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# Pellet optimization – influence of fine material

## KBP1011 Water handling during backfill installation

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*Keywords:* Bentonite pellets, Fine material, Fines, Wetting behaviour.

# Summary

In previous experiments aimed at optimizing pellet fillings, it was discovered that fine materials in pellet fillings has a clear impact on the water storage properties (Andersson and Sandén, 2012). It was observed that fine materials formed layers in the pellet filling which effectively redirected the wetting and prevented the wetting from continuing past the layer of fines. No investigations were however performed regarding how the presence of fines influenced the water storage capacity.

In another experiment in 2014 it was discovered that the water storing capacity of a pellet filling was increased when the used pellets were sieved, i.e. when no fines were present (Koskinen and Sandén, 2014).

This report describes new laboratory tests performed in order to study the influence of fines on the water storing capacity in pellet fillings of Asha and Cebogel pellets.

Tests were performed in two different setups: Tube tests in vertically mounted Plexiglas tubes (L=1.0 m, Ø=0.1 m) and large scale tests in a Plexiglas slot (L=2.0 m, H=1.0 m, W=0.25 m). In the tube tests the water storage capacity was examined for sieved pellet fillings, pellet fillings with 5 % respectively 10 % fines and pellet fillings with fines placed in layers. Water was added to the test equipment through water inlets. During the tests, the water inflow rates and water pressures were registered. The water storage capacity was documented by notes and photos.

The test results show that fines that are evenly distributed in a pellet filling does not affect the water storage capacity. However, if the fines are positioned in layers, the layers seem to direct the wetting in a certain direction and thereby decreasing the water storage. (The water storage is most efficient if the wetting can proceed symmetrically in all directions from an inflow point.)

A conclusion was also that the water content of the pellets has an impact on the water storage capacity of the pellet filling.

The test results have led to the following recommendations:

- Pellets should be sieved before installation.
- The pellet installation equipment should be set so that as little fines as possible is created during installation.
- Pellet water content should not exceed 20 % to optimize water storage capacity.

# Sammanfattning

I tidigare experiment som syftade till att optimera pelletsfyllningar upptäcktes att finmaterial i pelletsfyllningar har en tydlig inverkan på vattenlagringsegenskaperna (Andersson och Sandén, 2012). Det observerades att finmaterial bildade skikt i pelletsfyllningen som effektivt omdirigerade vätningen och förhindrade att vätningen fortsatte förbi skiktet. Inga undersökningar gjordes dock om hur förekomsten av finmaterial påverkat vattenlagringskapaciteten.

I ett annat experiment i 2014 upptäcktes att vattenlagringskapaciteten hos en pelletsfyllning ökades när pelletarna siktades, dvs. när pelletfyllningen inte innehöll något finmaterial (Koskinen och Sandén, 2014).

I denna rapport beskrivs nya laboratorietester som utförts för att studera finmaterialets inverkan på vattenlagringskapaciteten hos pellets framställda av bentoniterna Asha och Cebogel.

Tester utfördes i två olika testuppställningar: Försök i vertikalt monterade plexiglasrör (L=1,0 m, Ø=0,1 m) och storskaliga försök i en plexiglasspalt (L=2,0 m, H=1,0 m, W=0,25 m) . I rörförsöket undersöktes vattenlagringskapaciteten för siktade pelletsfyllningar, pelletsfyllningar med 5 % respektive 10 % finmaterial och pelletsfyllningar med finmaterial placerade i skikt. Vatten tillsattes till testutrustningen genom inflödespunkter. Under försöken registrerades vatteninflödet och vattentrycket. Vattenlagringskapaciteten dokumenterades med anteckningar och foton.

Resultaten visar att finmaterial som är jämnt fördelade i en pelletsfyllning inte påverkar vattenlagringskapaciteten. Om finmaterialet är placerat i skikt verkar skikten emellertid leda vätningen i en viss riktning och därigenom minska vattenlagringen. (Vattenlagringen är som mest effektiv om vätningen kan fortsätta symmetriskt i alla riktningar från en inflödespunkt.)

En slutsats var också att pelletarnas vattenhalt har en inverkan på pelletsfyllningens vattenlagringskapacitet.

Testresultaten har resulterat i följande rekommendationer:

- Pellets bör siktas före installation.
- Pelletsinstallationsutrustningen bör ställas in så att så små mängder finmaterial som möjligt genereras under installationen.
- Pelletarnas vattenhalt bör, för att optimera vattenlagringskapaciteten, inte överstiga 20 %.

# Contents

# 1 Introduction

## 1.1 Objectives

The influence of fine material (fines) in a pellet filling has been investigated earlier regarding erosion properties (Sandén et al. 2008). In the project "System Design of Backfill" one of the sub-projects aimed to optimize the pellet filling regarding both erosion properties and water storing capacity (Andersson and Sandén 2012). In these tests it was observed that there was a clear influence of fines present in the filling regarding sealing and water uptake. During installation, the fines ended up in layers within the pellet filling, which then prevented the wetting to continue past the layer. No investigations have, however, been made regarding how the presence of fines influences the water storing capacity.

Large scale tests have been performed at Äspö HRL in the steel tunnel equipment (Koskinen and Sandén 2014) aiming to investigate the water storing capacity of pellet fillings and also if the storing could be improved by using geotextile to distribute the inflowing water over a larger area. One of the tests was performed using sieved pellets i.e. all fines were removed before installation. The results from this test suggested that the water storing capacity increased when no fines were present.

Another objective with the performed test series was to compare the water storage properties of pellets manufactured of Asha bentonite and the commercial Cebogel pellets.

This report describes new laboratory tests performed in order to test pellets manufactured of Asha and Cebogel and to study the influence of fines on the water storing capacity.

## 1.2 Water storage capacity

In different tests it has been observed that a bentonite pellet filling has a large ability to store water flowing into the deposition tunnel from the rock, see e.g. Dixon et al. (2008a, b) and Andersson and Sandén (2012). It has also been assessed that this ability probably is enough in order to avoid problems with inflowing water reaching the backfill front for the main part of the tunnels in a future repository at Forsmark and Olkiluoto (Sandén and Börgesson 2014).

The water storage capacity of a pellet filling is defined as the amount of water that is stored in a pellet filling without the occurrence of a channel flow. The water is often stored according to a certain pattern e.g. symmetrical around the inflow point. The storage pattern is depending on the water inflow rate (Åkesson et al. 2017). The water inflow fills the voids between the pellets and the individual pellets also take up water and swell. The swelling closes temporarily the flow paths in one direction, an inflow resistance is generated, and the water starts to flow in another direction. The flow resistance in a pellet filling is, however, rather low and local piping occurs during the water storage.

The installation of pellets in the gap between backfill blocks and rock has so far been made with shotcrete equipment where the pellets are blown into the gap. It is known from several tests in large scale that there often is a certain amount of fines present in the delivered pellet, especially when reaching the bottom of a big bag filled with pellets. The influence of fines on the water storing capacity has been discussed, and in some tests the fines have been removed in order to minimize the dust formation during the installation process. Formation of dust is also assessed as a problem with the pellet installation method using air entrainment (blowing).

# 2 Bentonite pellets, fine material and water salinity used in the performed tests

## 2.1 Bentonite pellets

Earlier tests have shown that pellets shaped as cylindrical rods with a diameter of approximately 6 mm have the best properties regarding water storage (Andersson and Sandén 2012), when comparing different pellet shapes. Other important material parameters are initial water content and density of the pellets. The 6 mm cylindrical rod shaped pellets are manufactured by extrusion i.e. the bentonite is pressed through a hole-matrix. The length of the pellets used in the test varied between 5 and 25 mm. In the tests described in this report only this type of pellets has been used.

The tests have included pellets made of two different materials:

1. **Asha NW BFL-L.** This bentonite is produced by Ashapura Minechem Co. The bentonite is quarried in the Kutch area on the northwest coast of India. The bentonite is sodium dominated with a montmorillonite content of about 70 %. The pellets made of this material have been manufactured at Äspö HRL (batches of the raw material were delivered to SKB 2010 and 2012). Material data sheet is provided in Appendix 1.
2. **Cebogel QSE**. This is a commercial bentonite product. The bentonite is an activated sodium bentonite origin from the island Milos, Greece. Typical value of the montmorillonite content is 80 %. This pellets type has been used in many different large scale tests at Äspö HRL. Product data sheet is provided in Appendix 2.

The Asha material is of high interest for SKB as a backfill candidate material while Cebogel is of high interest for Posiva as backfill pellets.

### 2.1.1 Bentonite pellet properties

The bentonite pellet properties regarding water content, density of the single pellets and density of filling were measured.

#### *Water content*

The water content is defined as mass of water per mass of dry substance. The dry mass is obtained by drying the wet specimen at 105 °C for 24 hours.

The sample was placed in aluminium tin and the bulk mass ($m_b$) of the sample determined by use of a laboratory balance (accuracy 0.001 g). The sample was then placed in an oven for 24 h at a temperature of 105 °C. The dry mass of the sample ($m_s$) was determined immediately after take out. From these measurements the water mass ($m_w$) was calculated:

$$m_w = m_b - m_s \qquad 2\text{-}1$$

and the water content (w) of the sample determined:

$$w = \frac{m_w}{m_s} \qquad 2\text{-}2$$

#### *Bulk density, dry density and degree of saturation of single pellets*

The bulk density was determined by hanging the sample in a thin thread under a balance. The sample was then weighed, first in air ($m_b$) and then submerged into paraffin oil ($m_{bp}$). The volume of the sample was then calculated:

$$V = \frac{(m_b - m_{bp})}{\rho_p} \qquad 2\text{-}3$$

where $\rho_p$ is the paraffin oil density. The bulk density of the sample was then calculated:

$$\rho_b = \frac{m_b}{V} \tag{2-4}$$

After determining the water content and the bulk density of each sample it was possible to calculate the dry density ($\rho_d$):

$$\rho_d = \frac{\rho_b}{1+w} \tag{2-5}$$

Since the density of the particles ($\rho_s$) and the density of the water ($\rho_w$) are known the degree of saturation ($S_r$) can be calculated:

$$Sr = \frac{w \cdot \rho \cdot \rho_s}{\left[\rho_s \cdot [1+w] - \rho\right] \rho_w} \tag{2-6}$$

The void ratio $e$ may be calculated from the density of the clay solids $\rho_s$ and the dry density $\rho_d$ according to:

$$e = \frac{\rho_s}{\rho_d} - 1 \tag{2-7}$$

A value of the particle density ($\rho_s$) of 2910 kg/m$^3$ has been used for the Asha pellets and 2780 kg/m$^3$ has been used for the Cebogel pellets.

### *Bulk density, dry density and degree of saturation of as-placed pellets*

The determinations of the as-placed bulk densities were made using a vessel made of Plexiglass (d = 240 mm, height = 245 mm). The vessel was filled with pellets ($m_{pellet}$) and since the volume of the vessel was known, the density of the as-placed pellets could be calculated:

$$\rho_{pellet} = \frac{m_{pellet}}{V} \tag{2-8}$$

Using the same water content as determined earlier for the pellets type, the dry density and degree of saturation for the as-placed density could be calculated as described earlier.

## 2.1.2 Results

The results from the measurements are provided in Table 2-1 and in Figure 2-1.

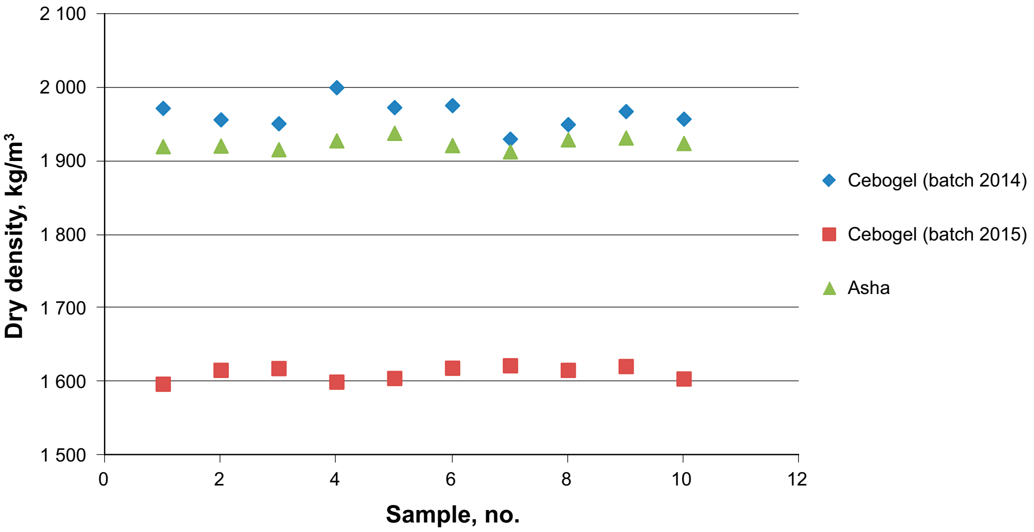


***Figure 2-1.** Dry density of single pellets plotted for the three batches.*

**Table 2-1. Data from the investigation of the pellets used in the tests.**

**Asha**

| Pellet no. | Water content % | Bulk density kg/m³ | Dry density kg/m³ | Void ratio – | Degree of sat. % |
|---|---|---|---|---|---|
| 1 | 16.1 | 2229 | 1920 | 0.505 | 92.1 |
| 2 | 16.1 | 2230 | 1921 | 0.505 | 92.2 |
| 3 | 16.1 | 2224 | 1916 | 0.509 | 91.5 |
| 4 | 16.1 | 2238 | 1928 | 0.499 | 93.2 |
| 5 | 16.1 | 2250 | 1938 | 0.491 | 94.7 |
| 6 | 16.1 | 2231 | 1921 | 0.504 | 92.3 |
| 7 | 16.1 | 2221 | 1913 | 0.511 | 91.1 |
| 8 | 16.1 | 2240 | 1929 | 0.498 | 93.4 |
| 9 | 16.1 | 2243 | 1932 | 0.496 | 93.8 |
| 10 | 16.1 | 2234 | 1924 | 0.502 | 92.7 |
| **Average** | **16.1** | **2234** | **1924** | **0.502** | **92.7** |

