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Evaluation of a new method to estimate the hydration time of the tunnel backfill

Urban Svensson, Computer-aided Fluid Engineering AB

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Preface

The work reported here was initiated in 2006 and finalised in 2008. Since 2008, the method has been applied in other studies, and hence the work reported here constitutes a reference for these studies. It is noted that several improvements have been suggested during the course of application and that the present-day version of the method differs in several ways from the 2008 version reported here.

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Abstract

A safety assessment of a repository requires that all stages (excavation, waste emplacement, etc) of a repository are analysed and understood. In this report the time after the waste emplacement will be in focus. One important issue during this phase is the saturation of the tunnel backfill. After the installation of the backfill, 30–50% of the pore space is filled with air; this volume will eventually be filled with water and it is the time scale for this hydration process that needs to be estimated.

A method to estimate the hydration time of a repository has been suggested and evaluated. The key idea in the suggested method is to "create" the volume initially filled with air by the use of the specific storage term and hence be able to stay within the single phase framework.

A series of test cases, defined and simulated in /Börgesson et al. 2006/, are used to demonstrate and evaluate the method. Encouraging results have been obtained. It is also shown that the simulation model can be applied to a real world case.

Sammanfattning

En säkerhetsanalys av ett förvar måste beakta alla stadier (byggskede, driftskede, etc) av ett förvar. I denna rapport studeras tiden efter återfyllnad av tunnlar. Det kan förväntas att återfyllnadsmaterialets porvolym innehåller 30–50 % luft vid inplaceringen. Det är av intresse att kunna uppskatta tiden tills denna volym fyllts med vatten.

En metod för att bestämma denna tid föreslås och utvärderas. Grundidén är att skapa ett hålrum, som motsvarar luftvolymen, genom specifika magasinskoefficienten. Fördelen är att ett betydligt enklare beräkningsproblem blir resultatet.

Ett antal testfall, som definieras och simuleras i /Börgesson et al. 2006/, används för att utvärdera metoden. Enligt författarens mening erhålls lovande resultat. Det visas även att metoden kan appliceras på en realistisk förvarsgeometri.

Contents

1 Introduction

1.1 Background

A safety assessment of a repository requires that all stages (excavation, waste emplacement, etc) of a repository are analysed and understood. In this report the time after the waste emplacement will be in focus. One important issue during this phase is the saturation of the tunnel backfill. After the installation of the backfill, 30–50% of the pore space is filled with air (the rest with water); this volume will eventually be filled with water and it is the time scale for this hydration process that needs to be estimated.

There are several reasons why this time scale is of interest:

- the needed properties of the backfill are those representing saturated conditions. During the hydration phase properties that are a function of saturation level can hence be expected,
- in the unsaturated state the heat transfer properties are affected by the air in the backfill, resulting in a lower thermal conductivity,
- during the saturation process the flow will generally be towards the repository (filling up the air volume). Considering that this flow will advect mass with properties, the water can for example have high salinity, it may have implications.

/Börgesson et al. 2006/ concluded that both the properties of the backfill and those of the surrounding rock may control the time scale of the hydration. /Börgesson et al. 2006/ studied the saturation of the buffer and the backfill using advanced two-phase models. These models provide realistic simulations based on fundamental physical laws and well established empirical relations. The drawback of this approach is that it is presently hard to include an adequate description of the fracture network in the rock. For this reason a much simpler approach was tested in /Svensson 2006 a, b/. The hydration phase was treated as a single-phase problem using the storage term to "create" the volume which represents the air volume to be filled with water. A calibration parameter was also introduced (which modified the conductivity of the backfill) and a qualitative agreement with the results by /Börgesson et al. 2006/ could be demonstrated. This simple approach has the advantage of being applicable to a realistic repository layout embedded in a rock with a water conducting fracture network. The method has however not been tested and evaluated so far and should only be considered as a suggestion. The present report aims at taking the method one step further in terms of verification and realism.

1.2 Objective

The main objective of the report is to verify and document a simple method for the simulation of the hydration of the tunnel backfill. The method should be applicable to a realistic repository layout embedded in a rock with a water conducting fracture network.

2 The problem considered

2.1 Physical processes

A number of complex interacting physical processes are active during the saturation phase (saturation and hydration are in the report used as synonyms). In Figure 2-1 an illustration of the more important processes is given. The illustration does not claim to be complete, but it is anyway clear that we are dealing with three phases (solid, air and water) with an air phase that is subject to compression and dissolution in the water phase. With reference to Figure 2-1 the following aspects of the situation considered are emphasised:

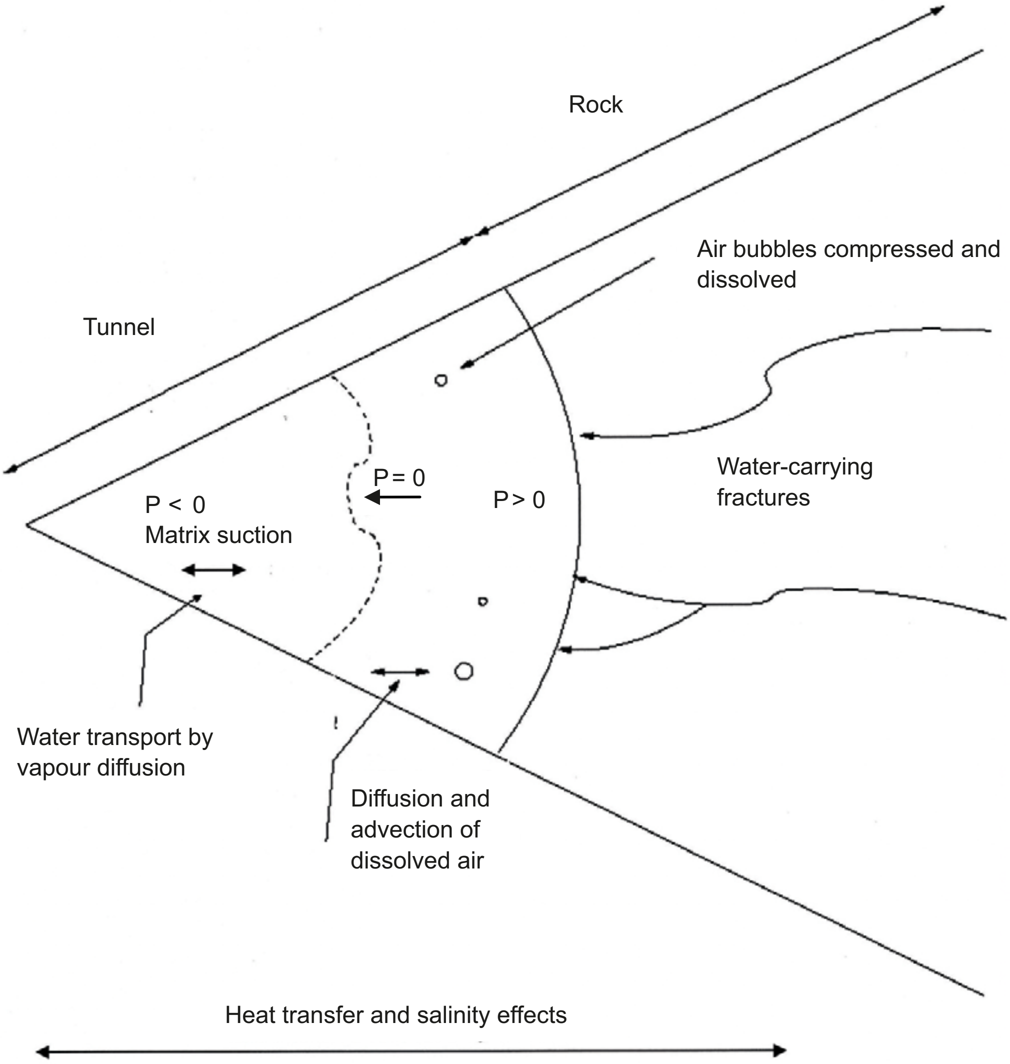
- in the rock a fracture network provides the water up to the tunnel face,
- the saturation front is defined by the zero gauge pressure line. Ahead of the saturation front the pressure is < 0 and it is > 0 behind the front,
- in the unsaturated part water is transported by suction and may also be transported as vapour diffusion,
- the air initially present in the backfill may disappear by several processes: dissolution in the water, gravitational rise (as small bubbles) and by diffusion and advection when dissolved in the water. When pressure rises a significant compression of the air (which reduces the volume) can be expected,
- temperature and salinity levels and gradients may affect most processes.

2.2 Suggested approach

If all, or most, of the processes discussed above should be included in a numerical simulation model we probably need to stay with one- or two-dimensional models. Our objective is to simulate hydration in a 3D repository geometry and hence a simpler approach is for this reason sought. As a basis for such an approach the following is suggested:

- stay within the single phase framework and use the storage term to "create" the space that the inflowing water should fill. It is assumed that the volume of this space is known and as we know the total pressure rise a suitable specific storage value for the backfill can be calculated,
- assume that the inflow of water is governed by the pressure gradients and the resistance in the rock, the saturated part of backfill and the wetting front. In the unsaturated part, the flow is governed by pressure gradients and a hydraulic conductivity that is a function of the saturation level. This means that we can use a Darcian flow formulation.

