Impact of bacterial activity on underground geological storage of H_2

Thesis subject

Hydrogen is considered as a clean and sustainable vector of renewable energy giving promising prospects, which would be able to replace fossil fuels in the near future. This promotes the development of large-scale hydrogen storage solutions to meet energy demands and mitigate the intermittency of wind and solar energy. Although storage in saline cavities appears today to be one of the most interesting solutions, guaranteeing long-term stability and sealing integrity, these cavities are not present everywhere. Other alternatives must therefore be considered, such as storage in saline aquifers or depleted reservoirs.

At the present time, however, the geological storage of H_2 remains very little studied despite of the specific behaviour of this gas (high reactivity and mobility). A better understanding of the mechanisms involved is therefore essential to better evaluate the economic viability and environmental impact. A key point in the development of such technology is to characterize and constrain the processes that could alter (biotic degradation of H_2) qualitatively and quantitatively the resource within the storage framework in porous reservoir rocks. As first electron donor for life and crucial energy source for subsurface microbial processes, indeed, H_2 allows the autotrophic growth of microorganisms under oligotrophic conditions (*i.e.* limited supply of carbon) in deep environments. In the presence of an available terminal electron acceptor such as nitrate (NO_3^-), ferric iron (Fe^{3+}), sulfate (SO_4^{2-}) or carbon dioxide (CO_2), H_2 is susceptible to be consumed by microorganisms to gain energy. To date, unravelling the contribution of H_2-consuming microbes in the biogeochemical cycle of hydrogen is of high importance in a number of subsurface industries including H_2 gas storage in the energy transition context. Particularly, bacterial activity is susceptible to produce methane (CH_4) or hydrogen sulfide (H_2S) to the detriment of H_2.
The main objective of this PhD thesis will be to **evaluate the kinetics of H_2 consumption by bacterial model strains and multi-bacterial consortia under geological storage conditions in terms of temperature, pressure, salt concentration and electron acceptor availability**. Three levels of experiment could be designed to reproduce these storage conditions such as:

- **Batch experiments**: We could firstly study incubations of different strains of hydrogenotrophic collections likely to live in different types of underground reservoirs and environmental conditions (e.g., halophilic, thermophilic, piezotolerant). Different types of electron acceptors for hydrogenotrophic bacteria will be considered, classically present in underground environments (ferric mineral phases, sulphates, CO_2). Pure strains (e.g., *Shewanella oneidensis* MR-1 , *Thermotoga subterranea*) and multi species consortia will be tested regarding their ability to sustain increasing pressures of hydrogen. High-pressure experiments with high pressure (up to 100 bar) high temperature (55-65°C) batch reactors will be realized to monitor the consumption of hydrogen (gas chromatography) and the growth rate. The reduction of electron acceptors (Fe^{III} and sulfate) will be followed by determination of Fe^{II} (ferrozine reaction) and sulfides (colorimetry). The solid transformations will be also carried out (transformation of iron and sulphur-based solids) by the solid technical analysis (XPS, Raman spectroscopy, XRD). The staining technique FISH (fluorescence in situ hybridization) will be used to obtain the relative number of specific bacteria and to identify spatial arrangements of bacteria in aggregates. Another technique as specific fluorescent (DAPI or SYBR green staining) will serve to count all microorganisms. The method qPCR (quantitative real time polymerase chain reaction) will be applied to quantify specific sequence of ribosomal DNA of all microorganisms or of a species or group.

- **Column experiments**: Percolation tests of dissolved H_2 could be then performed first in water-saturated column (crushed sandstone) enriched in electron acceptor, in the presence of hydrogenotrophic bacteria. The tests will be conducted on the pure strains or multi-species consortium previously studied in closed reactor. Post-experiment analyses (e.g., XRD, SEM, etc.) will also be performed to characterize potential neo-mineralizations, count bacteria and characterize the formation and growth of biofilms.
- **Flow-through experiments**: Finally, in order to get even closer to in situ conditions, gas injection tests in a triaxial mechanical cell (i.e., flow-through tests) powered by fluid pressure generators will be conducted under high temperature, high pressure and high stress on partially saturated core samples. The experiments will be performed in the presence of hydrogenotrophic bacteria under a gas pressure of 50 bars, a confining stress up to 200 bars and a temperature up to 60 degrees. Different tests will be performed by varying the injection conditions (flow rate, degree of saturation). The gas sampling at the output will be analyzed by gas chromatography (GC) in order to quantify the consumption of hydrogen and potential production of annex gas (H_2S). At the end of experiments, the final sample will be analyzed by X-ray 3D nano-tomography to characterize the microscopic repartition of the fluid fraction inside the porous medium.

On the basis of these data, a numerical approach will be conducted: a geochemical modeling of fluid-rock interactions catalyzed by bacteria within the rock formation will be carried out using geochemical modelling softwares.
This work will be carried out inside the **GeoRessources** laboratory in collaboration with LCPME.

Student profile: The candidate must be a highly-motivated and self-directed person with a solid knowledge of microbiology. Ideally, the candidate should have a recent university master degree (or equivalent) in microbiology, molecular biology, biological bioengineering, environmental geochemistry or other relevant fields. A strong interest for laboratory experimentations is required.

He or she may demonstrate proficiency in microbial physiology, molecular biology and general microbiology. Basic knowledge of geochemistry and motivation for work at the interface between disciplines would be appreciated. The candidate will need to be fluency in English. French is not mandatory but the willingness to learn French would be appreciated.

Funding: This thesis is funded for 3 years by the Lorraine University of Excellence (LUE) initiative, starting October 1st, 2022. The application deadline is **June 3rd, 2022**. The gross salary, will be 1975€/month including social benefits and health care. Applicants should email their Curriculum Vitae, copy of their master's thesis and the names and email addresses of two referees to:

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