**Cebogel (batch 2014)**

| Pellet no. | Water content % | Bulk density kg/m³ | Dry density kg/m³ | Void ratio – | Degree of sat. % |
|---|---|---|---|---|---|
| 1 | 12.0 | 2209 | 1972 | 0.420 | 80.0 |
| 2 | 12.0 | 2191 | 1956 | 0.431 | 77.9 |
| 3 | 12.0 | 2185 | 1951 | 0.435 | 77.2 |
| 4 | 12.0 | 2240 | 2000 | 0.400 | 84.0 |
| 5 | 12.0 | 2210 | 1973 | 0.419 | 80.1 |
| 6 | 12.0 | 2213 | 1976 | 0.417 | 80.5 |
| 7 | 12.0 | 2162 | 1930 | 0.451 | 74.5 |
| 8 | 12.0 | 2184 | 1950 | 0.436 | 77.1 |
| 9 | 12.0 | 2204 | 1968 | 0.423 | 79.4 |
| 10 | 12.0 | 2192 | 1957 | 0.431 | 78.0 |
| **Average** | **12.0** | **2199** | **1963** | **0.426** | **78.9** |

**Cebogel (batch 2015)**

| Pellet no. | Water content % | Bulk density kg/m³ | Dry density kg/m³ | Void ratio – | Degree of sat. % |
|---|---|---|---|---|---|
| 1 | 24.1 | 1982 | 1597 | 0.753 | 89.6 |
| 2 | 24.1 | 2005 | 1616 | 0.733 | 92.1 |
| 3 | 24.1 | 2008 | 1618 | 0.730 | 92.4 |
| 4 | 24.1 | 1986 | 1600 | 0.750 | 90.0 |
| 5 | 24.1 | 1992 | 1605 | 0.745 | 90.6 |
| 6 | 24.1 | 2009 | 1619 | 0.730 | 92.5 |
| 7 | 24.1 | 2013 | 1622 | 0.726 | 92.9 |
| 8 | 24.1 | 2005 | 1616 | 0.733 | 92.1 |
| 9 | 24.1 | 2012 | 1621 | 0.727 | 92.8 |
| 10 | 24.1 | 1991 | 1604 | 0.745 | 90.5 |
| **Average** | **24.1** | **2000** | **1612** | **0.737** | **91.6** |

As shown in the table and in the graph, the dry densities of the single pellets are similar for the Asha pellets and the Cebogel 2014 pellets, between 1 900 and 2 000 kg/m³. The Cebogel pellets delivered in 2014 have, however, a considerably lower density, about 1 600 kg/m³. The water content of these pellets is also high, 24.1 %. Some descriptive statistical measures on the determined dry density of the three pellet batches are compiled in Table 2-2.

**Table 2-2. Descriptive statistics on dry density determinations on the three batches of bentonite pellets.**

| Material | Number of samples | Average dry density, kg/m³ | Max. dry density, kg/m³ | Min. dry density, kg/m³ | Standard deviation, kg/m³ |
|---|---|---|---|---|---|
| Asha | 10 | 1 924 | 1 938 | 1 913 | 7.6 |
| Cebogel, batch 2014 | 10 | 1 963 | 2 000 | 1 930 | 18.9 |
| Cebogel, batch 2015 | 10 | 1 612 | 1 622 | 1 597 | 9.3 |

Tests were also performed in order to determine the as-placed density of the pellets. The Asha pellets have an as-placed dry density of 974 $kg/m^3$. Corresponding values for Cebogel 2014 is 997 $kg/m^3$ and for Cebogel 2015 860 $kg/m^3$.

The density measurements were made on ten randomly selected pellets from each batch. The reason for the large differences between the two batches of Cebogel is not known. One explanation could be that the batch delivered in 2014 has been stored in a warm room which has resulted in that the pellets have dried which in turn also will lead to shrinkage and higher density of the pellets. It should also be mentioned that there often are differences in water content both between different big bags with the same material but also within one big bag. The water content was determined a number of times on the same material in conjunction with the different tests described in this report and there were evident differences in water content for the same material. The water content for the Asha pellets varied e.g. between 15.0 and 16.9 %.

### 2.1.3 Bentonite pellets used in different tests

The Asha pellets used in the tests were manufactured at Äspö HRL during the beginning of 2015. The Cebogel pellets were delivered at two different occasions, December 2014 and June 2015. The first delivery came from B+tech, Finland and was intended for another project but was also used in the first small scale tests, see test description in Chapter 3. The latter delivery of Cebogel pellets was used in the large scale slot tests, see description in Chapter 4.

## 2.2 Bentonite fine material

The Asha fine material used in the tests described in this report were created during the pellet manufacturing at Äspö HRL. A graph showing the granule size distribution is provided in Figure 2-2. The origin of the Cebogel fine material used in the test was a mixture of sieved materials and fines manually created by crushing pellets. The granule size distribution of this material was not determined (it was visually looking similar to the Asha fines).

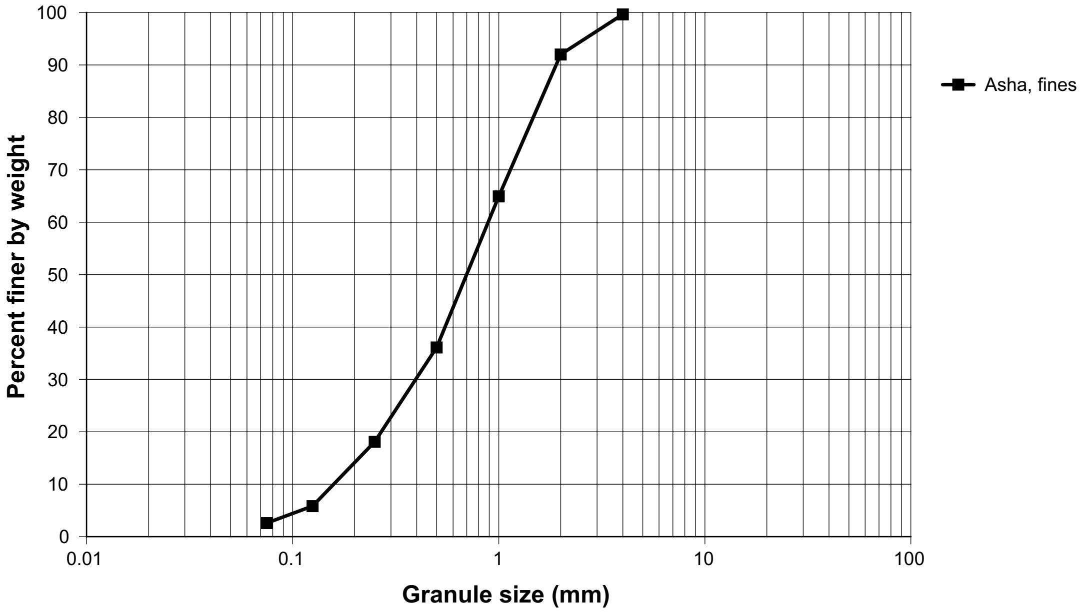


*Figure 2-2.* *Grain size distribution for the fine material used in the tests.*

## 2.3 Water

All tests have been performed using saline water with a salt content of 1 % (50/50 $NaCl/CaCl_2$). This water type corresponds well to the water salinity that is expected at the time for installation (Forsmark and Olkiluoto).

# 3 Tube tests

## 3.1 General

Two sources for fines present in a pellet filling have been identified:

1. As mentioned earlier, fines are often present at the bottom of big bags. These fines have probably been created in conjunction with the pellet manufacturing and perhaps also during the transportation.
2. Earlier tests performed within the project "System design of backfill" have shown that installation of pellets with a shotcrete equipment will create fines. Tests performed showed that at least 5 % fines will be created (Andersson and Sandén 2012).

It has also been found that the fines after installation of pellets often seems to be positioned in layers within the pellet filling (Andersson and Sandén 2012). The main reason is probably the difference in mass and size which make them separate during the flight (when blown or poured into the gaps) and also at landing when bouncing against pellets. A more careful installation of pellets may result in a more homogenous distribution of the fines in the filling.

## 3.2 Method

Tube tests have been performed in an earlier project in order to determine the water storing capacity for different pellet types (Andersson and Sandén 2012). The test equipment consists of a Plexiglas tube ($d = 0.1$ m, $L = 1.0$ m) that during the test is oriented vertically. The total volume of the tube is 7.85 litres. The pellet filling is held in place by perforated steel plates, mounted at the tube ends, through which the flowing water can easily pass, Figure 3-1. A water inlet (point inflow) is placed at the centre of the tube. During the tests the water inflow rate and the water pressure were registered at decided intervals. The water storing capacity, upwards and downwards was documented by notes and photos.

The content of fines has been carefully controlled in all tests in order to facilitate the test evaluations. All delivered pellets were sieved i.e. all fines were removed. The following test types were thereafter performed in the tubes:

1. Tests with pure pellet fillings, Figure 3-2.
2. Tests with different amounts of fines added (5 or 10 %), Figure 3-3.
3. Tests have also been made where the fines were placed in layers in the pellet filling, For each layer test about 0.8 kg of fines divided into two layers, placed 10 cm below and above the inlet port, were used.

*Figure 3-1.* *The "Tube test" equipment used for studying the influence of fines in the pellet filling.*

*Figure 3-2.* *Asha extruded 6 mm pellets used in the Tube tests.*

*Figure 3-3. Asha fine material used in the Tube tests.*

## 3.3 Test matrix

The planned test matrix included 18 tests performed with the two pellet materials of interest, Asha and Cebogel (batch 2014). The two pellet types were believed to have rather similar properties and therefore a selection of the tests that should be performed was made. It was assessed that the tests including 10 % fines have least interest (approx. 5 % fines have been estimated to be a realistic value) and therefore some of these test were removed. It has, however, been noted that the fines often end up in layers in the pellet filling and this kind of tests were also performed. The performed test matrix included in total 18 tests, 9 with each material, Table 3-1. The denominations of the performed tests are given in the table and if no denomination is stated, the test has not been performed.

**Table 3-1. Test matrix for the investigation of the influence of fines in a pellet filling.**

| **Asha extruded pellet** | | | | |
|---|---|---|---|---|
| **Water inflow rate** | **Fines** | | | |
| **l/min** | **0 % fines** | **5 % fines** | **10 % fines** | **Fines in layer** |
| 0.01 | AT_0.01_0 | AT_0.01_5 | | AT_0.01_L |
| 0.1 | AT_0.1_0 | AT_0.1_5 | AT_0.1_10 | AT_0.1_L |
| 0.25 | AT_0.25_0 | | | AT_0.25_L |

| **Cebogel extruded pellet** | | | | |
|---|---|---|---|---|
| **Water inflow rate** | **Fines** | | | |
| **l/min** | **0 % fines** | **5 % fines** | **10 % fines** | **Fines in layer** |
| 0.01 | CT_0.01_0 | | | CT_0.01_L |
| 0.1 | CT_0.1_0 | CT_0.1_5 | CT_0.1_10 | CT_0.1_L |
| 0.25 | CT_0.25_0 | CT_0.25_5 | | CT_0.25_L |

## 3.4 Results

A compilation of the results from the Tube tests is provided in Table 3-2. There was a small difference in the determined initial water content of the pellets compared to the results presented in Chapter 2. The difference depends probably on a certain variation between different big bags and probably also within an individual big bag. The two tested pellets types, Asha and Cebogel, behaved very similar. All tests performed with the highest inflow rate (0.25 l/min) and 0 % or 5 % fines in the filling, had an early flow downwards resulting in a leakage before the bentonite sealed and the water front instead went upwards. In general, the influence of fines mixed with the pellets was small; independent of the proportion of fines. However, if the fines were placed in layers, a phenomena that earlier have been observed could occur, there was a strong influence. At the position of the layers there was a local stop of the wetting process and the water pressure started to increase, see e.g. the green lines with pressure peaks between 150 and 700 kPa in Figure 3-4 and Figure 3-5.

**Table 3-2. Results from Tube tests with Asha and Cebogel 6 mm extruded pellet.**

| Test ID | Water content % | Bulk density kg/m³ | Water inflow l/min | Max. water pressure kPa | Time to first outflow h:mm | Test time h:mm |
|---|---|---|---|---|---|---|
| AT_0.01_0 | 17.0 | 1 198 | 0.01 | 65 | – | 3:10 |
| AT_0.1_0 | 17.0 | 1 195 | 0.1 | 18 | 0:10 | 0:32 |
| AT_0.25_0 | 17.0 | 1 179 | 0.25 | 39 | 0:01 | 0:23 |
| AT_0.01_5 | 17.0 | 1 172 | 0.01 | 39 | – | 2:57 |
| AT_0.1_5 | 17.0 | 1 172 | 0.1 | 20 | 0:12 | 0:33 |
| AT_0.1_10 | 17.0 | 1 185 | 0.1 | 15 | – | 0:27 |
| AT_0.01_L | 17.0 | 1 185 | 0.01 | 375 | – | 3:45 |
| AT_0.1_L | 17.0 | 1 172 | 0.1 | 500 | – | 0:25 |
| AT_0.25_L | 17.0 | 1 172 | 0.25 | 680 | – | 0:10 |
| CT_0.01_0 | 12.2 | 1 121 | 0.01 | 310 | – | 4:05 |
| CT_0.1_0 | 12.2 | 1 134 | 0.1 | 28 | 0:10 | 0:35 |
| CT_0.25_0 | 12.2 | 1 172 | 0.25 | 50 | 0:02 | 0:19 |
| CT_0.1_5 | 12.2 | 1 121 | 0.1 | 9 | – | 0:31 |
| CT_0.25_5 | 12.2 | 1 121 | 0.25 | 48 | 0:02 | 0:17 |
| CT_0.1_10 | 12.2 | 1 146 | 0.1 | 13 | – | 0:30 |
| CT_0.01_L | 12.2 | 1 146 | 0.01 | 335 | – | 1:45 |
| CT_0.1_L | 12.2 | 1 146 | 0.1 | 185 | – | 0:23 |
| CT_0.25_L | 12.2 | 1 146 | 0.25 | 135 | – | 0:09 |

Blue, red and orange small dotted lines show tests with water inflow 0.1 l/min and 0 %, 5 % and 10 % of fines respectively. Blue and red solid lines are tests with 0 % and 5 % fines together with 0.01 l/min inflow. The influence of fines on the water pressure in a pellet filling is evident when the fines are placed in layers, see all three green lines. Small water pressure peaks, which indicate local sealing and a following piping, could also be seen in all tests performed with the lowest water inflow rate (0.01 l/min).