With reference to Figure 2-1 it is obvious that we have simplified the problem drastically and for this reason we may need some "tuning knob" during the evaluation/calibration of the model. The storativity for the saturated backfill is one possible knob that can be used for this purpose. From a physical point of view this seems adequate, as air bubbles may be present in the backfill after saturation. These bubbles will be compressed due to the pressure rise and cause a storage effect.



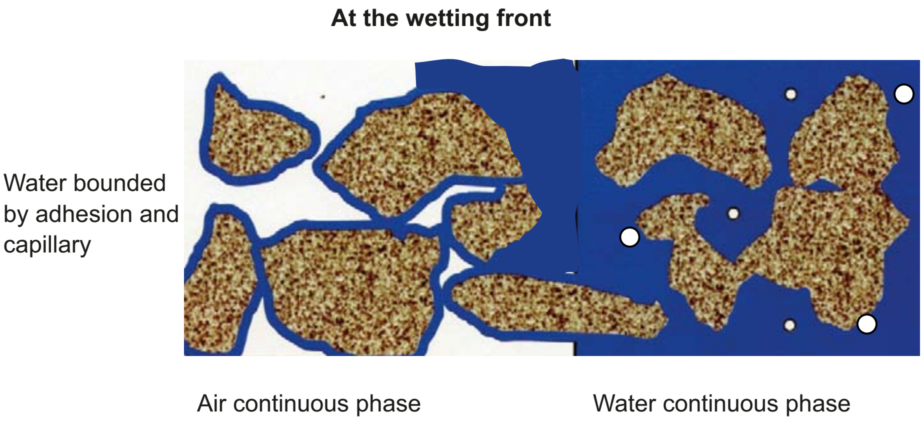


Figure 2-1. *Schematic illustration of relevant physical processes during the saturation of the tunnel backfill. Top figure shows a section through the tunnel and the rock, while the bottom figure illustrates conditions at the saturation front (P = 0).*

3 Mathematical formulation

For a general account of the mathematical models embodied in DarcyTools the reader is referred to /Svensson et al. 2010/. Considering the present application it suffices to state that the mass conservation and Darcy equations constitute the basis. The parameters of the suggested formulation do however need to be specified.

The hydraulic conductivity of the backfill is related to the degree of saturation, following /Börgesson et al. 2006/:

$$K_p = S_r^{\delta} K \tag{3-1}$$

where

K_p = hydraulic conductivity of the partly saturated backfill [m/s].

K = hydraulic conductivity of the saturated backfill [m/s].

S_r = degree of saturation [–].

δ = a parameter [–].

The degree of saturation will in this study be assumed to be related to the pressure by a so called retention curve, which is specific for each backfill material:

$$S_r = f(P) \tag{3-2}$$

where

P = gauge pressure [Pa].

Note that (3-2) will only be applied for unsaturated conditions, which by definition implies that the pressure is negative.

The specific storage is in the present approach given an untraditional role, as it should simulate the removal of the volume occupied by air in the backfill. An illustration of how this is accomplished is given by the following example:

Assume that the pressure in the backfill initially is –1.0 MPa and that the air volume to be filled with water is 0.1 m^3/m^3. We should then find a specific storage, S_s, which increases the porosity, n, with 10% for a pressure rise, ΔP, of 1.0 MPa:

$$\Delta n = S_s \times \frac{\Delta P}{\rho g} \tag{3-3}$$

where ρ is density [kg/m^3] and g is acceleration of gravity [m/s^2]. This gives a S_s, [m^{-1}], as $S_s = \Delta n \rho g \,/\, \Delta P = 9.81 \times 10^{-4}$. When $P > 0$ the backfill is saturated and the traditional role of S_s is applied.

4 Results

4.1 Introduction

In this section three sets of results are presented. The first two deal with comparisons with simulations presented by /Börgesson et al. 2006/, while the third case is an application to the Laxemar site.

4.2 Isothermal test cases

4.2.1 Specifications

The test cases will be the same as used by /Börgesson et al. 2006/, as the suggested method will be evaluated by direct comparisons with the simulations presented in this report. A tunnel of 12 m length and 5 m diameter is used, see Figure 4-1. Fractures cross the tunnel perpendicular to the axis of the tunnel and the problem is thus 2D in cylindrical coordinates. However, as DarcyTools does not embody this coordinate system (only Cartesian) all simulations in this report will be 3D. The distance between the fractures will be varied from 1 m to 24 m. When the fracture distance is 24 m, it is placed at one axial boundary while the other axial boundary is a symmetry plane. When the fracture distance is 1m it is possible, according to /Börgesson et al. 2006/, to replace the rock/fracture system with an equivalent higher conductivity; the problem then becomes 1D in cylindrical coordinates.

The axial boundary conditions are of the zero flux type, while the radial boundary is given a constant pressure value (simulating a deformation zone of infinite water supply).

A summary of the input data is given by Tables 4-1, 4-2, 4-3 and 4-4. As seen in Table 4-1, the properties of the backfill are fixed. The rock conductivity and fracture transmissivity are however varied by two orders of magnitude. This seems to be the right focus as the suggested method aims to include the properties of the rock (the large scale fracture network) in a realistic manner. We further choose to consider only the 1 m and 24 m fracture distances as other distances in between should work if the limiting cases are working correctly. The backfill materials considered (see Table 4-1) are 30/70, which is a mixture of bentonite and crushed rock, and F.Clay, which stands for Friedland Clay. The retention curves given in Table 4-3 are fitted to the empirical diagrams given in /Börgesson et al. 2006/.

4.2.2 Results

The time scales for saturation of the backfill are given in Table 4-5 (radial saturation) and Table 4-6 (axial saturation). The times found by /Börgesson et al. 2006/ are also included in the tables. We can directly conclude that the present results are in fair agreement with the results by /Börgesson et al. 2006/. It was earlier suggested that the specific storage for the backfill for $P > 0$ (after saturation) could be used as a calibration knob. The results are however not very sensitive to the value chosen as this parameter mainly determines the difference between the times t_{sat} and $t_{99\%}$. The values chosen ($10^{-5}\ m^{-1}$ for 30/70 and $3\times10^{-5}\ m^{-1}$ for F. Clay) seem appropriate. As the results are in fair agreement with the results by /Börgesson et al. 2006/, it was decided that no further “fine-tuning” is needed. One should note that all parameter values used are the once used by /Börgesson et al. 2006/ and it is of course an advantage if these values are kept.

Some further comparisons with the pressure fields given by /Börgesson et al. 2006/ can be found in Figures 4-2 and 4-3. Once again a good agreement is found. It is interesting to study the flow field for these cases, see Figure 4-4. The position where the flow starts to fill the space filled by air is easily identified.

Finally some tests with crushed rock as backfill were made. Crushed rock was simulated as part of a sandwich concept (bentonite and crushed rock layers); here we will use the crushed rock as a backfill material. As we can not compare these results with /Börgesson et al. 2006/ only two cases are reported, see Table 4-7.

