Geobacter sulfurreduscens: uranium and iron bioremediation

Javier Carmona Gimeno

Microbiology Degree, May 2015

1. Introduction

Extraction and processing of uranium ore have left large volumes of contaminated groundwater with uranium, with an inexpensive solution. In order to solve this problem, in situ bioremediation using the bacteria *Geobacter sufurreducens* appears to be a research path with good perspectives. Laboratory studies suggest that the addition of acetate and other electron donors seems to stimulate the reduction of U(VI) to an insoluble form, preventing it from further spread, along with the reduction of Fe(III) to Fe(II) (Fig. 1). Apart of *Geobacter sulfurreduscens,* other species of bacteria displays the ability to interact with this reaction, specially the sulfate reducing bacteria, being capable to even inhibit it. Moreover, environmental factors such as pH and the composition of the microbial community also plays a role in the reaction. The objective of this review is giving a brief overview on the actual state of the progress in this field, explaining all factors that take part in the process (1).

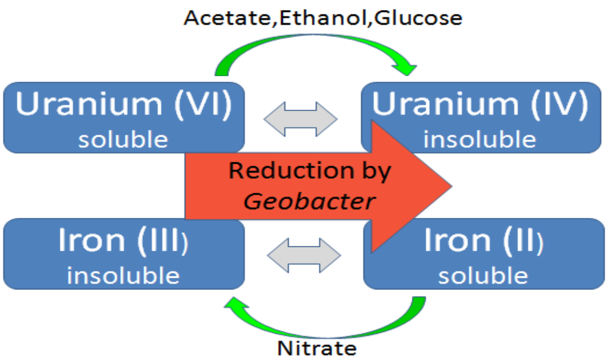

Fig. 1 Uranium and iron cycle

2.1 Uranium

Uranium in his oxidized state, U(VI), is highly soluble and toxic, easily contaminating the nearby water supplies. On the other hand, the reduced form, U(IV), is insoluble and rapidly precipitates, immobilizing it in the groundwater (Fig. 1). This reduction can occur abiotically (slowly), or by enzymatic processes catalyzed by microorganisms (2).

2.2 Iron

Iron can normally cause taste, odor and colour problems in water. In this case, uranium reduction comes with a reduction from Fe(III) to Fe(II), pointing that both reactions occurs at the same time, followed by a substantial enrichment of *Geobacter spp.* Because of that, *i*t is our interest to maximize this reaction to achieve the uranium removal (3).

3. Electron donors

Diverse electron donors stimulate the uranium reduction promoting the anaerobic respiration of *Geobacter spp*. The most used electron donor is acetate, with an excellent results adding it to aquifer and sediment samples in the laboratory. Other electron donors, such as ethanol and glucose, shows irregular conclusions, but with the advantage that acetate tends to dissociate in lower pH, which are the typical pH in contaminated aquifers (Fig. 2) (4).

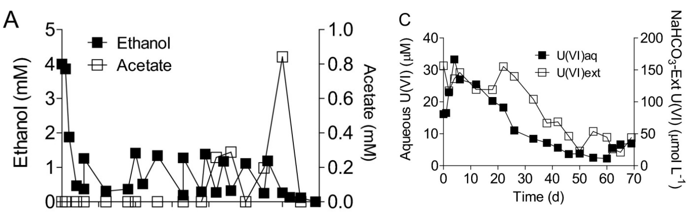

Fig. 2 Concentrations of ethanol, acetate, and aqueous U(VI),during the initial phase of the sediment slurry experiment (4)

4. Electron acceptors

Despite the effectivity of electron donors, they can also promote the activity of other bacterial species. For instance, the addition of acetate also stimulates the sulfate reducing bacteria (SRB), showing a first phase where *Geobacter spp.* predominates and U(VI) is reduced efficiently. But in the second phase SRB predominates and the U(VI) reduction is poor. However, further addition of acetate stimulates *Geobacter spp*. but not the SRB, finding that Fe(III) availability is the key limiting factor of the process (5).

