PROPOSAL FOR A THESIS TOPIC

« EFFECT OF HUMIDITY AND H_2S ON HYDROGEN EMBRITTLEMENT OF STEELS FOR UNDERGROUND GAS STORAGE CONTAINING H_2»

Start of thesis: 01/10/2024	**Application deadline:** 01/10/2024

Key words
Hydrogen Embrittlement; Underground gas storage; Fracture mechanics; Surface reactions; Thermodynamics; Steels

Profile and skills required
Master's degree in research or engineering in materials science/mechanics/corrosion
Ability to carry out on bibliography and independently experimental work. Ability to synthetize. An interest in developing new experimental devices and research in an industrial context.

Presentation of the doctoral project, context and objectives

Energy storage is a crucial issue in the deployment of renewable energies in the energy mix. As things stand, hydrogen seems to be the most promising energy vector for meeting this challenge and eventually achieving carbon neutrality. For this reason, specific gas infrastructures need to be developed. These will include salt caverns, as is already the case for natural gas. In addition, biomethane from pyrogasification contains 2% hydrogen. Hydrogen, whether mixed or pure, will therefore be present in existing natural gas infrastructures. In underground storage facilities, whether aquifers or salt caverns, liquid water (or brine) is in contact with the gas. As a result, the water vapour content of the gas withdrawn from storage is higher than that of the gas injected from the transmission network. It can even reach saturation under bottom-hole temperature and pressure conditions. In addition, under specific conditions (i.e. in particular storage facilities, mainly in aquifers), souring (production of H_2S) can occur.

The hydrogen injection, either pure or in biomethane mixed with natural gas, into underground storage assets exposes the materials in contact with it to the risk of hydrogen embrittlement. This physical phenomenon is based on the absorption of hydrogen by the metallic material. This reduces the strength of the interatomic bonds and ultimately degrades its mechanical properties (ductility, toughness...). This embrittlement can result in the accelerated propagation (compared with natural gas) of cracks on structural defects. There is a lack of data in the literature on the effect of water vapour and low H_2S levels on the susceptibility of steels used in underground gas storage infrastructures to hydrogen embrittlement. Nevertheless, the literature has highlighted the impact of certain impurities in the gas on the hydrogen embrittlement of steels. In particular, oxygen inhibits hydrogen embrittlement of steels, while H_2S acts as a catalyst.

The thesis will study an environmental configuration characteristic of underground gas storage: wet gas saturated with water, i.e. with a layer of surface liquid water in contact with the material surface. Two gas matrices will be investigated: natural gas and pure hydrogen. These matrices will be mixed in different proportions. In this context, the mechanical behaviour of the materials will be tested in these natural gas/hydrogen environments in the presence or absence of secondary constituents, i.e. water vapour, hydrogen sulphide and/or oxygen.

The aim of this thesis is to identify the mechanisms by which hydrogen is absorbed into the various media mentioned and its impact on the degradation of the mechanical properties of materials used industrially for underground gas storage.

This will be achieved by cross-experiments to understand the mechanisms of competition between the different sources of hydrogen (H_2, H_2O, H_2S) and the effect of the formation of surface layers on the steel (e.g. oxide, hydroxide, carbonate or sulphide layers).

This thesis has a substantial experimental basis at its core. The experimental work will be carried out by the student. The thesis will be organised as follows:

1) Carrying out a thermodynamic study based on literature data in order to establish thermodynamically stable corrosion products;
2) Experimental characterisation of the corrosion products actually formed on the steel under the various exposure conditions;
3) Elaboration of the mechanisms of chemical degradation of the materials in the environments studied and establishment of the kinetics of hydrogen absorption and/or corrosion product growth with identification of the kinetically limiting stages of these processes;
4) Carrying out fracture mechanics tests (toughness tests) in a high-pressure gaseous environment;
5) Experimental characterisation of damage modes;
6) Identification of the relationship between hydrogen activity and damage modes.

The student will be hired by and based at the French Corrosion Institut in Fraisses (42) and will be required to visit CEA Saclay (91) regularly during the three years of the thesis.

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Host laboratory	**Collaboration**
French Corrosion Institut Location: Fraisses (42)	CEA Saclay (91)
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