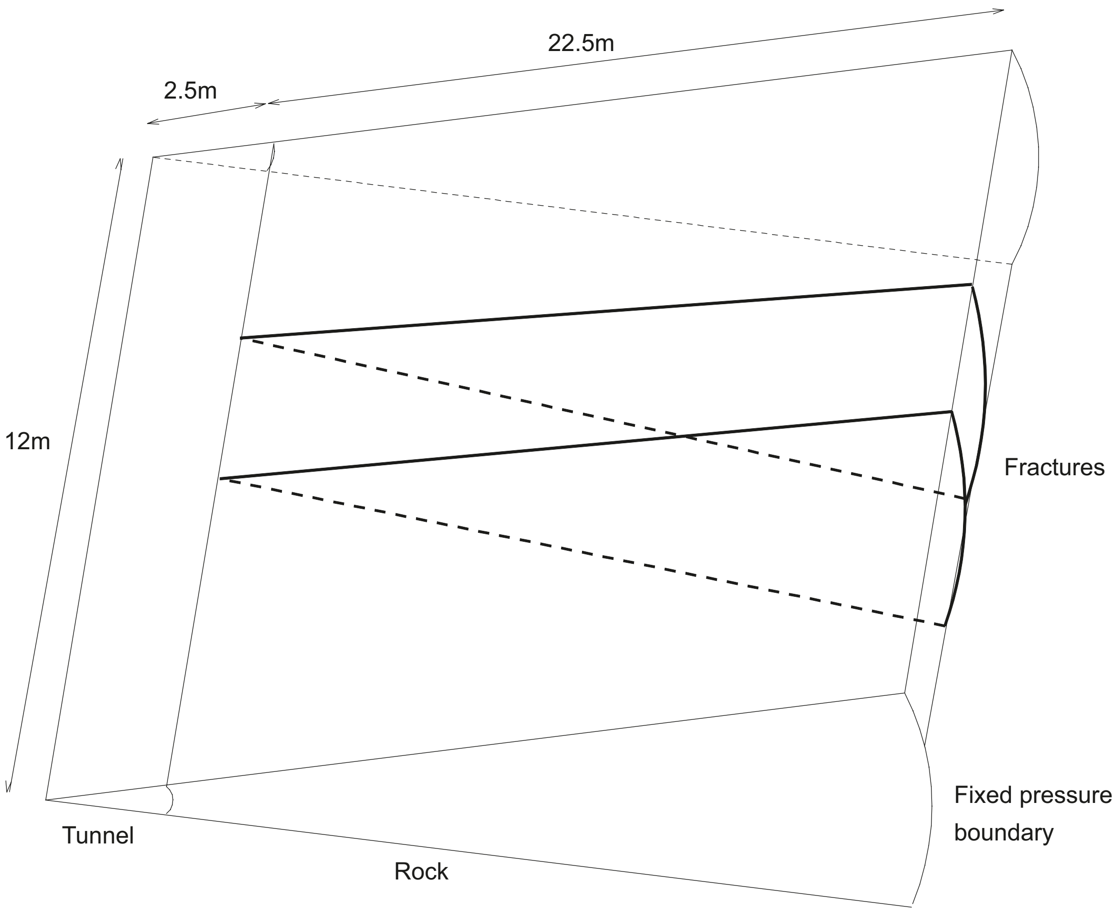


__Figure 4-1.__ Outline of the situation considered in the isothermal test cases.

Table 4-1. Compilation of calculation results for the *primary cases*. From /Börgesson et al. 2006/. Cases and properties shown in bold are considered in the present simulations.

Case	Boundary *u* (kPa)	Rock matrix *K* (m/s)	"EDZ" *K* (m/s)	Fracture dist. *d* (m)	Fracture *K* (m/s)	Average rock *K* (m/s)	*Q* into empty tunnel (l/min,m)	Time until saturation (years)			Remarks
								30/70	F. Clay	Sandwich	
aa1	**5,000**	**1E-13**	**1E-13**	**24**	**2.5E-7**	**2.1E-10**	**0.017**	**17.4–18.4** [3]	**120**	**270**	T_f **=5E-9** [5]
aa2	5,000	1E-13	1E-13	12	2.5E-7	4.2E-10	0.034	5.4–15.9	44	149	”
aa3	5,000	1E-13	1E-13	6	2.5E-7	8.3E-10	0.069	2.2–2.4	19	101	“
aa4	5,000	1E-13	1E-13	2	2.5E-7	2.5E-9	0.206	0.78–0.95	6.5	25	”
aa5	**5,000**	**1E-13**	**1E-13**	**1**	**2.5E-7**	**5.0E-9**	**0.413**	**0.52**	**4.3**	**24.4**	**“**
ab1	**5,000**	**1E-13**	**1E-13**	**24**	**2.5E-8**	**2.1E-11**	**0.0017**	**20.6–79**	**130**	**273**	T_f **=5E-10** [5]
ab2	5,000	1E-13	1E-13	12	2.5E-8	4.2E-11	0.0034	6.9–9.5	46	147	“
ab3	5,000	1E-13	1E-13	6	2.5E-8	8.3E-11	0.0069	3.0–(5.3)	20	99	“
ab4	5,000	1E-13	1E-13	2	2.5E-8	2.5E-10	0.0206	1.2–1.5	6.7	24–27 [3]	“
ab5	**5,000**	**1E-13**	**1E-13**	**1**	**2.5E-8**	**5.0E-10**	**0.0413**	**0.63(–0.87)**	**4.3**	**24–25** [3]	**“**
ac1	**5,000**	**1E-13**	**1E-13**	**24**	**2.5E-9**	**2.1E-12**	**0.00017**	**44–120**	**149–178**	**317**	T_f **=5E-11** [5]
ac2	5,000	1E-13	1E-13	12	2.5E-9	4.2E-12	0.00034	19–86	63–79	158	“
ac3	5,000	1E-13	1E-13	6	2.5E-9	8.3E-12	0.00069	9.5–79	31–33	105	“
ac4	5,000	1E-13	1E-13	2	2.5E-9	2.5E-11	0.00206	3.4–5.1	10.6	25	“
ac5	**5,000**	**1E-13**	**1E-13**	**1**	**2.5E-9**	**5.0E-11**	**0.00413**	**1.9–2.0**	**6.0**	**24–25** [3]	**“**

1) 1m on each side of the fracture.
2) Transmissivity of the "disturbed zone" that simulates piping along the rock surface.
3) First number: Time until *u*=0. Second number: Time until *u*=5,000 kPa.
4) Fracture(s) intersect(s) only the crushed rock part.
5) Transmissivity of fractures (m^2/s).

Table 4-2. Specification of properties and parameters for the backfill.

Parameter	Unit	Material 30/70	F.Clay	Crushed Rock
P_{ini}	Pa	-1.05×10^{6}	-43.1×10^{6}	-0.03×10^{6}
$S_{r,\ ini}$	–	0.58	0.3	0.7
K_{sat}	m/s	5×10^{-11}	7×10^{-12}	10^{-6}
δ	–	10	3	3
n	–	0.363	0.412	0.187
Δn	–	0.152	0.29	0.056
$S_{s,\ p>0}$	1/m	10^{-5}	3×10^{-5}	10^{-5}
$S_{s,\ p<0}$	1/m	1.5×10^{-3}	9.6×10^{-5}	1.8×10^{-2}

Table 4-3. Retention curves for the backfill ($S_{r,\ ini} \leq S_r \leq 1.0$).

Material	Retention curve
F.Clay	S_r = 0.30+0.70 (7.63–log (–P))/2.46
30/70	S_r = 0.58+0.29 (6.02–log (–P))/0.98
Crushed Rock	S_r = 0.68+0.32 (5.00–log (–P))/2.00

Table 4-4. Specification of properties and parameters for the rock.

Parameter	Unit	Fracture distance 1 m (radial)	24 m (axial)
K_{rock}	m/s	5×10^{-9}, 5×10^{-10}, 5×10^{-11}	10^{-13}
$S_{s,\ rock}$	1/m	10^{-8}	10^{-8}
n	–	10^{-3}	10^{-3}
T_f	m^2/s	–	5×10^{-9}, 5×10^{-10}, 5×10^{-11}
P_{ini}	Pa	0.	0.
$P_{bound.}$	Pa	5×10^{6}	5×10^{6}

Table 4-5. Radial saturation, time in years. t_{90} and t_{99} give the times for 90% and 99% of pressure recovery.

Case	Börgesson et al.	$t_{p>0}$	t_{90}	t_{99}
aa5, 30/70	0.52	0.39	0.40	0.42
ab5, 30/70	0.63–0.87	0.51	0.53	0.57
ac5, 30/70	1.9–2.0	1.8	1.9	2.0
aa5, F. Clay	3.2–3.5	3.8	4.1	4.5
ab5, F. Clay	4.3	4.0	4.3	4.7
ac5, F. Clay	6.0	5.8	6.3	6.9

Table 4-6. Axial saturation, time in years. t_{90} and t_{99} give the times for 90% and 99% of pressure recovery.

Case	Börgesson et al.	$t_{p>0}$	t_{90}	t_{99}
aa1, 30/70	17.4–18.4	17.5	19.7	22.6
ab1, 30/70	20.6 –79.	18.6	21.1	24.0
ac1, 30/70	44–120	33.0	38.4	44.9
aa1, F. Clay	120	125	144	164
ab1, F. Clay	130	127	145	165
ac1, F. Clay	149–178	138	159	182

Table 4-7. Results for crushed rock, time in days. t_{90} and t_{99} give the times for 90% and 99% of pressure recovery.

