SATURATION OF COMPACTED BENTONITE UNDER REPOSITORY CONDITIONS: LONG-TERM EXPERIMENTAL EVIDENCES

M.V. Villar[1], J.L. García-Siñeriz[2], P.L. Martín[1], A. Lloret[3], I. Bárcena[2] & R. Gómez-Espina[1]

1. CIEMAT, Madrid, Spain (mv.villar@ciemat.es; pedro.lmartin@ciemat.es; roberto.gomez@ciemat.es)
2. AITEMIN, Madrid, Spain (jlg.sineriz@aitemin.es; i.barcena@aitemin.es)
3. UPC, Barcelona, Spain, (antonio.lloret@upc.edu)

A current design for engineered barriers in the context of high-level radioactive waste disposal includes bentonite compacted blocks initially unsaturated. The heat released by the waste will induce high temperatures in the bentonite barrier. It is expected that full saturation of the buffer be reached before the dissipation of the thermal gradient. However, it still remains unclear whether the high temperatures around the canister would hinder the full saturation of the inner part of the barrier or just delay it. This paper summarises the information gathered in the last 15 years on the saturation of compacted FEBEX bentonite by means of different scale laboratory tests, a big-scale mock-up test and a real-scale in situ test, that were performed in order to simulate the conditions of the clay barrier in the repository and better understand the hydration/heating processes and their consequences on bentonite performance. FEBEX is a Spanish bentonite composed mainly of montmorillonite (about 92%). In the tests it has been used compacted with its hygroscopic water content (14%) at dry densities between 1.6 and 1.7 g/cm^3, which is the range expected in the repository. For these densities the saturated permeability of the bentonite is about $3 \cdot 10^{-14}$ m/s and its swelling pressure 8 MPa.

The FEBEX in situ test is being performed under natural conditions and at full scale within a drift excavated in the underground laboratory managed by NAGRA at the Grimsel Test Site (Switzerland). The thickness of the bentonite barrier is of 65 cm, and the surface heater temperature is 100°C. After five years of heating, and according to the sensors measurements, the bentonite closer to the heater had water contents below the initial ones, although they were recovering after the intense initial drying. On the contrary, for the same period of time, the sensors located at the same distance from the gallery wall, but in an area not affected by the thermal gradient, recorded much higher relative humidity (Figure 1, left). A section of the test was dismantled after these 5 years, and the bentonite extracted was analysed, what allowed to check the sharp water content and dry density gradients inside the barrier. The other half section continued running and currently, after more than 12 years of operation, the sensors show that 100% rela-

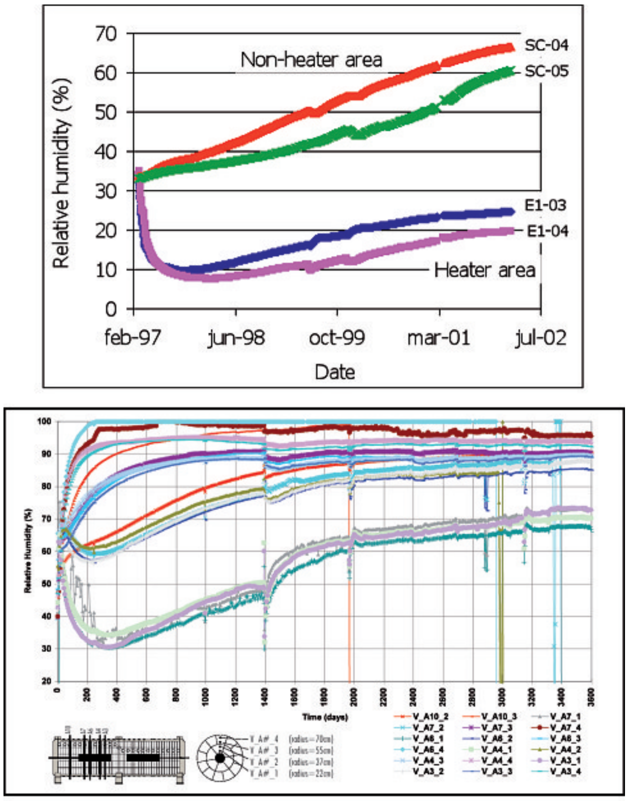

Figure 1: Left: Evolution of the relative humidity of the bentonite at 3.5 cm from the heater and at approximately the same distance from the gallery wall (54 cm) in a section not affected by the heater of the FEBEX *in situ* test. Right: Evolution of the relative humidity of the bentonite in various locations of the FEBEX mock-up test.

tive humidity has been reached in the colder areas (more than 1 m away from the heater), between 74 and 100% at the heater ends, and only 43% near the central part of the heater.