The determined water pressure over time for the tests performed with Cebogel pellets are shown in Figure 3-5. As mentioned earlier the wetting behaviour was similar to the Asha pellets. Both tests with inflows of 0.01 l/min were stopped when the water pressure approached 300 kPa and thereby risked cracking the Plexiglas tube. The Cebogel tests also indicate that fines placed in layers will result in increased water pressure while fines mixed with the pellet do not influence the results.

The results from water pressure and water inflow rate measurements for every individual test are provided in Appendix 4 and 5.

An example of results from a test (CT_0.25_0) performed with high water inflow rate, 0.25 l/min, and 0 % fines in the pellets, is provided in Figure 3-6. The photos are taken at different times after test start and show clearly how the inflowing water initially flows downwards, and there is also a leakage registered. However, after a few minutes the bentonite pellets starts to swell and seal, and the water front is instead progressing upwards, passes the inflow point and continue up to the top. The test is terminated after approximately 19 minutes when water starts to flow out through the perforated steel plate mounted at the top.

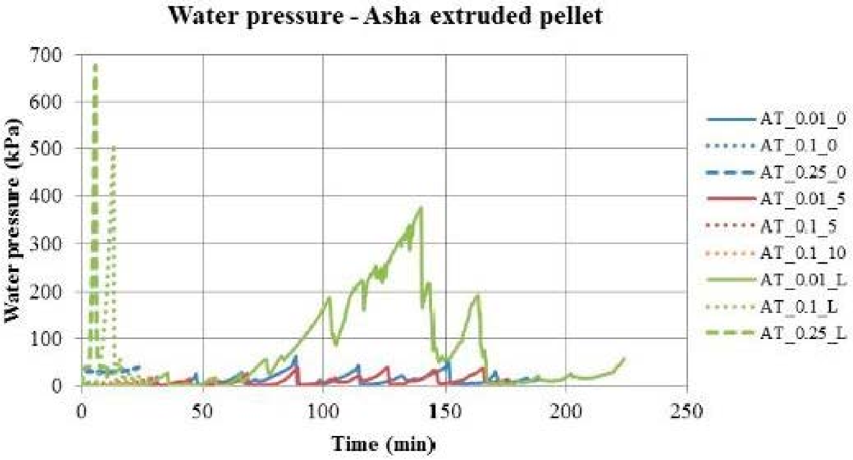


***Figure 3-4.*** *Water pressure for Asha Tube tests with 1 % salinity.*

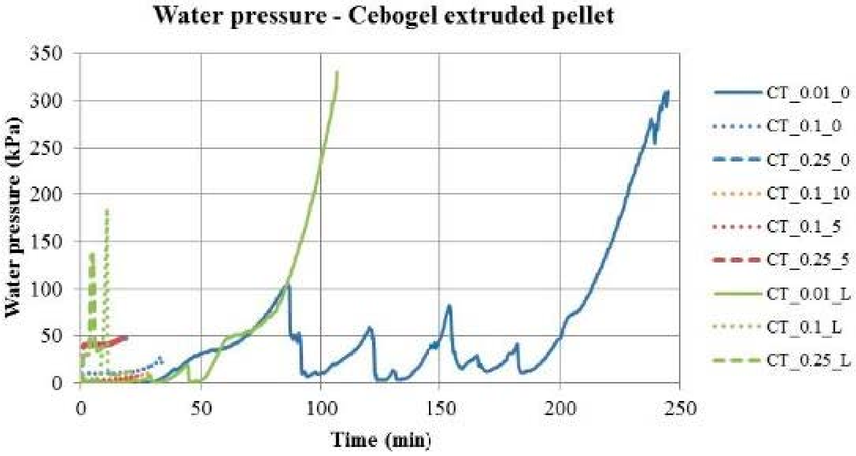


***Figure 3-5.*** *Water pressure for Cebogel Tube tests with 1 % salinity. CT_0.01_0 and CT_0.01_L were ended before water reached the top since high water pressure risked to break the equipment.*

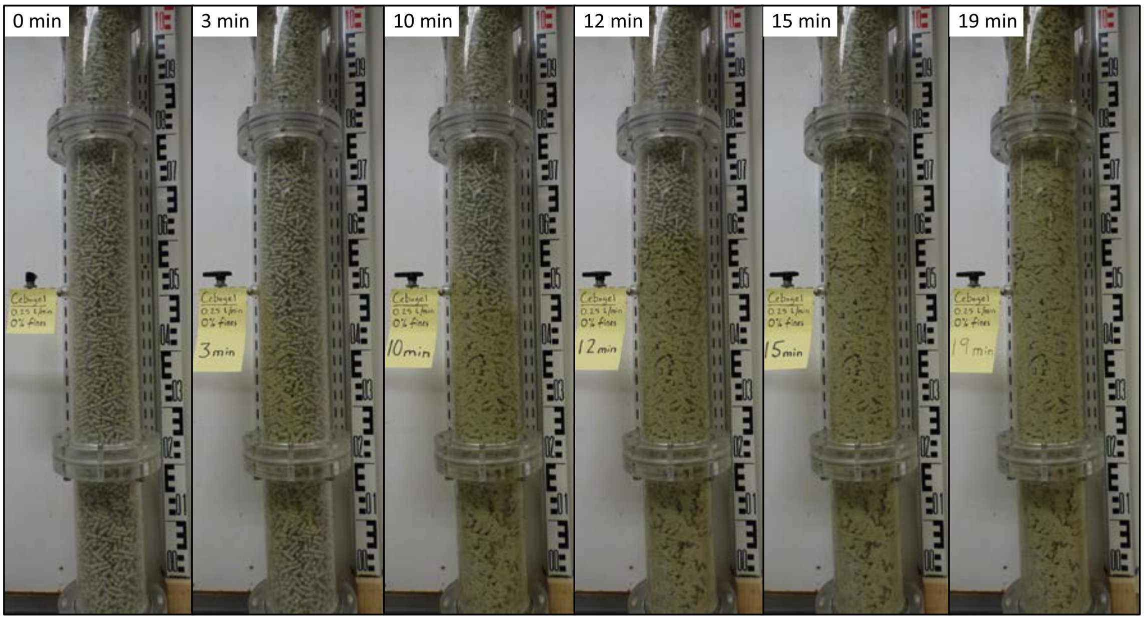


***Figure 3-6.*** *Photos of the test performed with Cebogel pellets, an inflow rate of 0.25 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*

The influence of fines can be studied by comparing tests performed with the same water inflow rate, 0.1 l/min, and different amounts of fines present in the pellet filling (0 %, 5 % and 10 %). Figure 3-7 shows how the pellet wetting has proceeded after 20 minutes tests. The photos show the results from both Asha and Cebogel tests. The influence of fines in the pellet filling seems to be very small when it is distributed reasonably evenly in the pellet filling.

Figure 3-8 shows the results from tests performed with fines positioned in layers. The photos show the results from tests performed with different water inflow rates with both Asha and Cebogel pellets. As shown in the photos, the layer of fines efficiently seals and prevents the wetting to continue to pellet filled parts on the other side. This prevents a continuous wetting and instead is a water pressure build up which, in a large filling, will result in piping and perhaps an establishment of a channel flow. The photos are taken at the time when the highest water pressure was reached (varies strongly depending on the applied water inflow rate).

Photos from all performed tests, taken at different times after test start, are provided in Appendix 6 and 7.

The visible water front level heights plotted over time are presented in Figure 3-9 and 3-10. Figure 3-11 and 3-12 shows the same plots during the initial 40 minutes in order to get better resolutions for the tests performed with higher inflow rates. The final sealing of the downwards water flow is marked with X in the figures.

As shown in the graphs, the progress of the water front level and sealing behaviour is similar for both Asha and Cebogel pellets. The overall tendency is initial downward movement of the water front followed by sealing whereupon water front level starts going upwards over the whole tube cross section.

The tests performed with pure pellets and pellets mixed with fines with the highest inflow rate, 0.25 l/min, resulted in immediate flow downwards and leakage of water through the bottom plate. The leakages in these tests did, however, seal and the wetting front could thereafter instead proceed upwards.

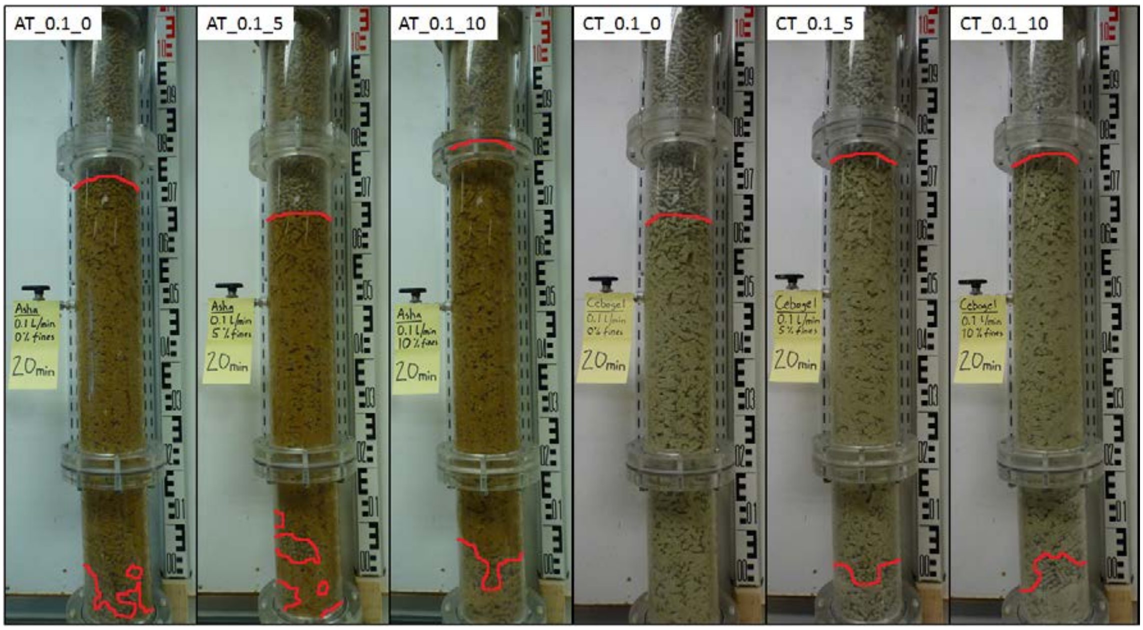


***Figure 3-7.*** *Photos of Asha and Cebogel Tube tests taken after 20 minutes test duration with water inflow rate of 0.1 l/min and different percentage of fines. The wetting behaviour is similar for all tests.*

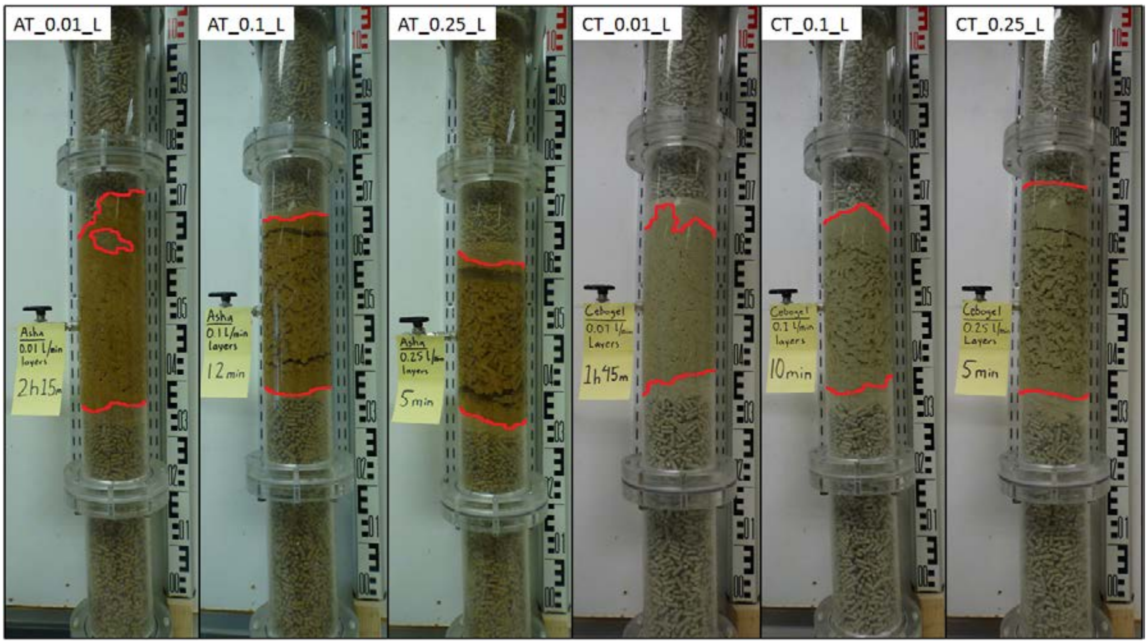


***Figure 3-8.*** *Photos of Asha and Cebogel tests where fines are positioned in layers. The photos were taken at the time for when maximum water pressure was reached.*