Case	$t_{p>0}$	t_{90}	t_{99}
aa5, radial	1.8	2.2	2.6
aa1, axial	19	271	492

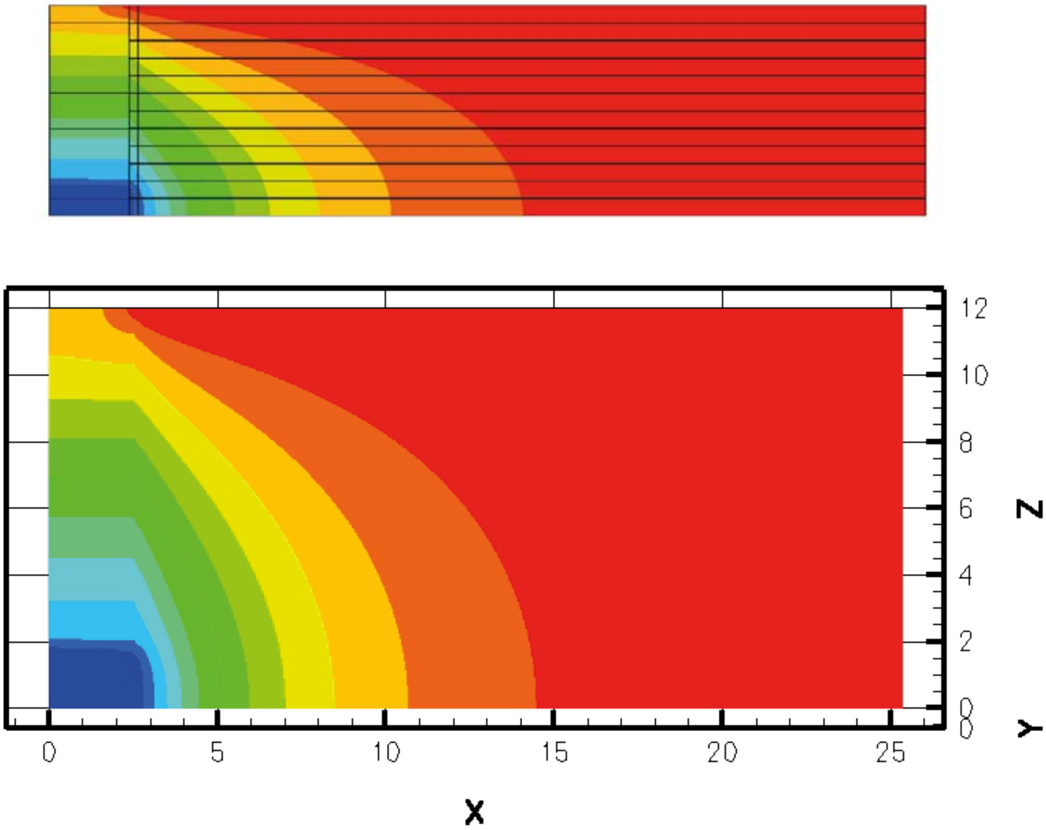


__Figure 4-2.__ Pressure. Axial saturation. Case aa1 after 13 years. /Börgesson et al. 2006/ (top) and present simulation. Red colour indicate maximum pressure (5 MPa) and blue minimum (–43 MPa).

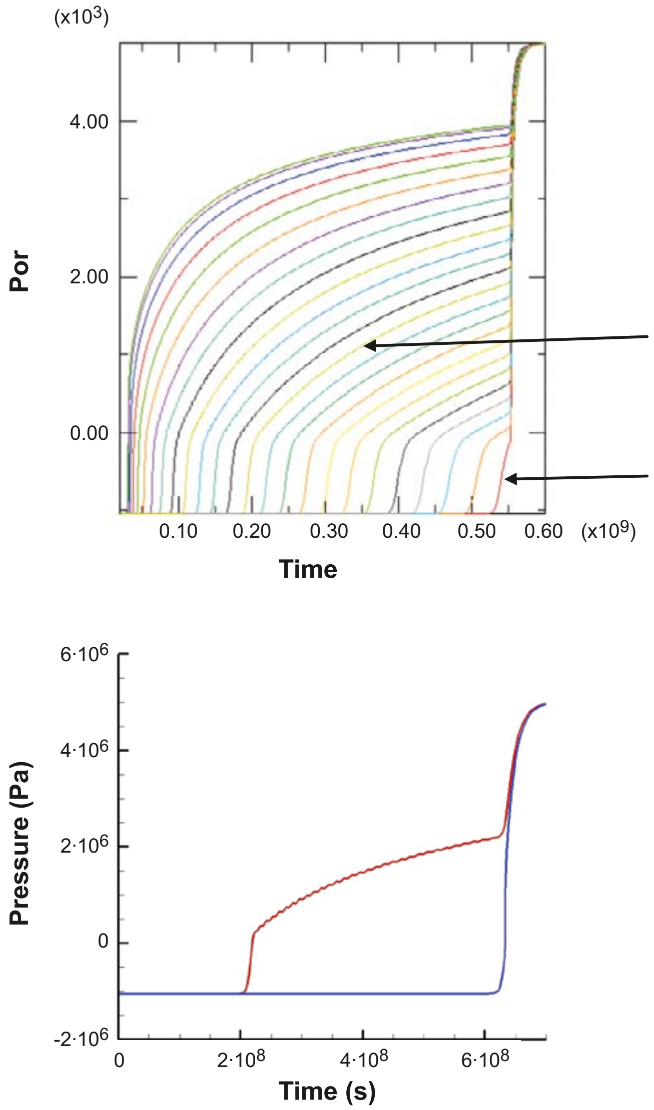


Figure 4-3. *Case aa1. Time development of pressure at 25 positions along the tunnel axis /Börgesson et al. 2006/ (top) and at two positions, bottom and midpoint (present simulation). In the top figure POR: means pressure in kPa, while Time is given in [s]. The two arrows in the top figure point to the curves that should be compared to the two curves in the bottom figure.*

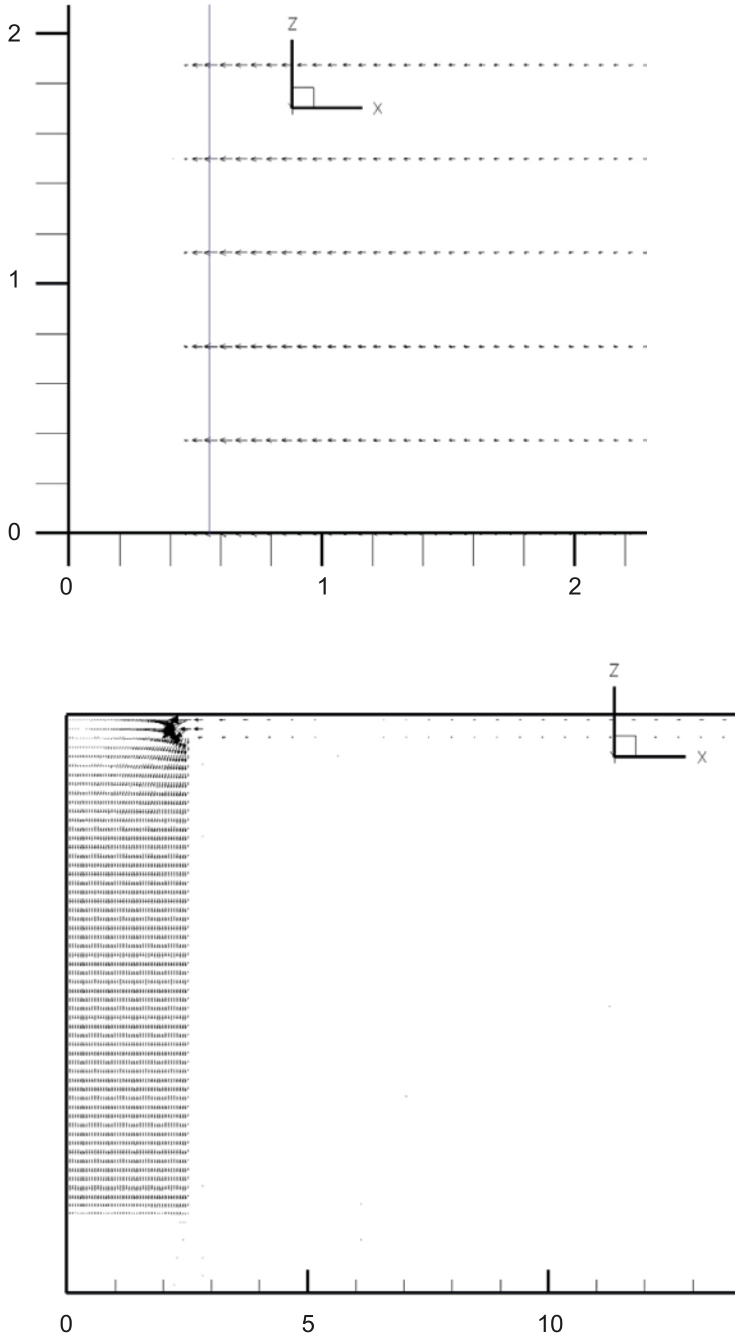


__Figure 4-4.__ Flow fields. Cases aa5 (top) and aa1. Case aa5 is a radial saturation case and the flow vectors are hence in the negative x-direction. As the radius of the tunnel is 2.5 m, the front has propagated for some time. From the figure we see that the front is at a distance of 0.5 m from the axis. Case aa1 is an axial case and the flow now enters by the horizontal fracture at the top boundary. In the tunnel the flow is in the axial direction and the front is a few meters above the lower boundary. Coordinates in the figures are given in [m].

4.3 A test case with a thermal load

4.3.1 Specifications

We quote the following sentences from /Börgesson et al. 2006/, see also Figure 4-5:

The geometry is shown in Figures 7-1 and 7-2. The model is 55 m high, 3 m thick (in direction 1) and 15 m deep (in direction 3). All vertical boundaries are symmetry planes, which mean that it models a KBS-3V repository of infinite extension with 6 m distance between the deposition holes and 30 m distance between the deposition tunnels. Figure 7-1 shows the different property areas and Figure 7-2 shows the fractures and the disturbed zones surrounding the hole and the tunnel. Since the disturbed zones have been given the same properties as the intact rock these zones will not be further dealt with. There are one horizontal fracture and four vertical fractures with a thickness of 2 cm (except the two fractures that form the vertical boundaries, which are 1 cm thick due to the symmetry conditions). The fractures are either given the same properties as the host rock and are thus not activated or given properties that yield a specified transmissivity.

