Thermo-hydraulic modeling of the bentonite buffer in deposition hole 6 of the Prototype Repository

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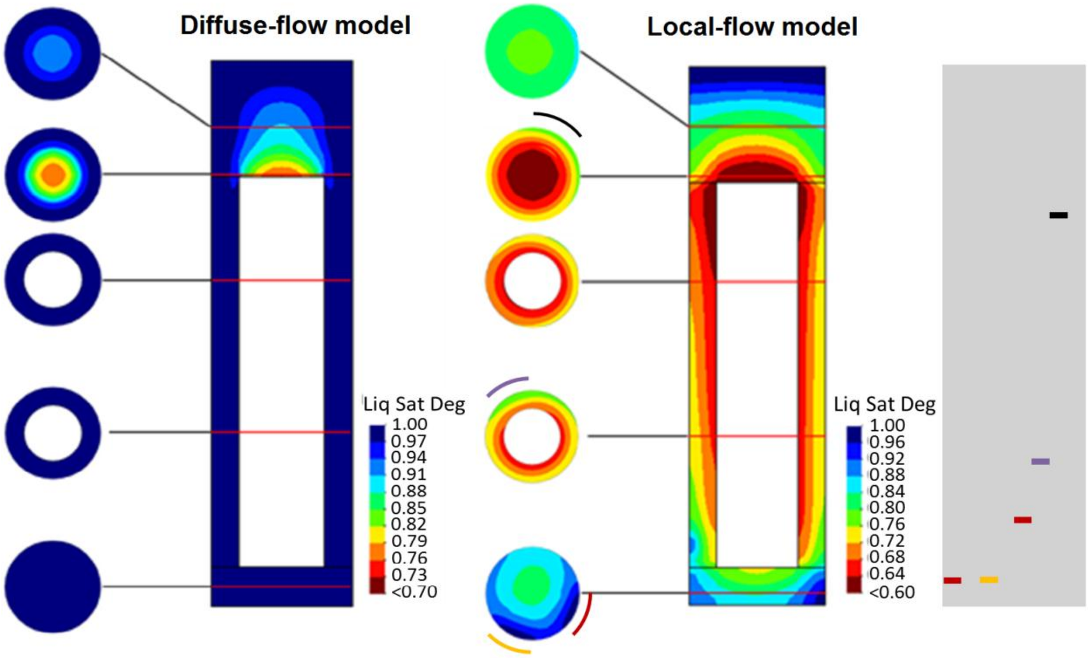

Figure 1. *Contour plots showing the liquid saturation at the time when the buffer was excavated in the experiment. In the right-most panel a schematic drawing, showing the position of the local-flow zones on the deposition-hole wall is included. Where appropriate, the orientation of these zones is also shown around the horizontal cuts in the figure.*

The evolution in the Prototype Repository, and in particular, the thermo-hydraulic evolution in the buffer in deposition hole 6 (DH6), has been modeled using the FEM program Code_Bright. To represent the hydraulic transport properties of the rock without including a complex fracture network, the host rock was represented by a set of volumes equipped with different conductivities calibrated by comparing simulated and measured inflows to tunnel and DHs.

To accurately predict the evolution in DH6, the influence from the other DHs, as well as the response in the rock due to the presence of both the heater and the unsaturated clay should be taken into account. Theoretically, this could be achieved with a coupled TH model of the entire experiment; however, to include fracture flow in the rock near the DHs and to resolve the bentonite buffer well enough, such a model would lead to exceedingly long computation times and numerical instability. To avoid this, the modeling was done in three steps using two types of geometries on different scales: (i) large-scale three-dimensional models of the entire experiment with a large volume of host rock, and (ii) a local-scale three-dimensional model of one DH, with corresponding tunnel backfill and a small part of the host rock. The following models were utilized in the three-step solution strategy:

1. A large-scale hydraulic model prior to installation of the experiment, with an empty tunnel and DHs, to calibrate the rock material with respect to measured inflows.
2. Large-scale uncoupled thermal and hydraulic models after installation of the experiment to determine boundary conditions for the local model.
3. A set of local-scale, coupled thermo-hydraulic models for studying the wetting process in the buffer from installation to excavation.

Large-scale models

In the purely hydraulic model in step 1 the host rock was represented by a set of volumes with different hydraulic conductivities; calibrated by comparing simulated and measured inflows to the tunnel and DHs. The accuracy of the model was tested by comparing measured and simulated water pressure.

In step 2 the calibrated conductivities were then used when simulating the hydraulic evolution in the experiment during the operational phase. The results from this model and a thermal model on the same scale were used to determine the boundary conditions applied on the local-scale model in step 3. This strategy enabled a detailed simulation of DH6 only, while still accounting for global effects through the applied boundary conditions.

Local-scale models

The DHs were extensively characterized before buffer installation. The *total* inflow was measured and local inflows, from identified water bearing features at the DH wall, were measured using a "*plastic bag*" and a "*diaper*" technique. These two local-inflow measurements were used to design the representation of the rock close to the DHs.

A 1 m thick material embedding the DH was equipped with "*DH Rock*" material. In this layer, five 0.1 m thick partial (45°) horizontal discs at different heights were inserted, to represent the identified local-inflow zones. The partial discs were assigned materials identified as "*Local Zone* 1 – 5". To the right in Figure 1 the position of the inflow zones are indicated in a schematic way. The rock materials close to the DH were calibrated in two different ways:

<u>*Diffuse-flow model*</u>: Local-inflow zones were calibrated as to give the "plastic bag" inflows. DH Rock was calibrated as to obtain the correct measured total inflow.

<u>*Local-flow model*</u>: DH Rock was calibrated from evaluating the "diaper" measurements. Local-inflow zones were calibrated so as to obtain the total inflow, with the restriction that their relative inflow remained as measured by the "plastic bag" technique.

Final state

One important result of the models is the final state of the buffer in terms of the degree of saturation. Contour graphs of the degree of saturation in the buffer from the two models can be seen in Figure 1. The figures show both a vertical cut through the entire DH, as well as horizontal cuts at four different depths. The contour graphs shows the state of the buffer at the time when the dismantling excavation of the buffer in DH6 was completed.

Several important features can be observed. If the plastic-bag measurements are most accurate (as assumed in the Diffuse-flow model) the inflow mainly comes from the DH Rock volume, i.e. the inflow is of diffuse character. The results indicate that the buffer should have been almost fully saturated at excavation of the experiment; the only unsaturated part is found on top of the heater. Furthermore, the degree of saturation should be essentially axisymmetric; hence no effect can be seen from the local inflow zones at this point.

On the other hand, if the diaper measurements are most accurate (as assumed in the Local-flow model) the excavated buffer should be relatively dry, with full saturation reached only just in front of the local inflow zones, as well as in the top buffer cylinder. At the latter position, the water has entered the DH via the tunnel backfill instead of through any of the local inflows zones. One important result in the local-flow models is that the wetting is far from axisymmetric.

As a conclusion, when comparing the model results with excavation data the findings above indicates that in order to make a precise prediction of the final state of the experiment, when only calibrating the model against measurements, more detailed and accurate characterization of the water flow or transport properties of the rock close to the DH would have been needed.