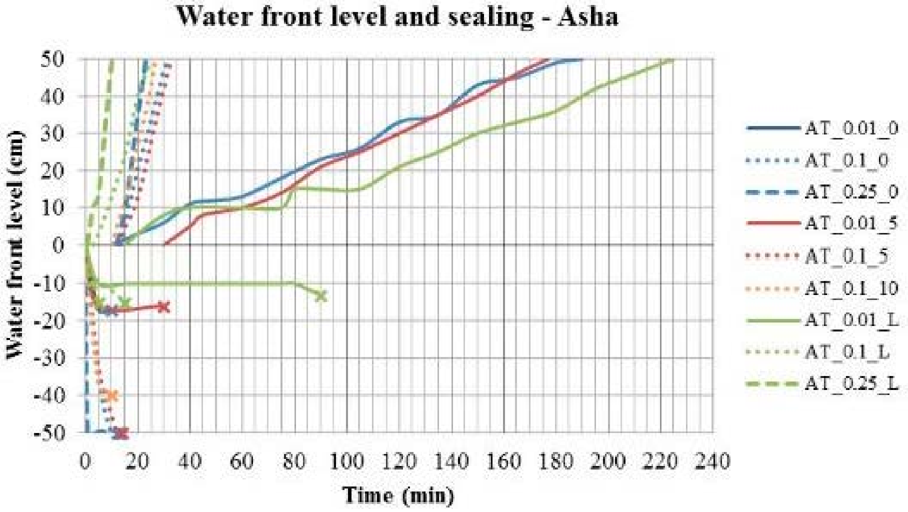


***Figure 3-9.*** *Water front level height and sealing for Asha Tube tests. The Y-axis displays the visible water front level in relation to the inflow point. X marks the eventual sealing of the water flow. Note the almost immediate flow downwards and following leakage through the bottom plate for test AT_0.25_0.*

***Figure 3-10.*** *Water front level height and sealing for Cebogel Tube tests. The Y-axis displays the visible water front level in relation to the inflow point. X marks the eventual sealing of the water flow. CT_0.01_0 and CT_0.01_L were ended before water reached the top since high water pressure risked to break the equipment. Note the almost immediate flow downwards and following leakage through the bottom plate for test CT_0.25_0 and CT_0.25_5.*

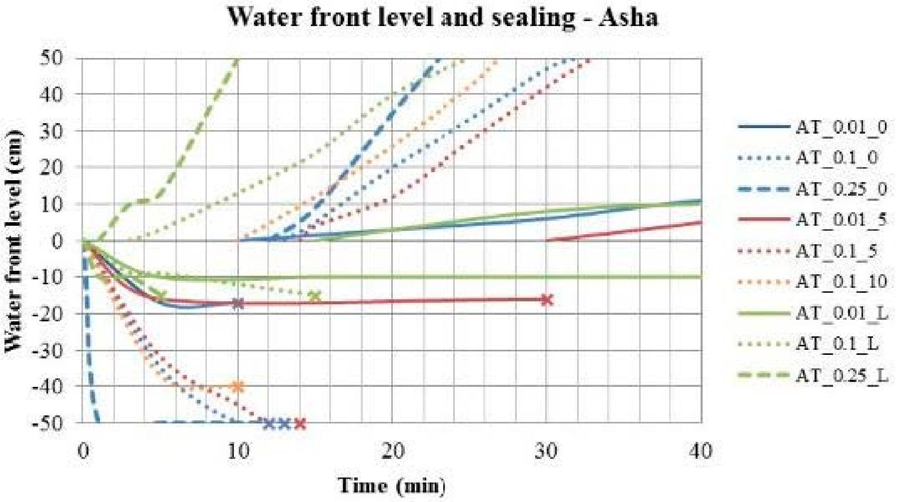


***Figure 3-11.*** *Initial 40 minutes water front level and sealing for Asha Tube tests.*

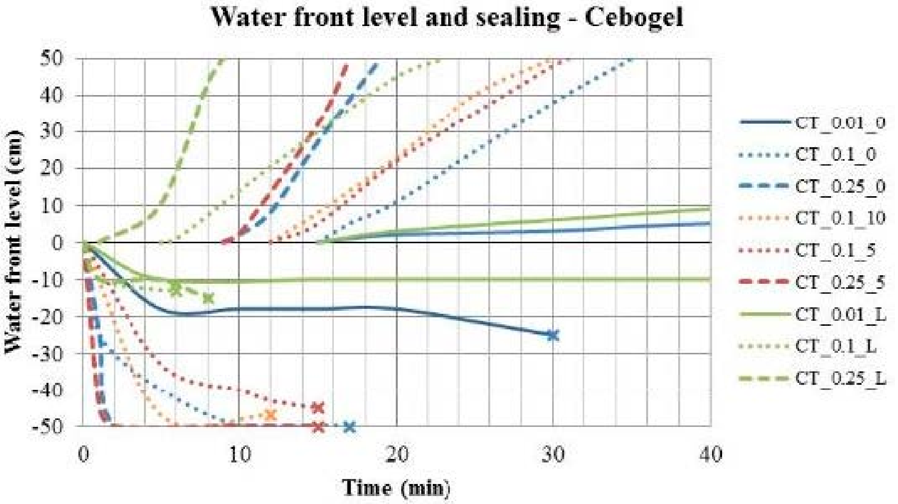


***Figure 3-12.*** *Initial 40 minutes water front level and sealing for Cebogel Tube tests.*

## 3.5 Comments

The performed tube tests are assessed to be a simple way to test pellets in rather small scale regarding different material parameters influencing the water storage capacity. The resulting wetting pattern for a certain water inflow is ultimately controlling the water storage capacity i.e. the time to first outflow from a pellet filling. A fast channel flow will result in a low water storage capacity while a symmetrical wetting around the inflow point will result in high water storage capacity. The tube tests show in principle only if the wetting is proceeding downwards or upwards in the filling while the larger slot tests presented in next chapter also shows the actual wetting pattern around the inflow point. From the tube tests the following conclusions can be made:

- Pellets made of Asha or Cebogel, with the tested properties regarding water content and density, have similar behaviour regarding water storage capacity. The later performed "Large slot tests", see Chapter 4, were performed with Cebogel pellets with different properties (high water content and low density) which strongly influenced the behaviour.
- All tested inflow rates results in an initial flow downwards from the inflow point. The highest inflow rate tested, 0.25 l/min, results in a water leakage through the perforated bottom plate, before the pellets can swell and seal. For all tested flow rates, the pellets swell and seal after a certain time, resulting in a water front that instead is proceeding upwards.
- Fines mixed with the pellet filling seem to be of less importance for the wetting behaviour. Tests have been made with 0 %, 5 % and 10 % of fines mixed with the pellets and no clear difference in behaviour could be detected. This depends probably on the fact that when the fines are evenly distributed between the pellets (in the macro voids), the amount of fast reacting swelling material is too small in order to seal the pathways which results in little or no effect on the wetting behaviour.
- When fines are positioned in layers, a phenomena that earlier have been noted could occur, the influence on the wetting behaviour was strong. The layer of fines seals efficiently and prevents the water front from proceeding. Instead a water pressure is built up which may lead to piping and establishment of a flow channel. Fines in layers, randomly positioned in a pellet filling can be a disadvantage, preventing the wetting process and decreasing the water storage capacity. The method may, however, also be used to direct the flow in a certain direction. Changing the pellet installation method from shotcrete equipment to a more gentle method will probably result in that the problem with layers disappears.

# 4 Large slot tests

## 4.1 Method

Besides the small scale tube tests described in Chapter 3, tests were also performed in larger scale using a test equipment especially designed for pellet filling tests. The test equipment is designed as a large slot made of Plexiglas. The Plexiglas is supported by a steel frame. The test equipment has a length of 2 m, a height of 1 m and a width 0.25 m, see Figure 4-1. This width is close to what is expected in the pellet filled gap between rock and backfill blocks in a deposition tunnel.

The slot was filled with pellets and then a constant flow rate was applied at the midpoint of one side. The water pressure and the water flow rate were continuously registered during the test duration and photos were taken at pre-determined intervals. The tests were stopped when water reached the top of the slot. Tests were performed with both sieved pellets i.e. all fines were removed but also with fines positioned in layers below and above the water inflow point. The layers were positioned at a distance of about 15 cm below and above the inflow point, see photos provided in this chapter. The amount of fines for two layers was about 12–13 kg.

At test termination, samples were taken from the pellets in order to determine the water content at a number of different spots. These values were then used to produce contour plots showing the wetting pattern at the time for termination.

***Figure 4-1.*** *The new "Large slot test" equipment.*

## 4.2 Test matrix

The original test matrix for the large slot tests is provided in Table 4-1. The original plan was to perform eight tests with each pellets type, four tests with sieved pellets and four tests where fines were placed in layers i.e. in total 16 tests. The tests were performed with four different water inflow rates, 0.1, 0.25, 0.5 and 0.75 l/min. The following two deviations were made from the original test matrix:

1. Asha pellets. Since the Asha pellets were delivered early and there was some extra time available before the delivery of Cebogel pellets, two extra tests were made:
   a. One extra test was performed with sieved pellets and an inflow rate of 1 l/min. The first tests with flow rates between 0.1 to 0.75 l/min had all shown similar behaviour and this was an attempt to check the limits regarding the water storing capacity.
   b. One test was performed where a geotextile filter was placed on the front with connection to the water inflow point. The geotextile had been tested in small scale tests earlier and this was an extra test in order to verify the function of the geotextile as a water distributor.
2. The behaviour of the Cebogel pellets was not as expected and the reason for this was found to be the high water content and the low density of the pellets (batch 2015). Due to these properties, observed wetting behaviours were similar regardless of inflow rate. In consideration of this fact and that the equipment was needed within another project, conducted by B+Tech, Finland, it was decided to not perform two of the planned tests with fines placed in layers (0.1 l/min and 0.5 l/min). The first test performed with Cebogel, 0.1 l/min with sieved pellets, was performed with a mixture of pellets from the old batch and from the latter batch. This test was later repeated in order to facilitate the test evaluation.

**Table 4-1. Original test matrix for the large slot tests. Test CL_0.1_L and CL_0.5_L were not performed but instead three extra tests were made.**

**Asha extruded pellet**

| **Water inflow rate l/min** | **Fines**<br>**0 % fines** | **Fines in layer** |
|---|---|---|
| 0.1 | AL_0.1_0 | AL_0.1_L |
| 0.25 | AL_0.25_0 | AL_0.25_L |
| 0.5 | AL_0.5_0 | AL_0.5_L |
| 0.75 | AL_0.75_0 | AL_0.75_L |

**Cebogel extruded pellet**

| **Water inflow rate l/min** | **Fines**<br>**0 % fines** | **Fines in layer** |
|---|---|---|
| 0.1 | CL_0.1_0 | CL_0.1_L |
| 0.25 | CL_0.25_0 | CL_0.25_L |
| 0.5 | CL_0.5_0 | CL_0.5_L |
| 0.75 | CL_0.75_0 | CL_0.75_L |

In total 17 tests were performed in the "Large slot test" equipment.

## 4.3 Results

A compilation of the performed tests and some important test data is provided in Table 4-2. The three extra tests, AL_0.5_geo (the test with geotextile attached on the inlet side), AL_1.0_0 (sieved Asha pellets with an inflow rate of 1.0 l/min), and CL_0.1_mix (this test was performed using pellets from two different batches) are also included in the table.

In conjunction with the preparation of a test, a sample was taken from the pellets in order to determine the water content. There was a small variation in water content in the pellets between the delivered big bags. The total amount of pellets installed in a test was weighed and thereafter an average bulk density could be calculated, Table 4-2.

The total amount of water injected during test time is also provided in the table. These figures could be compared to the theoretically available macro voids in a test which is about 225 litres.

The water pressure needed in order to keep up the applied water inflow rate was registered continuously. Graphs showing the registered water pressure and water inflow rate are provided for every individual test in Appendix 8 and 9. The water pressure varied a lot in all tests and the reason for this is partly due to the pump (the pump strokes) and partly due to the flow resistance in the pellet filling. In general, the water pressure increases when the applied water inflow rate is increased. It was not possible to see any special pressure peaks during the test durations, not even in the tests that were performed with special layers of fines in the pellet filling. This depends probably on the rather large size of the test equipment which made it possible for the water to instead choose another direction. The registered water pressures were in general somewhat higher for the tests including layers with exception for the tests with an inflow rate of 0.75 l/min were the situation instead was the opposite which is difficult to explain. Besides the ordinary pressure peaks, a small general water pressure increase was registered in most of the tests.