A large number of parameters and property data is needed for a full specification of this case. This information is compiled from the report by /Börgesson et al. 2006/ and summarised in Table 4-8 and Table 4-9. The specific storage values are however based on the experiences from the present isothermal cases above. The data specified for the canister, gives in practice a hydraulically impermeable solid.

Boundary conditions are set as fixed pressure (5 MPa) and temperature (12°C) at the upper and lower boundaries. Vertical boundaries are symmertry planes. The power generation in the canister was modelled with a decay function, for details see /Börgesson et al. 2006/.

The variation in thermal conductivity for the buffer, λ [W/m,K], with saturation was specified as:

$$\lambda = 0.95+0.35\ (S_r - 0.61)/0.39 \quad (4\text{-}1)$$

which is a good approximation in the saturation interval considered /Börgesson et al. 2006/.

The computational grid used is illustrated in Figure 4-6. A fine grid is specified for the canister and the buffer regions, with an expansion out in the rock part.

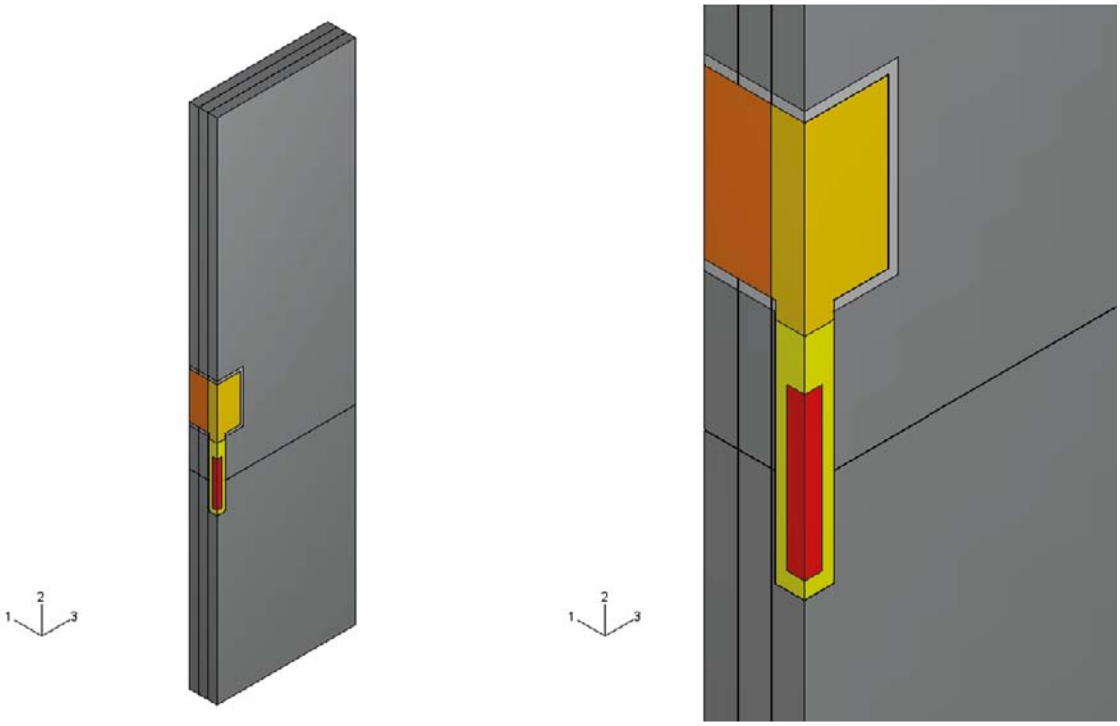
Several cases were considered by /Börgesson et al. 2006/, see Figure 4-7. Here we will focus on Case 4, the main case, which involves one horizontal and one vertical fracture. The fracture transmissivity was put to 5×10^{-10} m^2/s.

4.3.2 Results

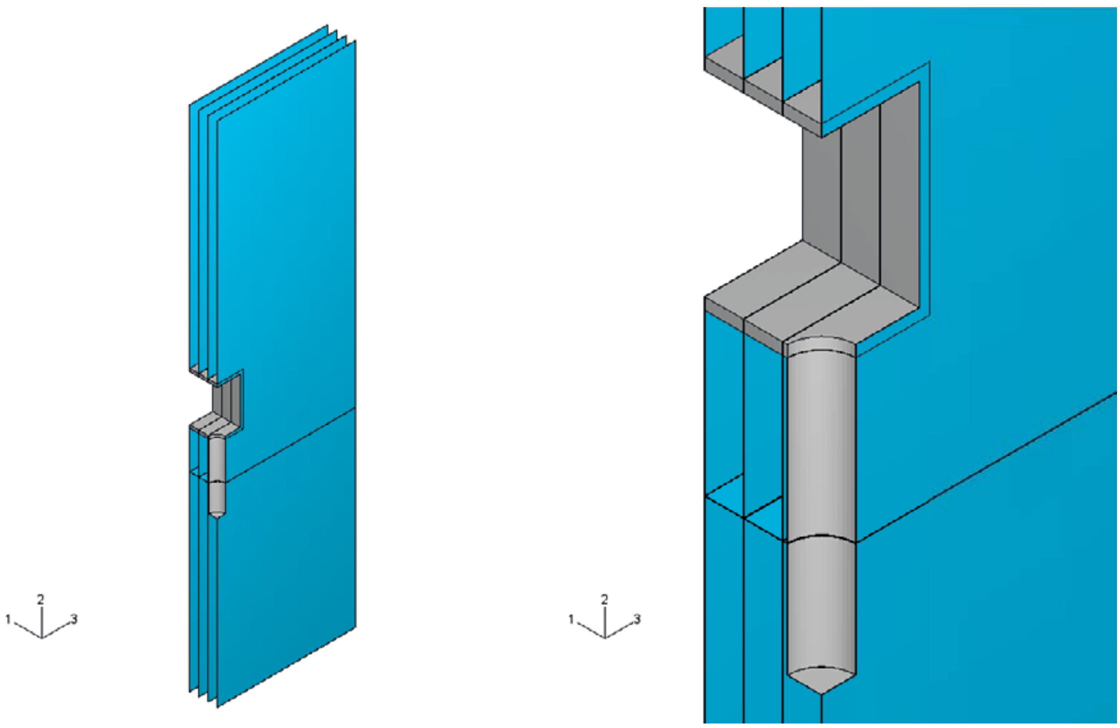
This is a 3D transient case with both heat transfer and flow and a huge amount of output data results. Here we will focus on the temperature development at the canister surface, Figure 4-8, and the saturation of the buffer, Figure 4-9.

A comparison of the temperature development on the canister surface, mid-height, can be found in Figure 4-8. In the figure from /Börgesson et al. 2006/, several curves are shown as four cases were considered. However, the difference between the four cases is not dramatic. The curve with the highest maximum temperature represents a case where the thermal conductivity specification given as initial conditions (i.e. unsaturated buffer) is kept throughout the simulation. As can be seen the maximum temperature will then increase by about 5°C, as the thermal conductivity is lower for this case. The same variation of Case 4 is considered in the present simulation, see Figure 4-8, and a very close agreement with the results by /Börgesson et al. 2006/ is found. The main conclusion from this is that the peak temperatures agree and that the sensitivity to the specification of the thermal conductivity is the same.

Times to reach 99% degree of saturation can be found in Figure 4-7. The present simulation gives roughly (± 20%) the same times for Case 4. In Figure 4-9 the pressure distributions after four years are compared. In both simulations the lowest pressure (about -10^7 Pa) is found above the horizontal fracture.



3D model. All vertical boundaries are symmetry planes. Grey: rock. Yellow: buffer. Orange-coloured: backfill. Red: canister.



Fracture configuration. Blue: fractures. Grey: EDZ (not activated).

Figure 4-5. *Outline of the situation studied. Reproduced from Figures 7-1 and 7-2 in /Börgesson et al. 2006/.*

Table 4-8. Specification of hydraulic properties and parameters.

Parameter	Unit	Region rock	 backfill	 buffer	 canister
K_{sat}	m/s	10^{-13}	5×10^{-11}	1.5×10^{-13}	10^{-14}
$S_{r,\ ini}$	–	1.0	0.58	0.61	0.61
P_{ini}	Pa	5×10^{6}	-1.05×10^{6}	-31×10^{6}	-31×10^{6}
$S_{s,\ p>0}$	–	10^{-8}	10^{-5}	3×10^{-5}	10^{-8}
$S_{s,\ p<0}$	–	10^{-8}	1.5×10^{-3}	8.5×10^{-5}	10^{-8}
n	–	10^{-3}	0.36	0.44	10^{-3}
Δn	–	–	0.152	0.17	–
δ	–	–	10	3	–

Table 4-9. Specification of thermal properties and parameters.