The mock-up test has been running at almost full scale and under controlled boundary conditions at CIEMAT for more than 12 years. The overall water content reached is very high (almost 23%), but it does not correspond to full saturation and is increasing very slowly (Figure 1, right). Besides, the relative humidity distribution inside the barrier, whose thickness is 62 cm, is greatly affected by the thermal gradient and seems to have reached a quasi-steady state.

The performance of large-scale tests as those mentioned above is complicated and time-consuming. For this reason, laboratory tests of different scales are very useful to identify and quantify processes in shorter periods of time. These are performed in cells in which the compacted bentonite is subjected simultaneously to heating and hydration, in opposite directions. In particular, a series of infiltration tests performed under thermal gradient in bentonite columns of 60 cm length were dismantled after 0.5, 1, 2 and 7.6 years (Figure 2, left). At the end of all the tests there were important water content and dry density gradients along the bentonite columns. After 7.6 years of testing the water content of the bentonite was lower than the initial one in the 5 cm closest to the heater. The final average degree of saturation in the longest test (7.6 years), considering a water density of 1 g/cm^3, was 92 percent, what highlights the slowness of the hydration process of compacted bentonite. Two similar tests performed with 40-cm long bentonite columns have been running for 7 years. In one of them hydration is taking place at room isothermal conditions. The water intake is higher for the sample tested at room temperature, because the hot zones of the sample tested under thermal gradient remain desiccated for long time. In fact, both tests seem to have reached a steady state, since the relative humidity inside the bentonite barely changes (Figure 2, right), what suggests that the process that causes the water intake to be so slow, must not be solely connected to the thermal gradient. Other tests performed in smaller samples (8 cm length) under thermal gradient did show a final full saturation for tests durations around 30-40 days and homogenisation of water contents along the blocks for longer testing periods.

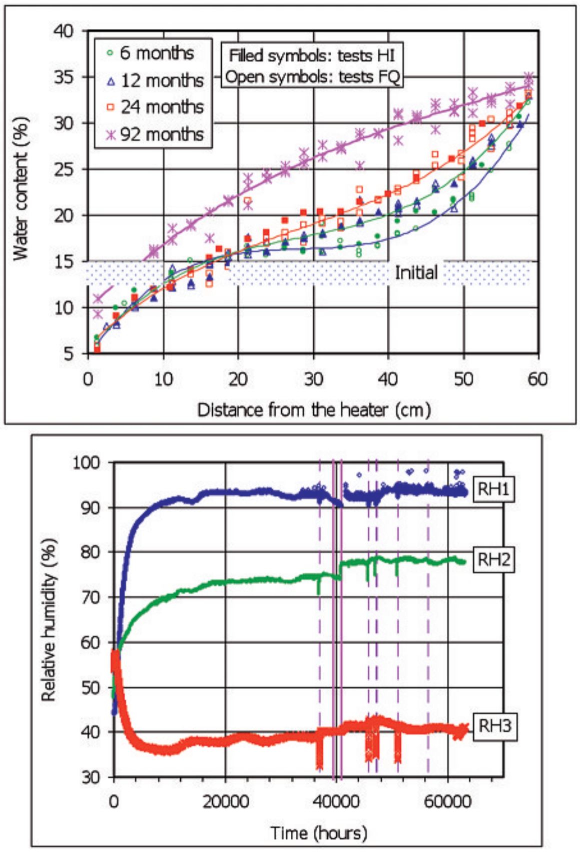

Figure 2: Left: Final water contents along the 60-cm long bentonite columns. Right: Evolution of relative humidity in a 40-cm long bentonite column hydrated under thermal gradient (sensor 1 placed at 30 cm from the heater, sensor 2 at 20 cm and sensor 3 at 10 cm).

Some conclusions could be drawn from these experimental observations:

- The rate of hydration depends on the buffer and surrounding media permeabilities, waste temperature and buffer thickness.
- It is not clear if full saturation can be reached for any combination of barrier thickness, thermal gradient and material permeability (among other parameters).
- For predicting the long-term behaviour of the barrier, the numerical models must take into account the effect on bentonite permeability of the change in its microstructure upon hydration.
- When the dry density of the barrier is high, the density of the adsorbed water would be higher than 1 g/cm^3, and more water than expected would fit in the bentonite pores.