**Table 4-2. Compilation of important data for the performed tests.**

| Test ID | Water content<br>% | Bulk density<br>kg/m³ | Dry density<br>kg/m³ | Inflow<br>l/min | Total amount of water injected<br>litres | Test time<br>h:mm |
|---|---|---|---|---|---|---|
| AL_0.1_0 | 15.9 | 1 113 | 960 | 0.1 | 39 | 6:30 |
| AL_0.25_0 | 15.9 | 1 079 | 931 | 0.25 | 35 | 2:20 |
| AL_0.5_0 | 16.1 | 1 117 | 962 | 0.5 | 69 | 2:17 |
| AL_0.75_0 | 15.2 | 1 141 | 990 | 0.75 | 77 | 1:43 |
| AL_1.0_0 | 15.0 | 1 085 | 943 | 1.0 | 110 | 1:50 |
| AL_0.1_L | 15.0 | 1 139 | 990 | 0.1 | 40 | 6:40 |
| AL_0.25_L | 15.9 | 1 118 | 965 | 0.25 | 37 | 2:29 |
| AL_0.5_L | 15.9 | 1 149 | 991 | 0.5 | 55 | 1:49 |
| AL_0.75_L | 15.9 | 1 141 | 984 | 0.75 | 71 | 1:35 |
| AL_0.5_geo | 15.0 | 1 109 | 964 | 0.5 | 75 | 2:30 |
| CL_0.1_mix | 11.0 + 25.1 | 1 052 | na | 0.1 | 45 | 7:31 |
| CL_0.1_0 | 25.1 | 1 046 | 836 | 0.1 | 141 | 23:34 |
| CL_0.25_0 | 25.1 | 1 043 | 834 | 0.25 | 124 | 8:16 |
| CL_0.5_0 | 25.1 | 1 049 | 839 | 0.5 | 220 | 7:19 |
| CL_0.75_0 | 25.1 | 1 048 | 838 | 0.75 | 240 | 5:20 |
| CL_0.25_L | 25.1 | 1 052 | 841 | 0.25 | 118 | 7:52 |
| CL_0.75_L | 25.1 | 1 050 | 839 | 0.75 | 185 | 4:06 |

### 4.3.1 Wetting behaviour, Asha

The wetting pattern at termination of test AL_0.1_0 (sieved) and AL_0.1_L (fines in layer) is shown in Figure 4-2. It is clear that the two layers of fines have influenced on the water distribution. The lower layer has stopped the downward wetting and the upper layer has then spread the water to the right side before penetration of the upper layer occurs and water is reaching the top of the slot. Close-up photos of the test with layers are provided in Figure 4-3, showing the test after installation and just after having stopped the water inflow. The inflow rate is 0.1 l/min in both tests and the photos were taken at test termination after about 6.5 hours. The corresponding water content contour plots are presented in Figure 4-4. The black lines in the contour plot showing the test with layers installed, indicates the position of the layers at time for termination.

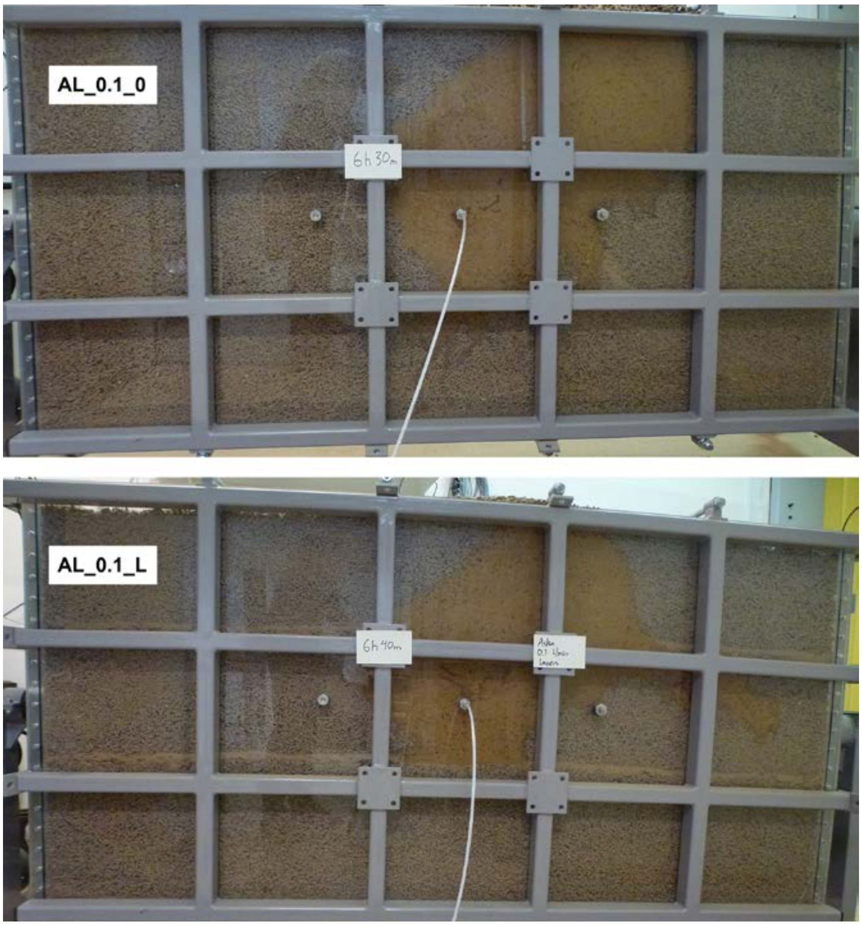


***Figure 4-2.** Photos showing the wetting pattern at time for termination. **Upper:** AL_0.1_0 (Asha, 0.1 l/min and sieved pellets) **Lower:** AL_0.1_L (Asha, 0.1 l/min, fines in layers)*

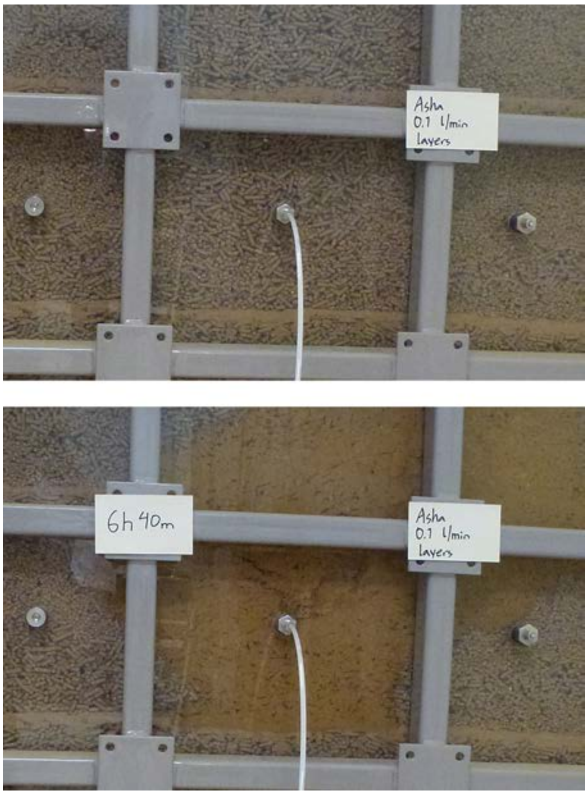
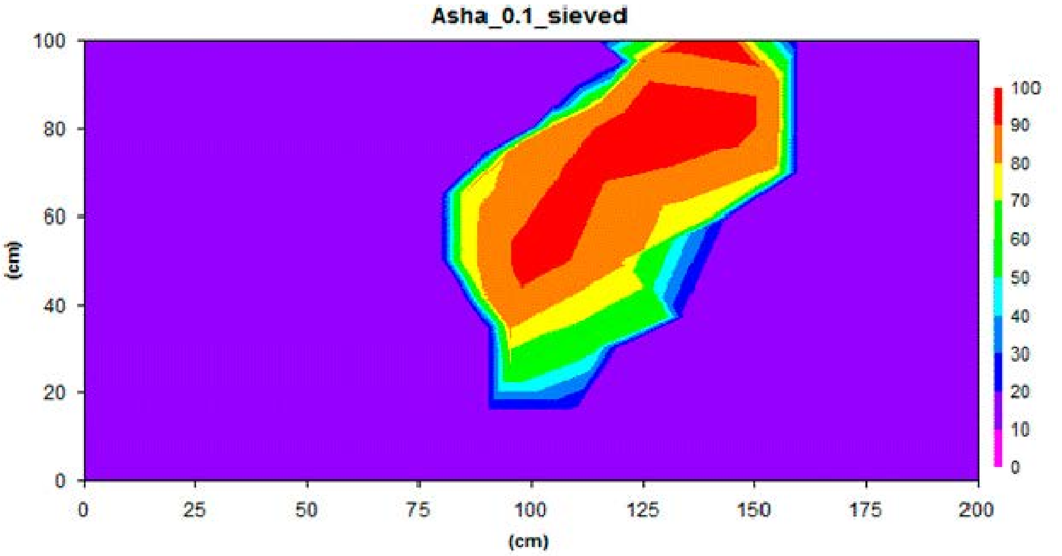


***Figure 4-3.** Photos showing close-ups of the test performed with layers, AL_0.1_L (Asha, 0.1 l/min, fines in layers). **Upper:** After installation **Lower:** At termination.*



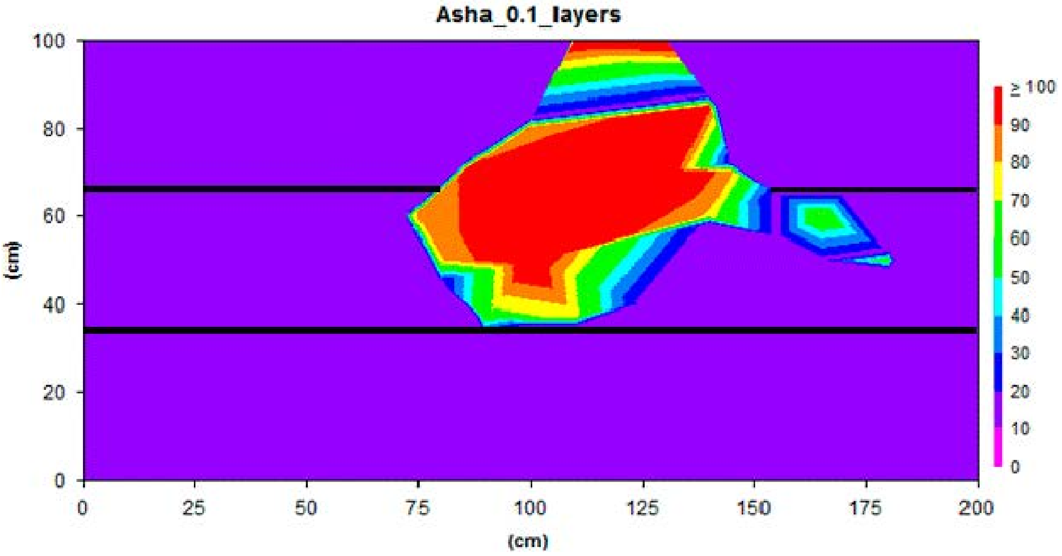


***Figure 4-4.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *AL_0.1_0 (Asha, 0.1 l/min and sieved pellets)* ***Lower:*** *AL_0.1_L (Asha, 0.1 l/min, fines in layers)*

Photos showing the wetting patterns at time for test termination, for the two tests performed with an inflow rate of 0.25 l/min (AL_0.25_0 and AL_0.25_L), are provided in Figure 4-5. The influence of fines present as layers in the pellet filling is obvious. Close-up photos of the test with layers are provided in Figure 4-6, showing the test after installation and just after having stopped the water inflow. The test performed with sieved pellets shows clearly that after initial wetting downwards, the wetting instead continues upwards. The photos are taken at test termination after about 2.5 hours test duration. Figure 4-7 shows the corresponding contour plots of the water content distribution. The graphs are based on the post mortem water content determinations. The black lines in the contour plot showing the test with layers installed, indicates the position of the layers at time for termination. The figure shows clearly that the fine material has stopped the wetting upwards and instead forced the wetting to proceed between the two layers. This behaviour can also be used as a water handling method to direct the wetting process and thereby delay flowing water from reaching the backfill front.

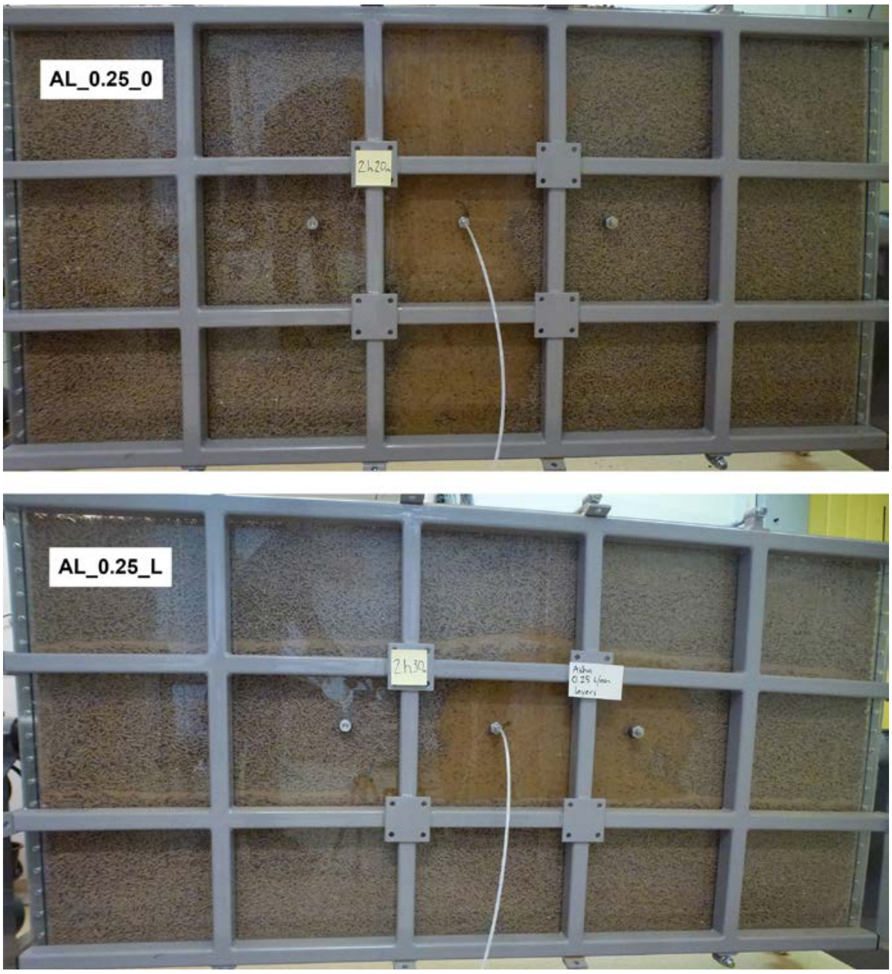


***Figure 4-5.** Photos showing the wetting pattern at time for termination.* ***Upper:*** *AL_0.25_0 (Asha, 0.25 l/min and sieved pellets)* ***Lower:*** *AL_0.25_L (Asha, 0.25 l/min, fines in layers)*