Parameter	Unit	Region rock	 backfill	 buffer	 canister
λ	W/m,K	3.0	1.5	1.3 (S_r = 1.0)	200
ρ	kg/m^3	2,600	2,000	2,010 (S_r = 1.0)	7,000
c	J/m^{3}K	2.1–10^6	2.4–10^6	2.6–10^6	2.8–10^6
T_{ini}	°C	12	12	12	12

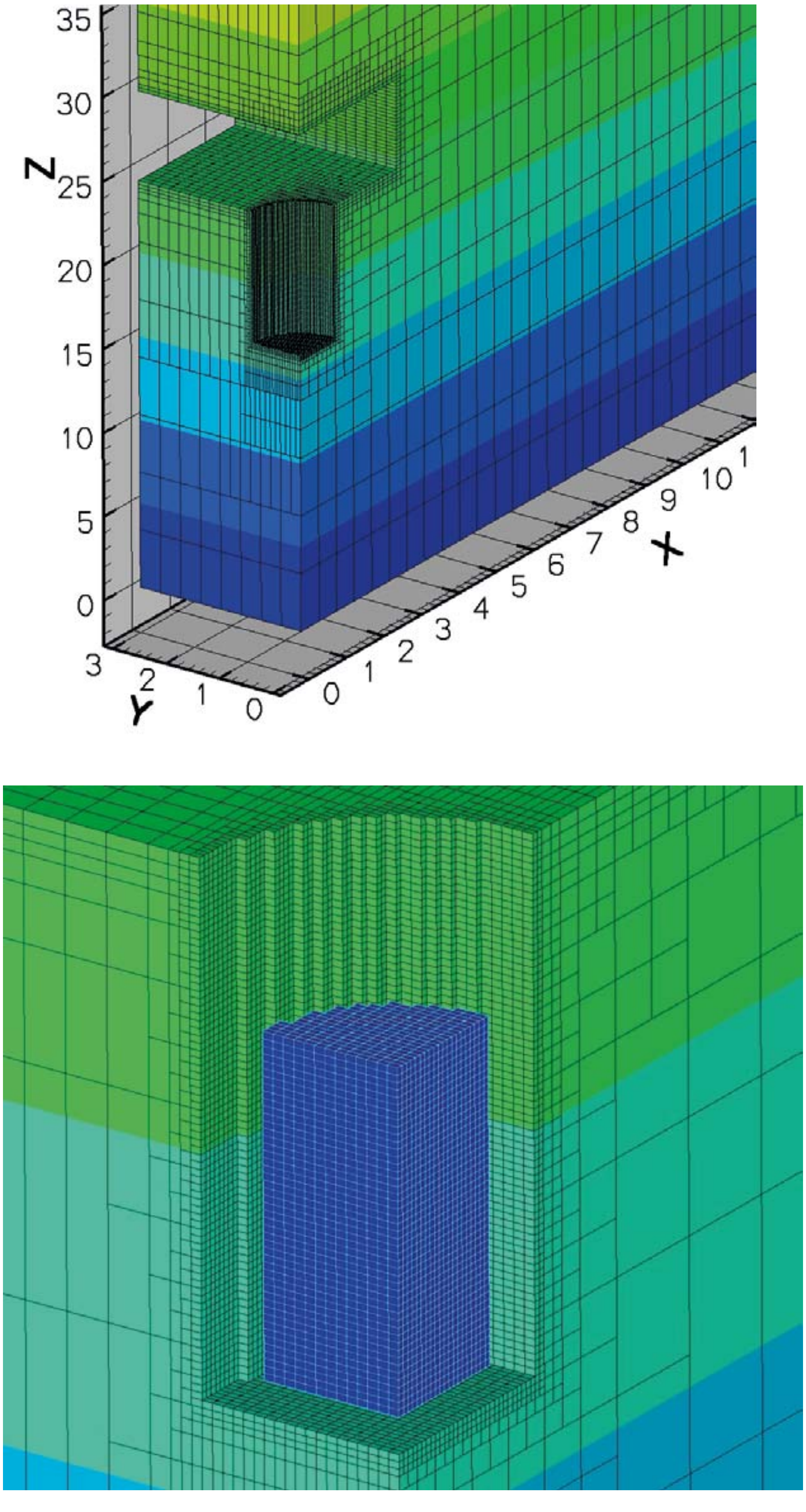
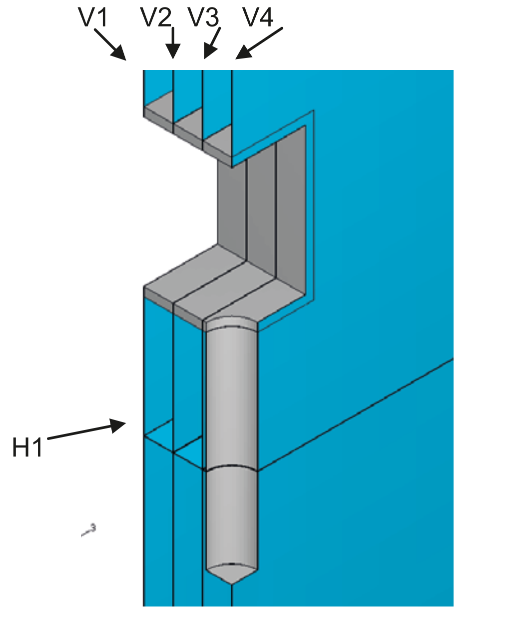


Figure 4-6. *Computational grid for present simulations. Rock domain (top) and detail showing the canister (blue) and the rock. The space in between the canister and the rock is the buffer zone.*

Overview of performed calculations.

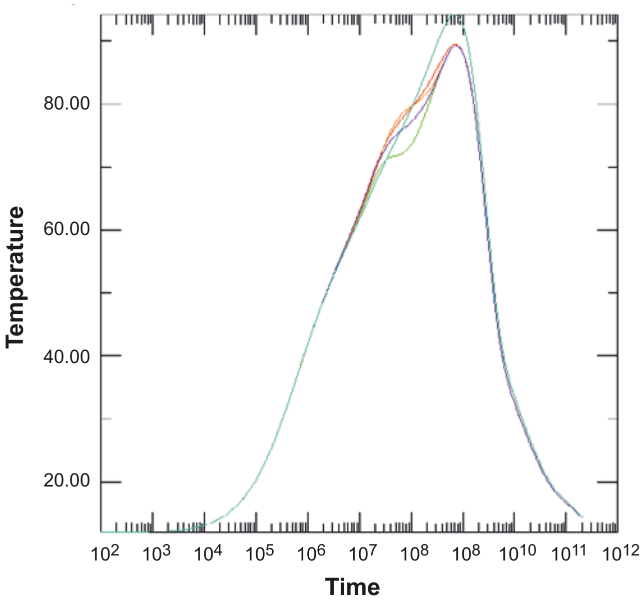
Calculation	Activated fractures	Comment
Case1	H1	Fed with water by the rock matrix
Case2	All	
Case3	V1	
Case4	V1 and H1	H1 fed with water by V1



Summary of results. Time until 99% degree of saturation of buffer and backfill.

Case	A ctivated fractures	Time to 99% degree of saturation			Remarks
		Buffer, mid can.	All buffer	Backfill	
1	H1	62 years	570 years	1 100 years	Wetted through matrix
2	H1, V1-V4	2.4 years	8.6 years	1.0 year	
3	V1	14 years	15 years	3.8 years	
4	H1, V1	4.4 years	16 years	4.4 years	Main case

Figure 4-7. *Specification of cases and results by /Börgesson et al. 2006/. Reproduced from Table 7-2 and Table 7-3 in /Börgesson et al. 2006/. Here only Case 4, the main case, is simulated.*



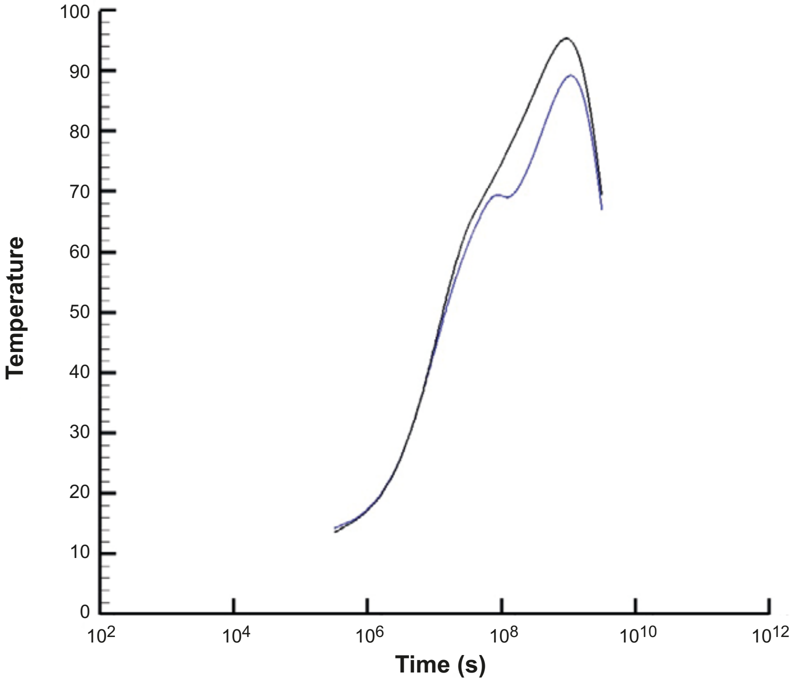


Figure 4-8. *Temperature development on the canister surface, mid-height canister. Top curve is based on a constant thermal conductivity, representative for unsaturated conditions. /Börgesson et al. 2006/ (top) and present simulations. In the top figure four cases are shown for a variable thermal conductivity; these are the cases specified in Figure 4-7. In the present simulations (lower figure) only one case with a variable conductivity is simulated (blue curve).*

