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H_2-gas diffusion in porous media as observed by NMR

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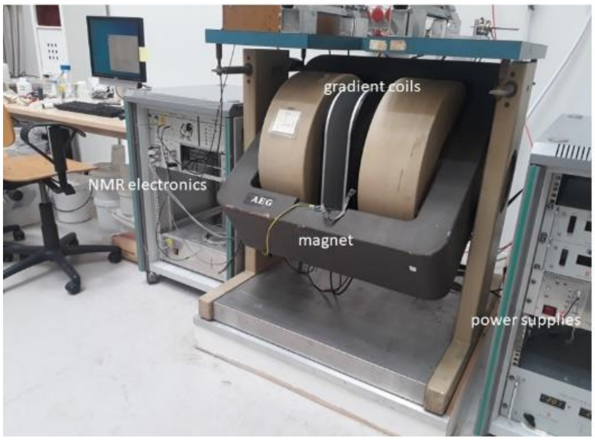
Not only is hydrogen (H_2) the simplest and most abundant gas in our universe, it also plays a pivotal role in the decarbonization of our energy. As such hydrogen will be one of the most important critical enablers for industry in the global energy transition. Hydrogen's low density hinders the wide-scale deployment and therefore, it is important to come to large scale low-cost H_2 storage capacity as a source of hydrogen gas. In order, to store the energy in the TW h/GW h-range subsurface storage of hydrogen in depleted hydrocarbon reservoir and/or deep saline aquifers is needed. Concerning the hydrogen storage in depleted gas/oil reservoirs there are still many scientific questions open, which have to be addressed in order to come to reliable, efficient and cost-effective storage [1, 2]. For example, the injected hydrogen will displace the pore residual oil/gas and spread out in a reservoir; a trap structure is needed to prevent the hydrogen from escaping and allowing reproduction of the hydrogen, i.e., leakage is a major concern. Accurate predictions are needed of multi-phase fluid displacement in porous media, e.g., the interaction/displacement of cushion gas and the interactions with the solid matrix.

In this study we have used NMR to image the diffusion and interaction in porous media. NMR is one the few methods by which H_2-gas can be directly imaged in porous media. In order to do so, we have constructed a special NMR setup to measure the diffusion in porous media up to 60 bar. As the relaxation times measured for hydrogen are too short for 3D imaging this setup is limited to 1D measurement [3]. As, to be able to measure also on real porous media containing magnetic impurities, it was chosen to keep the main field at 0.7 T. The present setup is made up of an electromagnet generating a main magnetic field of 0.7 T with a gap of 70 mm and a picture is given in Fig 1. The NMR setup itself is equipped with Anderson gradient coils which can generate up to 0.3 T/m. An RF insert was made which is equipped with a special Faraday-shield, to be able to perform quantitative measurements and as such this setup is directed towards quantitative H_2 profile measurements [4].



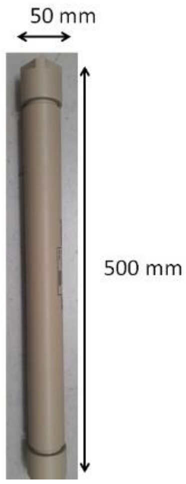


Figure 1: (left) A picture of the 0.7 T homebuilt NMR setup which makes use of an electromagnet (right) A picture of the PEEK reactor as used in the NMR measurement.

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For the NMR measurements a special PEEK reactor was purchased, which can be operated on up to 60 bars. The PEEK reactor has an outer diameter of 50 mm and inner diameter of 30 mm with a length of 500 mm. The reactor can be moved through the RF-coil with the help of a stepper motor, hence giving the possibility to measure the H_2 content profile over the length of the reactor.

In the initial tests we looked at the quantitative measurement of H_2 as a function of the gas pressure. These initial measurements show that the H_2 gas has a T_1 in the order of 0.5 ms. Hence, as the signal of the H_2 gas is quite low in comparison to the background noise, it was decided to measure the H_2 gas at a high repetition rate, i.e., TR=2 ms. The results as function of the gas pressure up in the initial test upto 15 bars are given in Fig 2. As can be seen a clear linear behavior is found and only a minor contribution of the background is observed. In the next experiment the reactor was filled with 0.06 mm glass beads to mimic an ideal porous material and the results are also given in Fig 2. Again, a clear linear behavior can be observed, indicating measurements can also be performed in porous media.

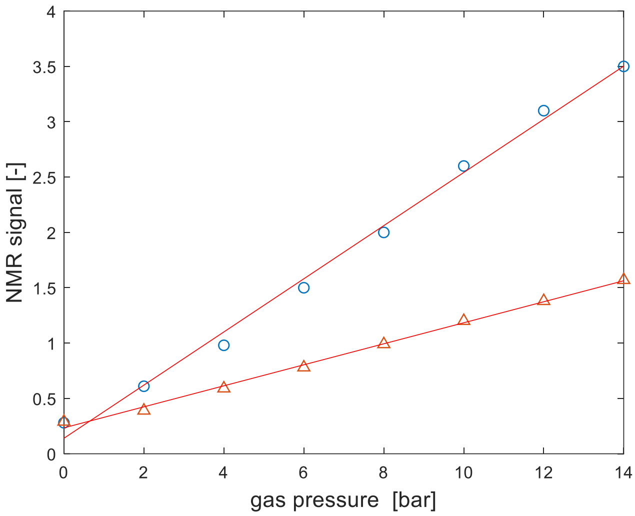

Figure 2: The NMR signal as a function of the H_2-gas pressure. (○) pure H_2-gas, (Δ) reactor filled with 0.6 mm glass pellets

After this preliminary study in which we have tested the setup, we now intend to conduct measurements on porous glass beads up to 2 mm under various prewetting conditions, e.g., water, NaCl solution, oil and at various pressures. Here we want to measure the exchange of H_2 gas by other gases such as N_2 up to 60 bar and see the influence of the various prewetting conditions.

Contributor statement

The authors confirm contribution to the paper as follows: study conception and design: Leo Pel, David Smeulders and Maja Rucker; data collection: Leo Pel; analysis and interpretation of results: Leo Pel, David Smeulders and Maja Rucker; all authors reviewed the results and approved the final version of the manuscript.

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