are narrower than a millimetre, but fluid plumes can span several kilometres. In addition to these, it is often important to describe processes occurring at the scale of a microbial cell (micrometre scale) when dealing with microbial processes. When considering laboratory experiments, frequently the aim is to understand processes happening over kilometre scales (and often geological time scales) when restricted to relatively small amounts of material and limited time periods. Additional complications arise from having to simulate the in-situ environment by running experiments at elevated pressures and temperatures, which add to the cost and complexity of experiments. Some of these problems can be overcome if one can access facilities at suitable underground laboratories or geo-observatories.

Obtaining suitable samples for experiments can be an additional challenge. As well as the usual issues associated with drilling operations (e.g., cost and timing), it is vital that samples are not contaminated by microorganisms from drilling fluids or by surface microorganisms during handling of the core. This is particularly important as we have already noted that subsurface samples often have low biomass, and indigenous microorganisms could easily be masked by contaminating microorganisms. A further complication is that the microbial communities will continue to grow and change once at the surface (e.g., in response to exposure to oxygen), so conventionally stored core material is of little use in understanding the microorganisms in the subsurface. To address these problems, protocols have been developed for sterile collection, including the use of tracers to monitor contamination, rapid handling and subsampling at the surface followed by immediate use of the material or suitable preservation (often by freezing). It is critical that these requirements are discussed with drilling teams as early as possible if samples are to be collected for microbiological analysis.

If a numerical model is to be used to aid in the description and quantification of microbial processes in the subsurface, one is faced with many of the same challenges described above. Of course, the question of the large range of spatial and temporal scales has to be addressed, typically, by some form of upscaling or multiscale modelling. This is part of the bigger challenge of striving for a reasonable abstraction and simplification of the processes. The simpler and more straightforward the underlying conceptual model, the more useful the numerical simulations tend to be. Even with a suitable numerical model, it is usually difficult to obtain all the parameters required due to the scarcity of data. However, if plausible upper and lower bounds of parameters are known, numerical models can be useful in sensitivity or uncertainty analyses.

Summary. The activity of subsurface microorganisms in geo-energy applications, whether beneficial or detrimental, can be relevant for the overall success of the project. Even though the quantification of this activity is particularly difficult, failure to consider it could lead to unexpected economic costs. In other cases, encouraging microbial activity could yield beneficial results. Therefore, microbial activity should be considered an integral part of the system.

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Conflict of interest

The authors declare no competing interest.

References

Brookshaw, D. R., Pattrick, R. A. D., Lloyd, J. R., et al. Microbial effects on mineral-radionuclide interactions and radionuclide solid-phase capture processes. Mineralogical Magazine, 2012, 76(3): 777-806.

Cunningham, A. B., Lauchnor, E., Eldring, J., et al. Abandoned well CO_2 leakage mitigation using biologically induced mineralization: Current progress and future directions. Greenhouse Gases: Science and Technology, 2013, 3(1): 40-49.

Gniese, C., Bombach, P., Rakoczy, J., et al. Relevance of deep-subsurface microbiology for underground gas storage and geothermal energy production. Advances in Biochemical Engineering/Biotechnology, 2014, 142: 95-121.

Morita, R. Y., ZoBell, C. E. Occurrence of bacteria in pelagic sediments collected during the Mid-Pacific Expedition. Deep Sea Research, 1953, 3(1): 66-73.

Simonoff, M., Sergeant, C., Poulain, S., et al. Microorganisms and migration of radionuclides in environment. Comptes Rendus Chimie, 2007, 10(10-11): 1092-1107.

Strobel, G., Hagemann, B., Huppertz, T. M., et al. Underground bio-methanation: Concept and potential. Renewable and Sustainable Energy Reviews, 2020, 123: 109747.

Trias, R., Ménez, B., le Campion, P., et al. High reactivity of deep biota under anthropogenic CO_2 injection into basalt. Nature communications, 2017, 8(1): 1-14.

Wood, D. A. Microbial improved and enhanced oil recovery (MIEOR): Review of a set of technologies diversifying their applications. Advances in Geo-Energy Research, 2019, 3(2): 122-140.