***Figure 4-6.** Photos showing close-ups of the test performed with layers, AL_0.25_L (Asha, 0.1 l/min, fines in layers).*
***Upper:*** *After installation*
***Lower:*** *At termination.*

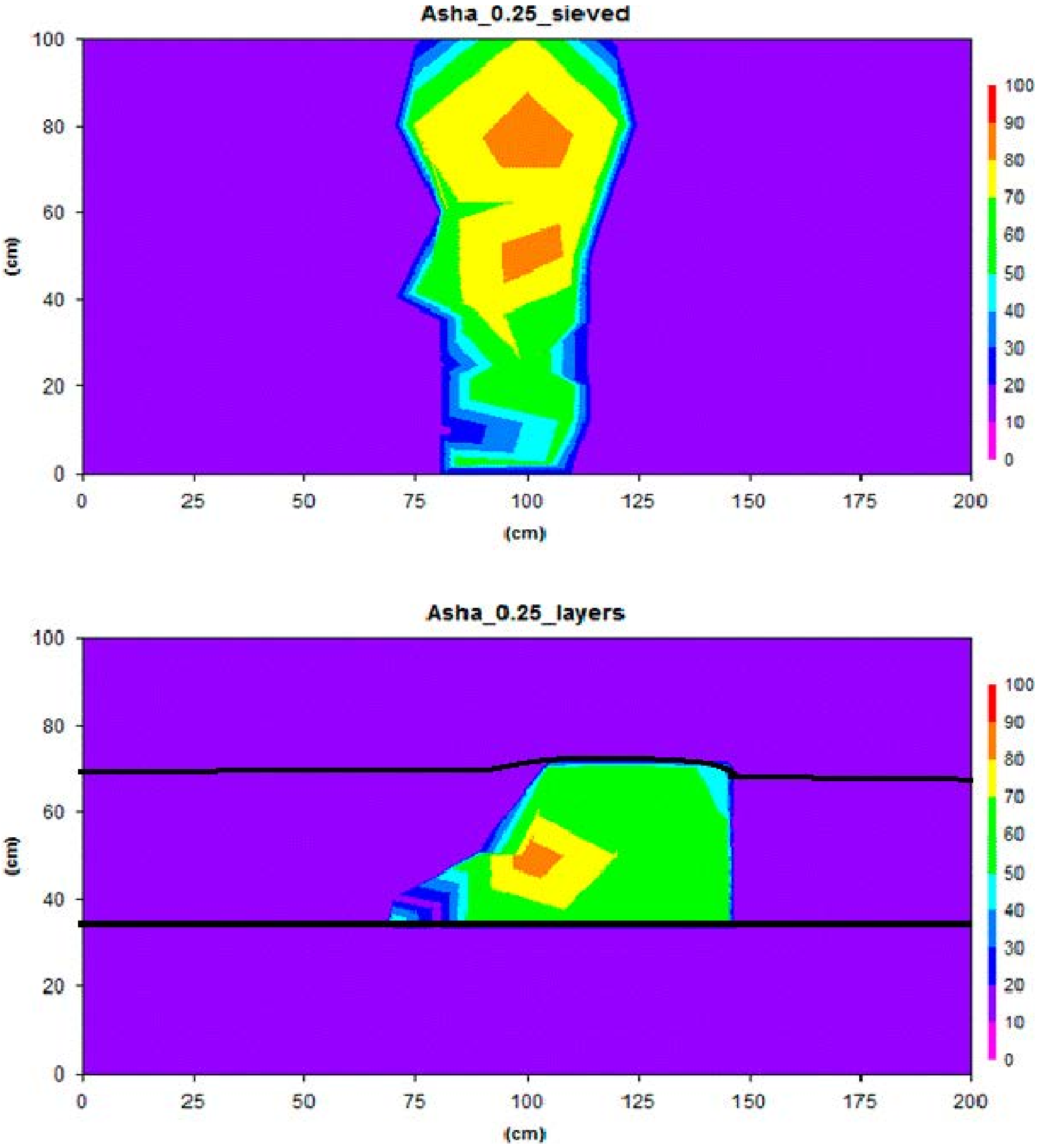


***Figure 4-7.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *AL_0.25_0 (Asha, 0.25 l/min and sieved pellets)* ***Lower:*** *AL_0.25_L (Asha, 0.25 l/min, fines in layers)*

The wetting patterns for the two tests performed with an inflow rate of 0.5 l/min (AL_0.5_0 and AL_0.5_L) are provided in Figure 4-8. Close-up photos of the test with layers are provided in Figure 4-9, showing the test after installation and just after having stopped the water inflow. With an inflow rate of 0.5 l/min and no fines present in the filling, the water initially flows downwards, but after a certain time for the bentonite to swell and seal, the water front instead proceeds upwards. With the same inflow rate, 0.5 l/min, and fines placed in two layers below and above the inflow point, the lower layer stops the initial flow downwards and instead the water distributes sideways along the fine layer. Finally sealing occurs and the water penetrates the upper layer whereas the same wetting behaviour takes place above this layer surface. The corresponding contour plots for AL_0.5_0 and AL_0.5_L are provided in Figure 4-10. The black lines in the contour plot showing the test with layers installed, indicates the position of the layers at time for termination.

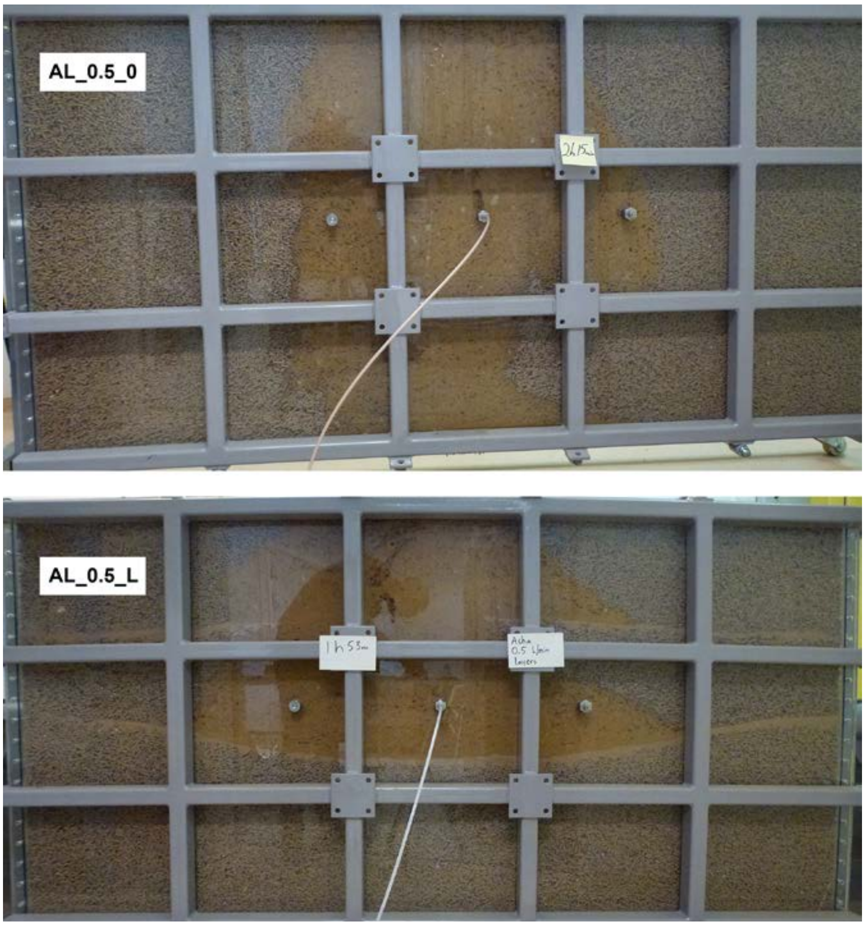


***Figure 4-8.** Photos showing the wetting pattern at time for termination. **Upper:** AL_0.5_0 (Asha, 0.5 l/min and sieved pellets) **Lower:** AL_0.5_L (Asha, 0.5 l/min, fines in layers)*

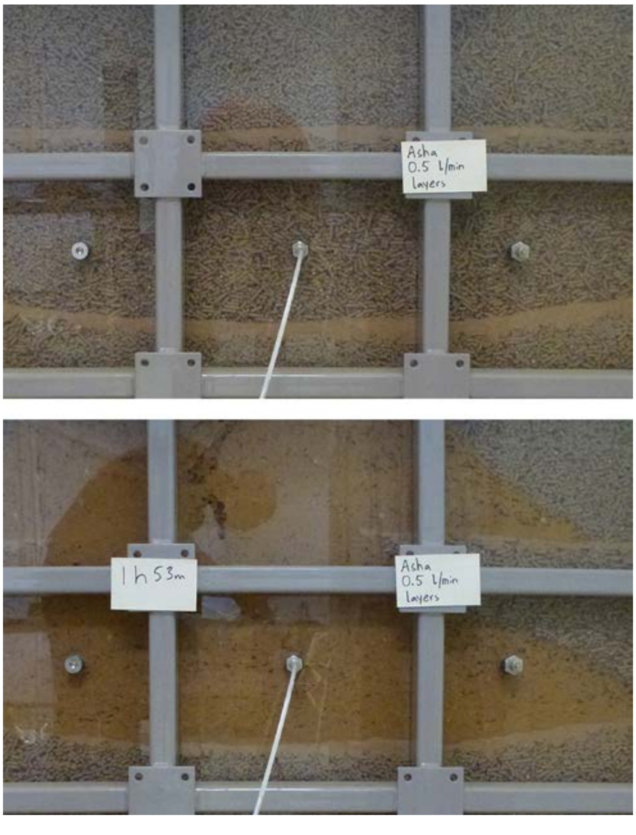


***Figure 4-9.** Photos showing close-ups of the test performed with layers, AL_0. 5_L (Asha, 0.5 l/min, fines in layers). **Upper:** After installation **Lower:** At termination.*

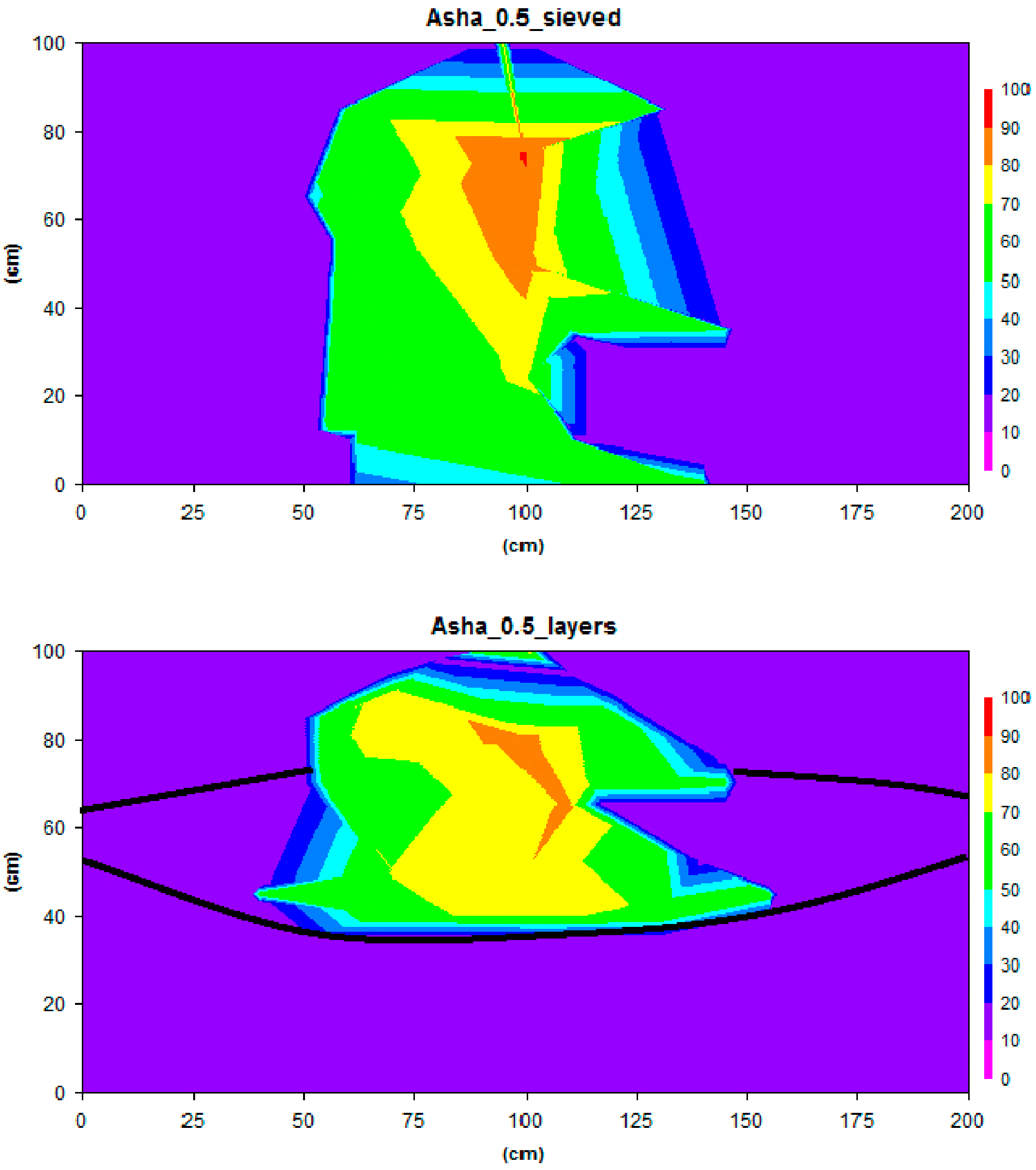


***Figure 4-10.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *AL_0. 5_0 (Asha, 0.5 l/min and sieved pellets)* ***Lower:*** *AL_0.5_L (Asha, 0.5 l/min, fines in layers)*

Figure 4-11 shows the results from the two tests performed with an inflow rate of 0.75 l/min. Close-up photos of the test with layers are provided in Figure 4-12, showing the test after installation and just after having stopped the water inflow. In test AL_0.75_0 (sieved pellets) the water flows initially downwards and spreads over the floor before it starts to move upwards and then wets the pellets symmetrically around the inflow point. AL_0.75_L (fines in layer) shows similar wetting pattern as Al_0.5_L where water distributes along the two fine layers before reaching the top. The corresponding contour plots based on water content samples taken at test termination are provided in Figure 4-13. The black lines in the contour plot showing the test with layers installed, indicates the position of the layers at time for termination.