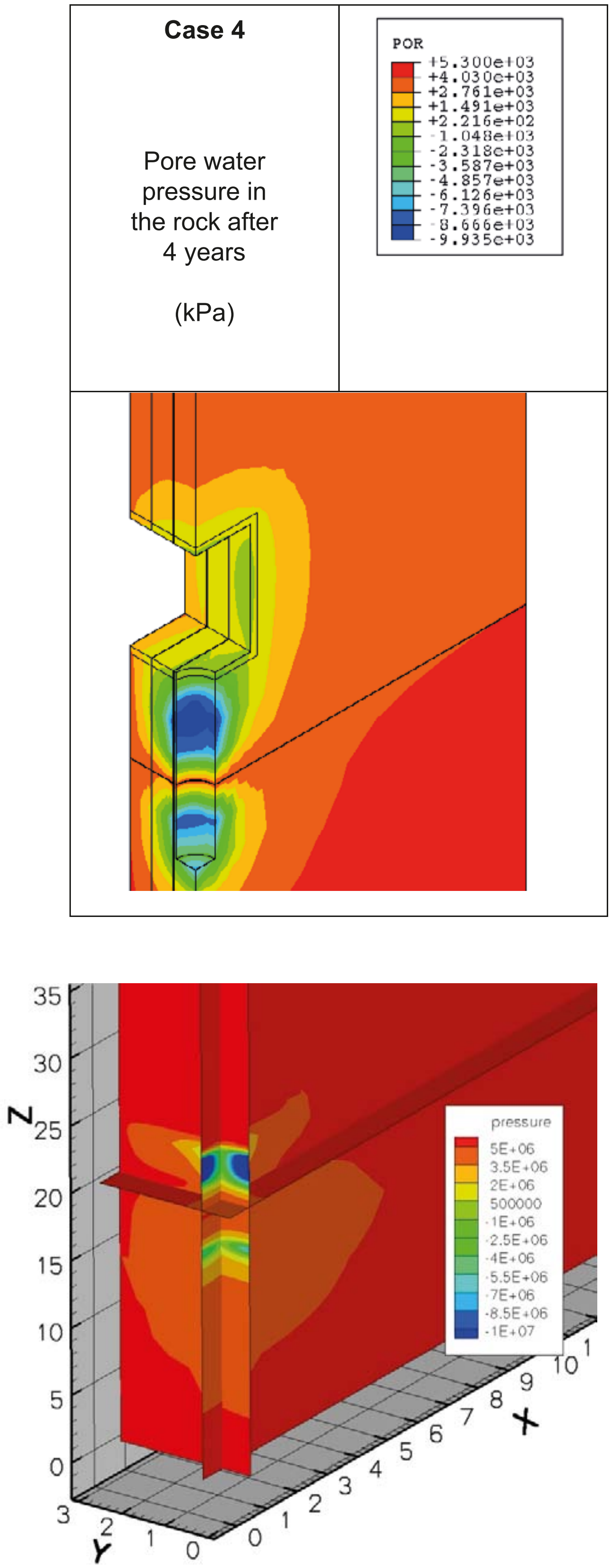


Figure 4-9. *Pressure distribution after four years. /Börgesson et al. 2006/ (top) and present simulations. The horizontal section in the lower figure is at the same position as the horizontal fracture, indicated in the top figure. Note that the pressure is given in kPa in the top figure and in Pa in the lower one.*

4.4 Application to the Laxemar repository

4.4.1 Introduction

The final case to be discussed concerns an application to the Laxemar repository. The main objective is to demonstrate that the suggested model can be applied to a real world case.

The following points give the main specification of the case:

- a computational domain of size 600×700×40 m^3 encloses part B /Svensson 2006b/, see Figure 4-10, of the Laxemar repository,
- the fracture network is the same as used in earlier site scale models /Svensson 2006b/,
- the backfill is 30/70 which is assumed to fill all parts of the repository (also the deposition holes). Properties for 30/70 as given in Table 4-2.

It should be pointed out that both the layout and the fracture network are not relevant for the current view of the fracture network and layout. For this demo simulation this is however of no significance.

4.4.2 Results

The pressure fields at four times can be studied in Figure 4-11. It is clear that the fracture network controls the hydration, as the tunnel parts that are crossed by a fracture are saturated already after 50 days. After 10 years most of the tunnels are saturated.

As stated above these results should be considered as demo simulations. The sensitivity to domain size, computational grid and time steps have not been tested.

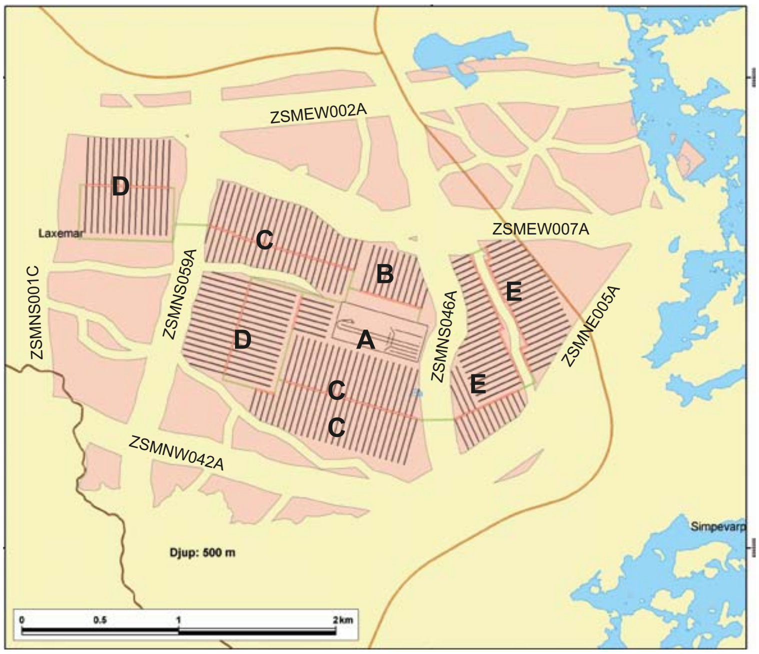
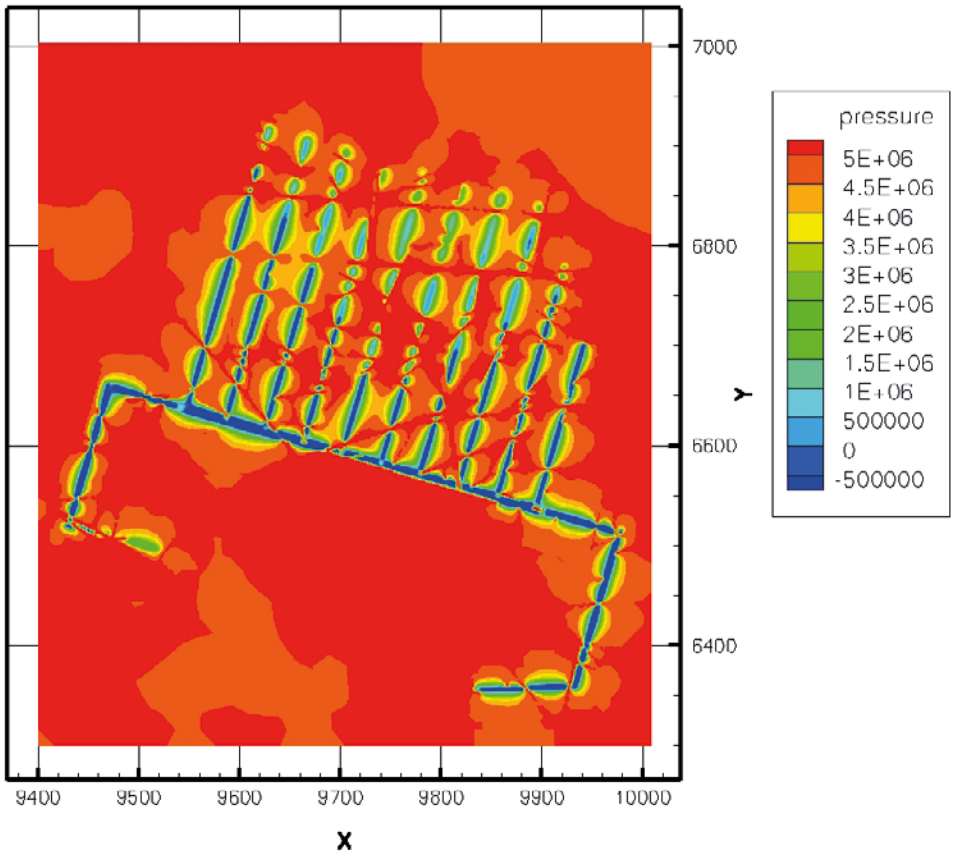


