MOLECULAR HYDROGEN : AN ENERGY SOURCE FOR BACTERIAL ACTIVITY IN NUCLEAR WASTE DISPOSAL

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NATURAL ORIGIN OF H_2

Hydrogen is a common product of microbial metabolism, large number of bacteria are able to use it as energetic substrate in subsurface ecosystems. Moreover H_2 is known as one of the most energetic substrates for deep subsurface ecosystem. It could be produced in different ways mainly volcanic activity (basalts iron rich volcanic rocks) or natural radiolysis of water or even fermentation (Lin *et al.*, 2005). The millimolar concentrations of H_2 observed in the ground waters are consistent with the activity of a large variety of hydrogen-oxidising bacteria as described in the following Table. Electron acceptors are identified as O_2, CO_2, NO_3, SO_4 or Fe^{+++}. Aerobic, anaerobic, obligate and facultative autotrophs are included. Numerous of these bacteria are thermophilic bacteria. This bacterial activity leads to the production of methane, acetate, nitrogen, hydrogen sulphur or ferrous oxides. In anoxic environments, H_2 concentrations are governed by microbial metabolism. In most cases, H_2 producing microorganisms are thermodynamically controlled by the abundance of H_2, and survive thanks to H_2 consumers, a metabolism called interspecies H_2 transfer. Metabolism of H_2 is catalysed by hydrogenase as cytoplasmic enzymes or membrane bound enzymes.

Examples of H_2 oxidation by aerobic or anaerobic microorganisms

Reaction	Microorganisms species
$2\ H_2+O_2 \Rightarrow 2\ H_2O$	Aerobic hydrogen bacteria (*Ralstonia sp.*)
$4\ H_2 + CO_2 \Rightarrow CH_4 + 2\ H_2O$	Methanogens bacteria (*Methanobacterium sp.*)
$4\ H_2 + 2\ CO_2 \Rightarrow CH_3COOH + 2\ H_2O$	Acetogens bacteria (*Acetobacterium sp.*)
$5\ H_2 + 2\ NO_3^- + 2\ H^+ \Rightarrow N_2 + 6\ H_2O$	Denitryfing bacteria (*Paracoccus denitrificans*)
$4H_2 + SO_4^{2-} + 2\ H^+ \Rightarrow H_2S + 4\ H_2O$	Sulfate reducing bacteria (*Desulfovibrio sp.*)
$H_2 + 2\ Fe\ (OH)_3 + 4\ H^+ \Rightarrow 2Fe^{2+} + 6H_2O$	Iron reducing bacteria (*Shewanella sp.*)

H_2 IN NUCLEAR WASTE DEEP REPOSITORIES

Several situations of H_2 production will occur in nuclear waste repository:

- Radiolysis of water.
- Radiolysis of organic matter (such as bitumen , in case of B waste), H_2 production due to gamma radiolysis of bitumen is evaluated to 1 L H_2 /kg of bitumen /MGy .
- Corrosion of metal containers (in deaerated solutions).

Large amount of H_2 are predicted in some situations, and will select the development of hydrogen species.

Then, aerobic hydrogen bacteria oxidising hydrogen could be found in basins containing irradiating waste, or during the oxic period of storage, denitrifying bacteria or sulfate reducing bacteria will develop near the bitumen waste. Groundwater of the Callovo-Oxfordian will support sulfate reducing bacteria or methanogen bacteria. Iron reducing activity could develop near containers or in argillite.

Several examples and results of kinetic of H_2 consumption by microorganisms are here presented:

- The development of bacteria using oxygen and H_2 from radiolysis of water in basin containing irradiating waste (Galés *et al.*, 2004).

- The development of denitrifying bacteria using nitrates and H_2 in the environment of bituminized embedded waste (Figure 1, B waste , Libert *et al.*, 1999). In presence of H_2, bacteria will reduce the released nitrates from bituminized waste: the limiting factor of the kinetic is the amount of released nitrates.
- The development of iron reducing bacteria using ferric iron and H_2 from container corrosion products (Figure 2, C waste, Esnault *et al.*, 2009). *Shewanella* sp is able to oxidise 1.2 mmoles of H_2/day by iron reduction.

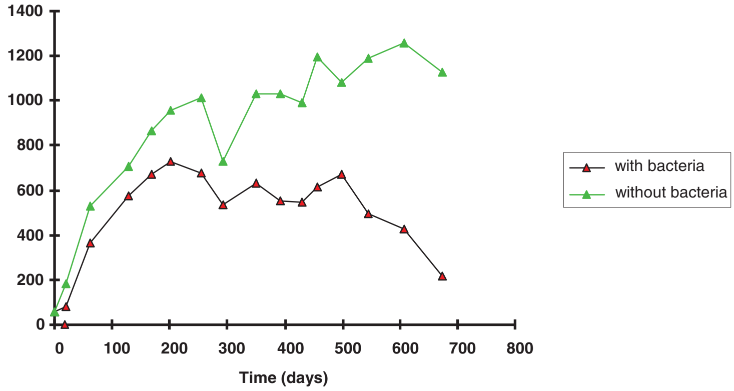

Figure 1: Activity of nitrate reducing bacteria oxidizing H_2 as a function of time, measured by the decrease of nitrate concentration (medium contains embedded bitumen leachates, NO_3 reducing bacteria, 10% of H_2).

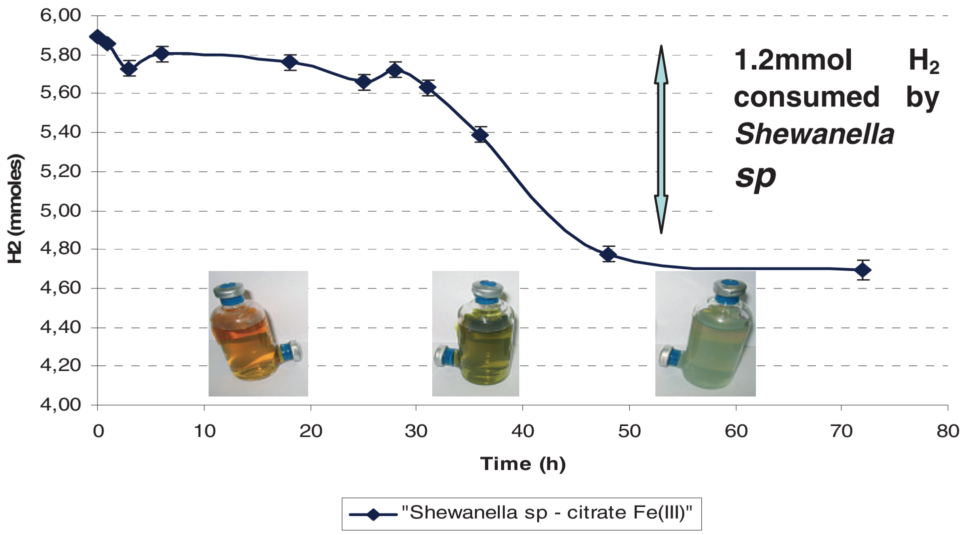

Figure 2: Consumption of H_2 by iron reducing bacteria in presence of Fe (III).

The consequences of the development of H_2 oxidising bacteria are discussed in terms of physico-chemical modifications in geological disposal: biomass production, gas production and consumption, biocorrosion.

References:

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