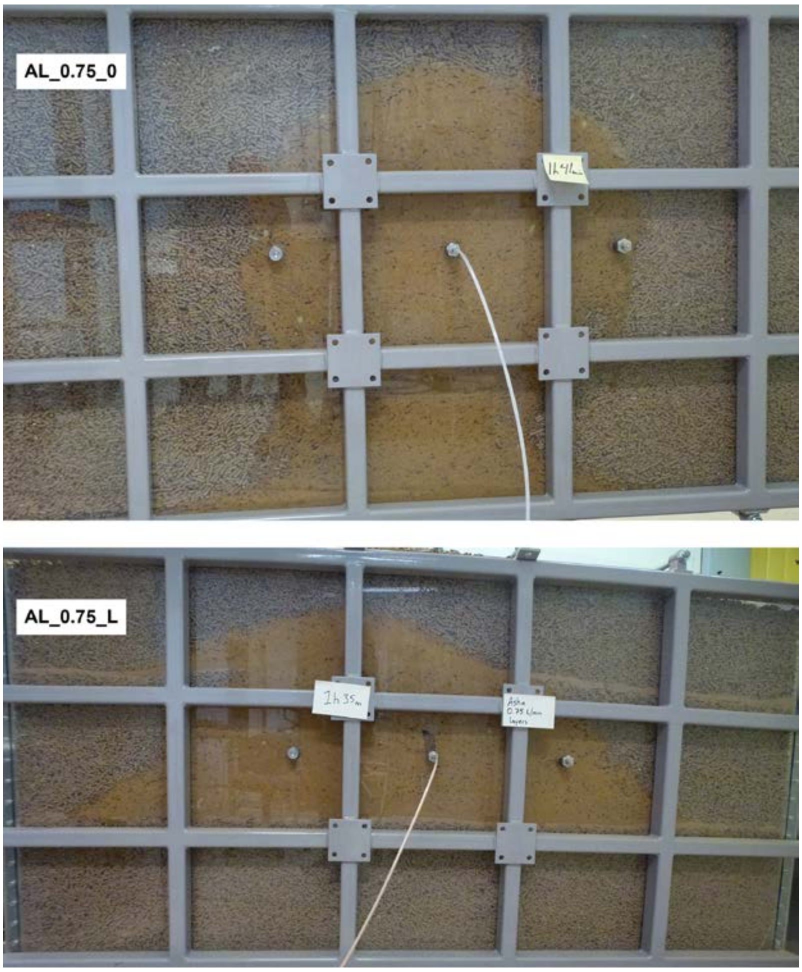


*Figure 4-11. Photos showing the wetting pattern at time for termination.* ***Upper:*** *AL_0.75_0 (Asha, 0.75 l/min and sieved pellets)* ***Lower:*** *AL_0.75_L (Asha, 0.75 l/min, fines in layers)*

*Figure 4-12. Photos showing close-ups of the test performed with layers, AL_0. 75_L (Asha, 0.75 l/min, fines in layers).*
***Upper:*** *After installation*
***Lower:*** *At termination.*

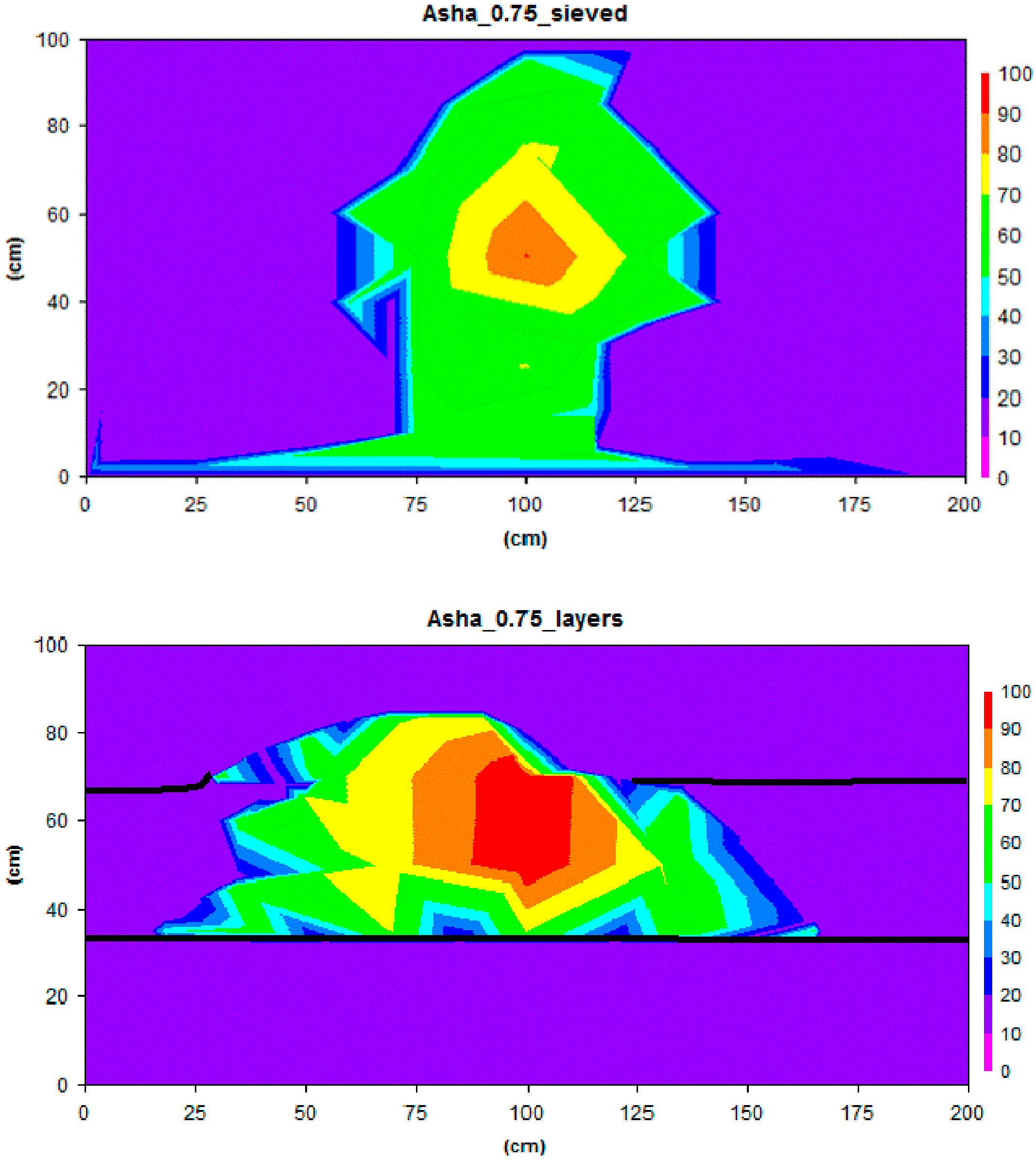


***Figure 4-13.** Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *AL_0.75_0 (Asha, 0.75 l/min and sieved pellets)* ***Lower:*** *AL_0.75_L (Asha, 0.75 l/min, fines in layers)*

An extra test was performed with a water inflow rate of 1.0 l/min. A photo showing the wetting pattern at time for termination is provided in Figure 4-14 together with a contour plot showing the water content distribution. It was expected that the wetting behaviour at this rather high inflow rate should occur mainly downwards and that the wetting after that should proceed like filling up a bathtub. But instead the wetting was quite similar to the ones achieved with inflow rates of 0.5 and 0.75 l/min i.e. there was an initial wetting downwards which after a certain time proceeded upwards and then almost symmetrically around the inflow point. This is considered as an important result that shows that the water storing in the pellet filling will continue in a controlled way also at these high inflow rates.

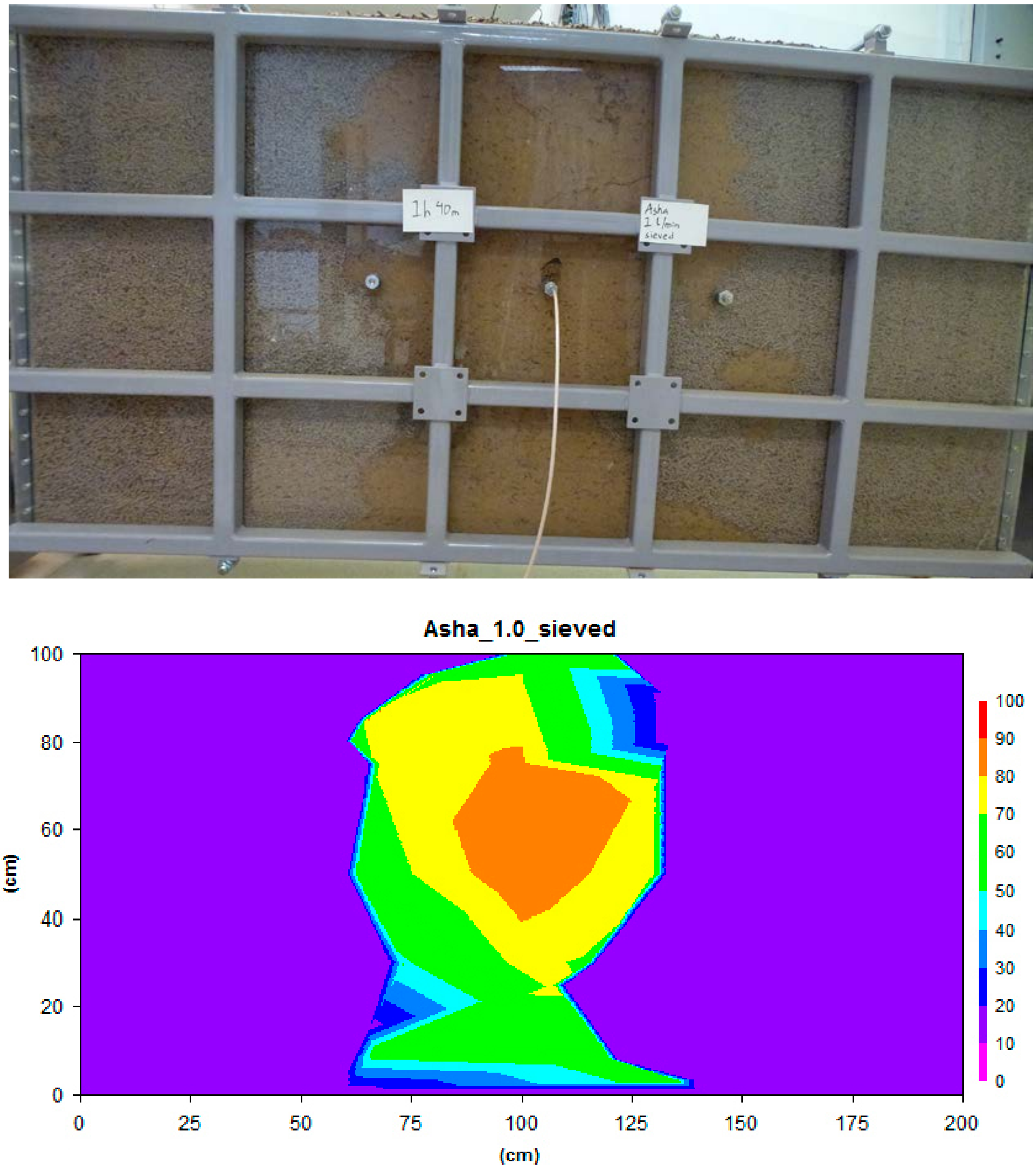


***Figure 4-14.** Photo and contour plot showing the wetting pattern at time for termination for the test performed with an inflow rate of 1.0 l/min (AL_1.0_0).*

The other extra test performed with the Asha pellets (AL_0.5_geo) was performed with a water inflow rate of 0.5 l/min and with a geotextile attached as a strip horizontally over the Plexiglas, including the inlet port. A photo showing the wetting pattern at time for termination is provided in Figure 4-15 together with a contour plot showing the water content distribution. The geotextile has facilitated vertical water transportation from the inlet point towards the sides but water has at the same time also moved upwards. The total water storage before the water front reached the uppermost level had increased somewhat when comparing the results with the corresponding test performed without geotextile, AL_0.5_0. The increase was, however, rather small; approximately 13 minutes corresponding to 6.5 litres or 9.5 %.