Another relevant electron donor is nitrate. It has been observed that until nitrate has not been reduced the uranium reduction does not start. Another member of *Geobacter spp.* is able to couple the nitrate reduction to an iron and uranium oxidation, reverting the desired uranium reduction (Fig. 3). But once the nitrate runs out, the uranium reduction only goes in one direction. This proves that although the presence of nitrate is not likely to be an impediment to the bioremediation, it is necessary to reduce the nitrate before U(VI) can be reduced (6).

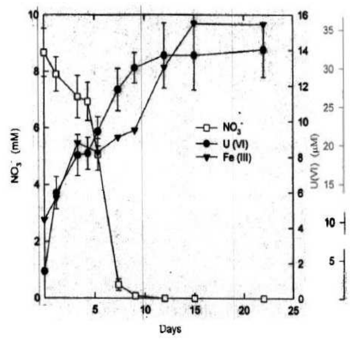

Fig. 3 Nitrate reduction, and U(VI) and Fe(III) production when nitrate was added to sediments in which Fe(III) and U(VI) had already been completely reduced (6)

5. Experimental models

In order to determinate if the results obtained in the laboratory are applicable to the reality, is necessary to perform tests in real contaminated sites like former ore mines, like one placed in Rifle, Colorado. Acetate was injected via injection galleries during 3 months. U(VI) concentrations decreased 9 days after injection, reaching the minimum levels 50 days after injection (Fig. 4). DNA analysis proved that this loss of uranium was correlated with an increase of *Geobacter spp*., followed by the increase of Fe(II) levels. Past 50 days, there was a loss of sulfate and the microbial community changed, with the SRB becoming dominant (1).

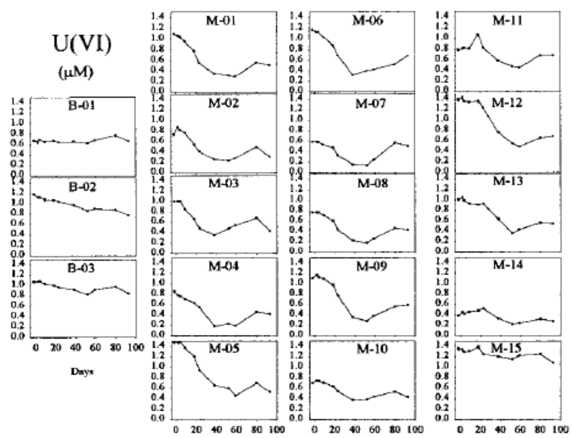

Fig. 4 U(VI) in groundwater samples over time (1)

Conclusions

To sum up, several studies demonstrates that *Geobacter* species might be important agents for in situ uranium bioremediation, according to the results obtained in different investigation groups. Thus, further studies will be needed evaluate the different strategies to promote the long-term reduction of uranium, developing the capacity to control the diverse parameters that affect the reaction. Furthermore, it will be needed more in depth sampling of the microbial community during the bioremediation.

References

1. Anderson R. **Stimulating the In Situ Activity of *Geobacter* Species To Remove Uranium from the Groundwater of a Uranium Contaminated Aquifer** Appl Environ Microbiol, 2003; 69(10):5884-5891.
2. Gavrilescu M. **Characterization and remediation of soils contaminated with uranium** J Hazard Mater. 2009; 163(2-3):475-510
3. Nevin P. **Microorganisms Associated with Uranium Bioremediation in a High-Salinity Subsurface Sediment Microorganisms Associated with Uranium Bioremediation in a High-Salinity Subsurface Sediment** Appl Environ Microbiol 2003; p. 3672–3675
4. Brandon J. **U(VI) Reduction in Sulfate-Reducing Subsurface Sediments Amended with Ethanol or Acetate** Appl Environ Microbiol. 2013; 79(13): 4173–4177
5. Barlett M. **Integrative analysis of Geobacter spp. and sulfate-reducing bacteria during uranium bioremediation** Biogeosciences, 2012; 9, 1033–1040
6. Finneran T. **Multiple influences of nitrate on uranium solubility during bioremediation of uranium-contaminated subsurface sediments** Environ. Microbiol. 2002; 4(9), 510-516