Figure 4-10. *Layout of the Laxemar repository, with specification of different parts.*



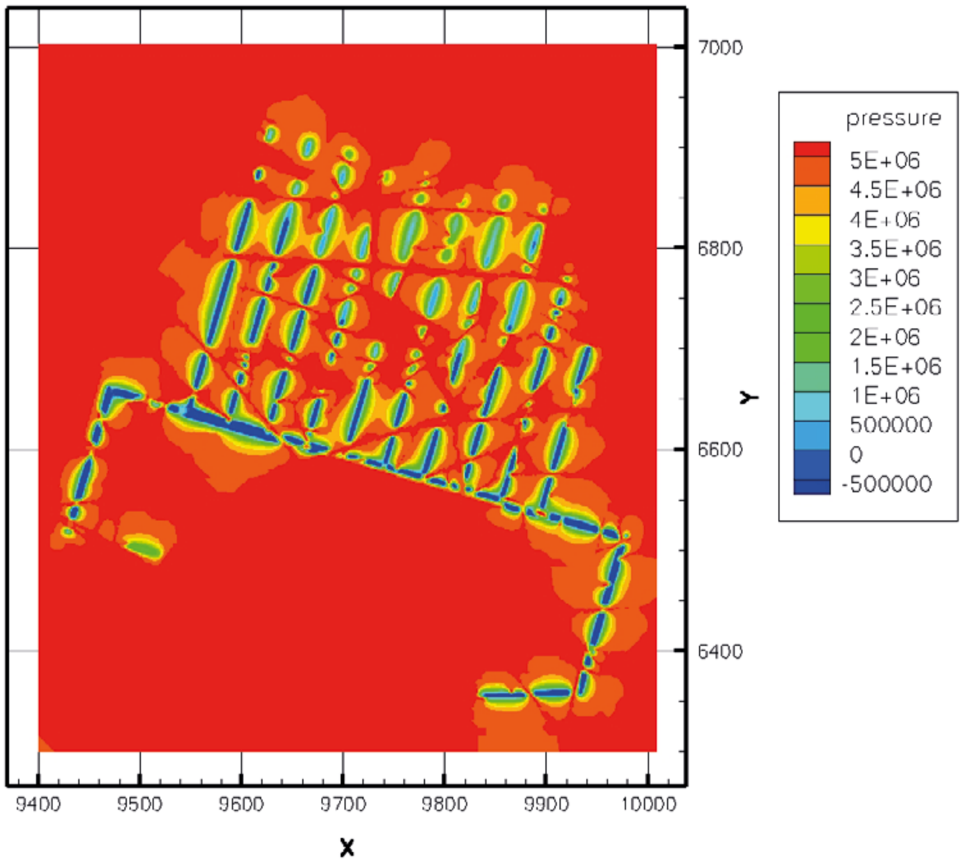


Figure 4-11. *Resaturation of tunnel part B. Pressure field after 50 days (top) and one year.*

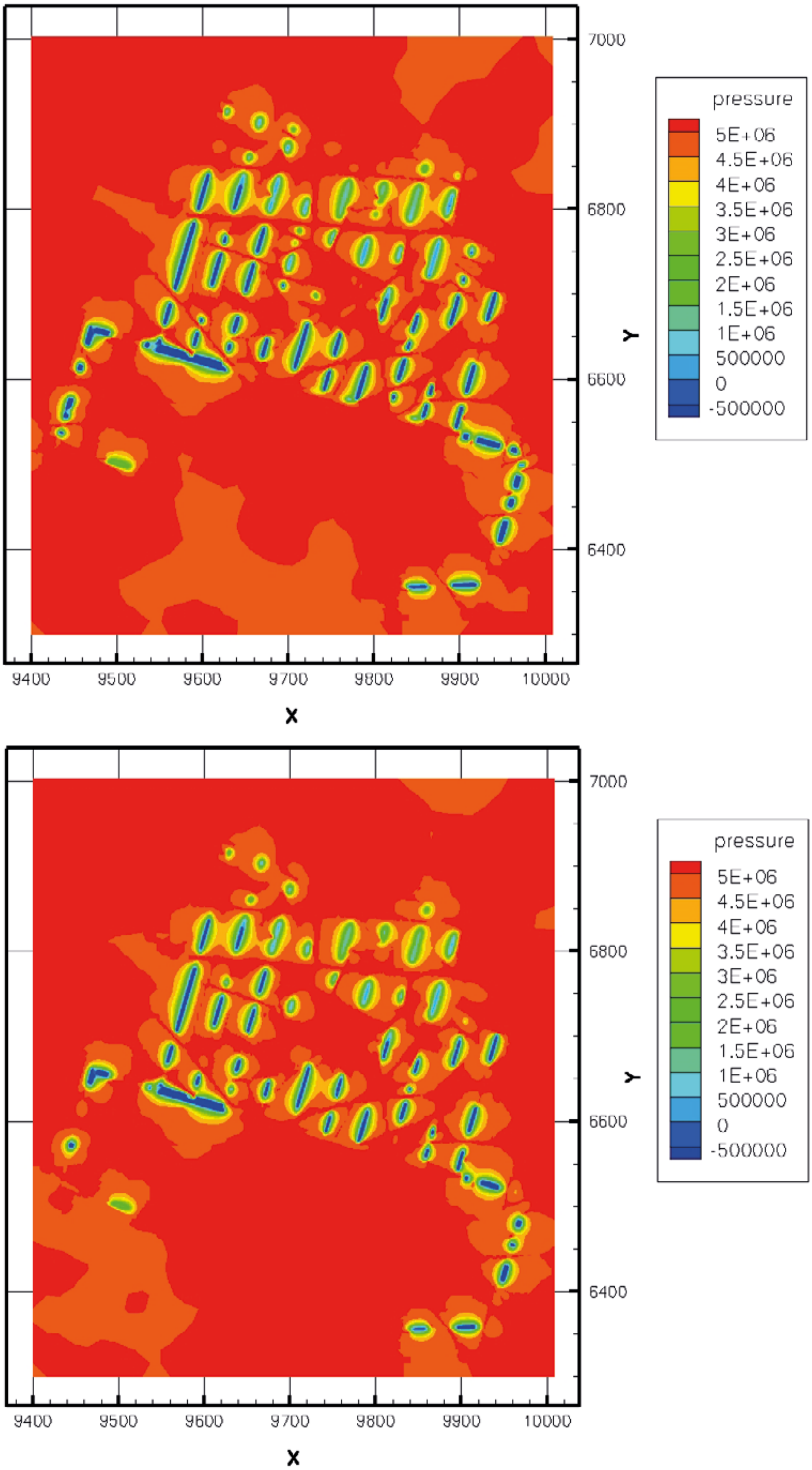


Figure 4-11, cont. *Pressure field after 5 years (top) and 10 years.*

5 Discussion

In the introduction it was stated that the method was introduced in /Svensson 2006 a, b/ and should now be "taken one step further". The link to the previous work is mainly that the idea of using the storativity term was introduced in the earlier work. We should hence regard the present report as the main reference for the method.

We will use the discussion section to give an overview of what has been presented; "Why is the development needed?" and "How can it be used?"

Needs

The reasons for our interest in the hydration time of a repository are listed in the introduction. Probably we can only estimate the hydration time by numerical simulation models. The presently available models, see /Börgesson et al. 2006/, have a good description of the basic physical processes but may not be applicable to a realistic repository geometry and a realistic fracture network. The method and model presented in this report aims at fulfilling also this requirement.

Use

If the present model can be claimed to be applicable to more realistic conditions, this comes with a price; the description of physical processes is simplified. For this reason it is suggested that the present model is used in combination with the more advanced two-phase models. If a certain backfill material is to be evaluated, it should first be simulated by the two-phase model and then the present model should be applied to the same test cases and results be compared; very much the same procedure as used in the present report.

6 Concluding remarks

A method to estimate the hydration time of a repository is suggested and evaluated. When a tunnel system has been backfilled with a certain material, it is expected that 30–50% of the pore volume is occupied by air. In the fully saturated limit this air has been replaced by water. The key idea in the suggested method is to "create" this volume by the use of the specific storage term and hence be able to stay within the single phase framework.

A series of test cases, defined and simulated in /Börgesson et al. 2006/, are used to demonstrate and evaluate the method. Encouraging results have been obtained. It is also shown that the simulation model can be applied to a real world case.

7 References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

Börgesson L, Fälth B, Hernelind J, 2006. Water saturation phase of the buffer backfill in the KBS-3V concept. Special emphasis given to the influence of the backfill on the wetting of the buffer. SKB TR-06-14, Svensk Kärnbränslehantering AB.

Svensson U, 2006a. The Forsmark repository. Modelling changes in the flow, pressure and salinity fields, due to a repository for spent nuclear fuel. SKB R-05-57, Svensk Kärnbränslehantering AB.

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Svensson U, Ferry M, Kuylenstierna H-O, 2010. DarcyTools, Version 3.4. Concepts, methods and equations. SKB R-07-38, Svensk Kärnbränslehantering AB.