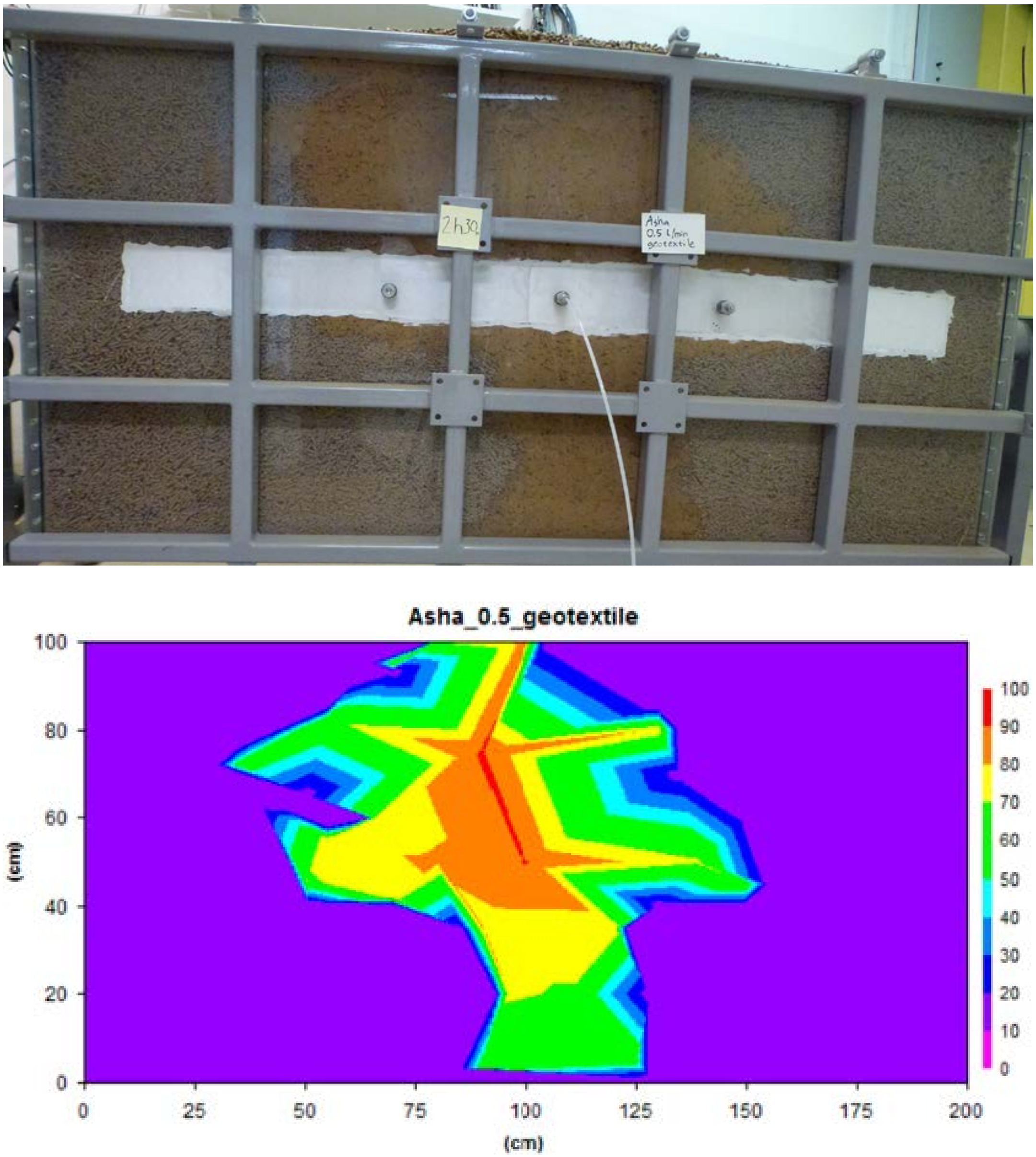


*Figure 4-15. Photo and contour plot showing the wetting pattern at time for termination for the test performed with an inflow rate of 0.5 l/min and with a geotextile mounted across the Plexiglas wall (AL_0.5_geo).*

### 4.3.2 Wetting behaviour, Cebogel

The first Large slot test with Cebogel pellets became special since it coincidentally was performed with a mixture of two different batches, batch 2014 and batch 2015. At the time for test preparation, the large differences in pellet properties between the two batches were not known. The lower part was filled with pellets from the 2014 batch and the upper part with pellets from the 2015 batch, Figure 4-16. After having filled up the test equipment the difference in pellet properties could be visually seen very clear and later determinations of water content and density confirmed this (see results provided in Chapter 2). Despite the detected differences in pellet properties, it was decided to run the test as planned.

***Figure 4-16.*** *Photos showing a photo of the Test CL_0.1_mix after installation of pellets from two different batches. There was a visually very clear difference between the two batches.*

The wetting pattern at time for test termination is provided in Figure 4-17 together with a contour plot showing the water content distribution. It is obvious that the wetting behaviour is affected by the differences in pellet properties between bottom part and the top part. The initial behaviour is similar to the corresponding test performed with Asha pellets i.e. there is a flow downwards but rather soon the pellets swell and seal and the wetting instead proceeds upwards. However, when the water front reaches the pellets from batch 2015, the behaviour is radically changed. The water flows now instead mainly out horizontally. The relative low water inflow rate allows the pellets to seal which results in a continued wetting also upwards, however with reduced rate. The low density and high water content of the pellets from the new batch decreases the bentonite's affinity for taking up water. This results in a lower water storage capacity of the pellets and a much higher risk for inflowing water reaching the backfill front early. The behaviour of the pellets with high water content can, however, be used as a water handling method under right circumstances e.g. this type of pellets could be used as a filling in a section of a deposition tunnel that is separated with two water tight walls. The pellet filling could in that case work as a water storage for inflowing water.

This first test performed with pellets from two different batches was denominated CL_0_mix and depending on the uncertainty of the results it was decided to repeat the test using pellets only from the batch from 2015.

The results from the four tests performed with sieved Cebogel pellets (batch 2015) and different flow rates are quite different when compared to the corresponding tests performed with Asha pellets. Photos from the tests performed with water inflow rates of 0.1 and 0. 25 l/min (Test CL_0.1_0 and CL_0.25_0) are provided in Figure 4-18. The corresponding contour plots showing the water content distribution after test termination are provided in Figure 4-19. The photos show that the water flows into the pellet filling almost like filling up a tub. These inflow rates are, however, rather low and there is a small tendency for the pellet to have time to swell and seal and by that proceed with the wetting also upwards.

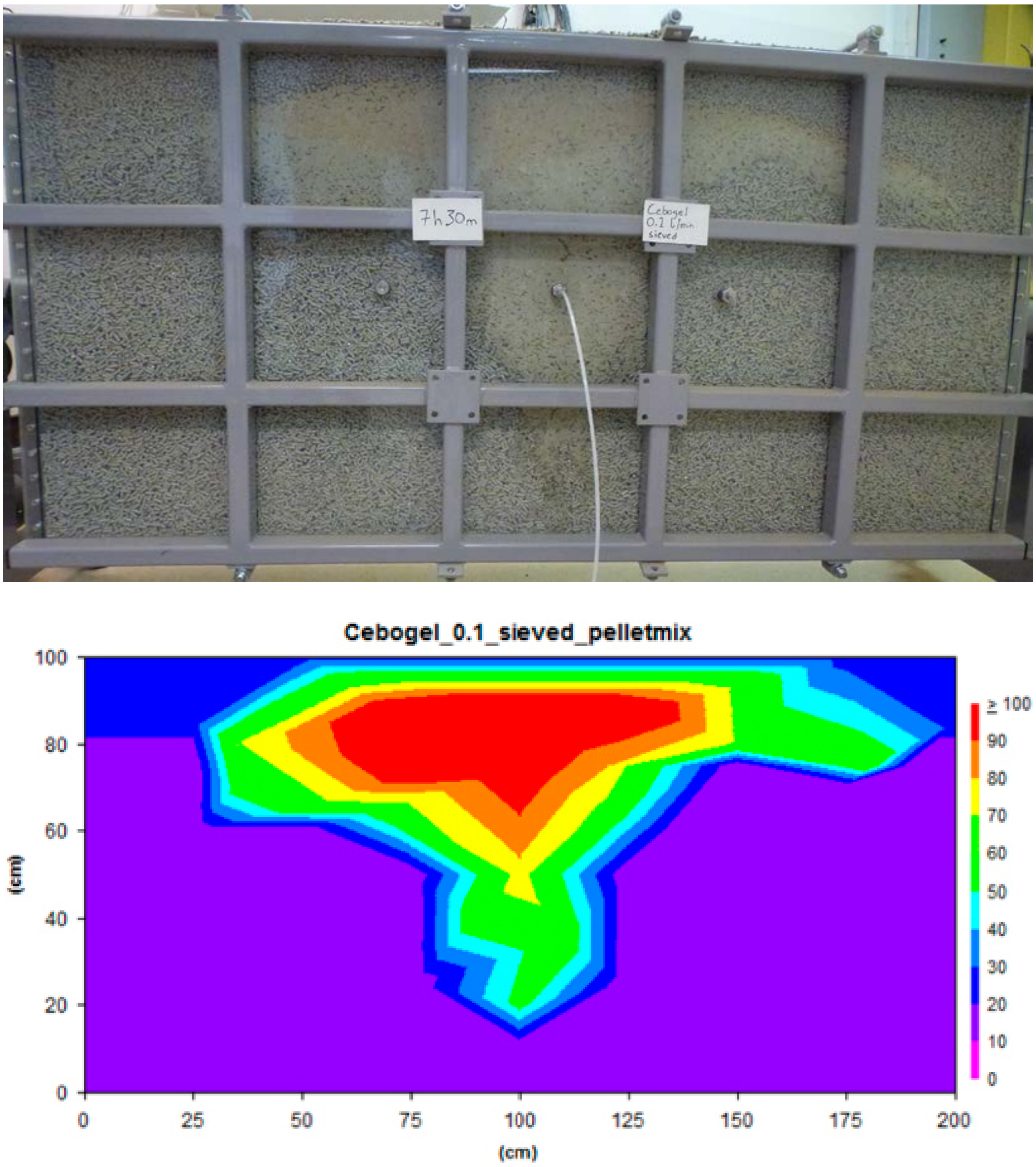


***Figure 4-17.*** *Photo and contour plot showing the wetting pattern at time for termination for the test performed with an inflow rate of 0.1 l/min and with a mixture of pellets from two different batches (CL_0.1_mix).*

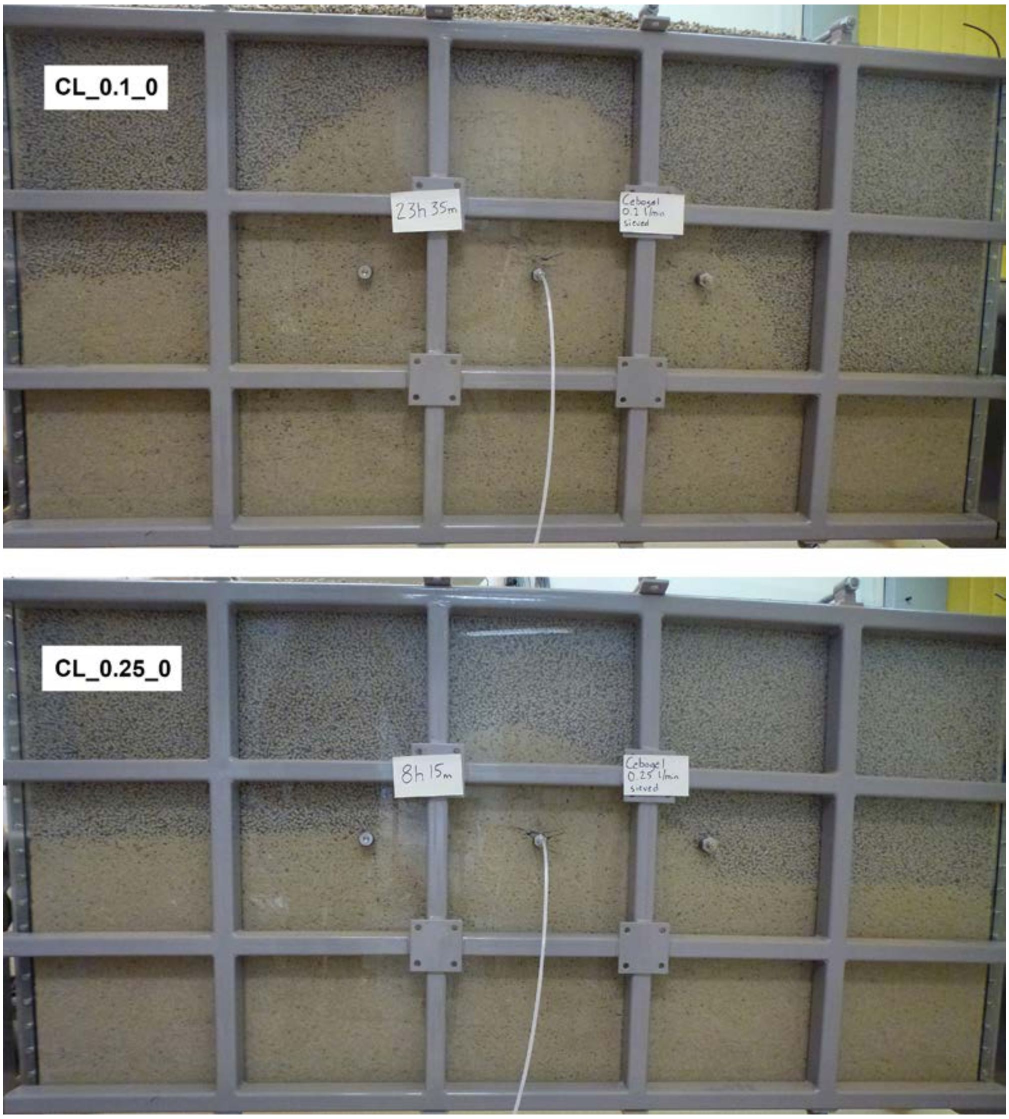


***Figure 4-18.*** *Photos showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.1_0 (Cebogel, 0.1 l/min and sieved pellets)* ***Lower:*** *CL_0.25_0 (Cebogel, 0.25 l/min and sieved pellets).*

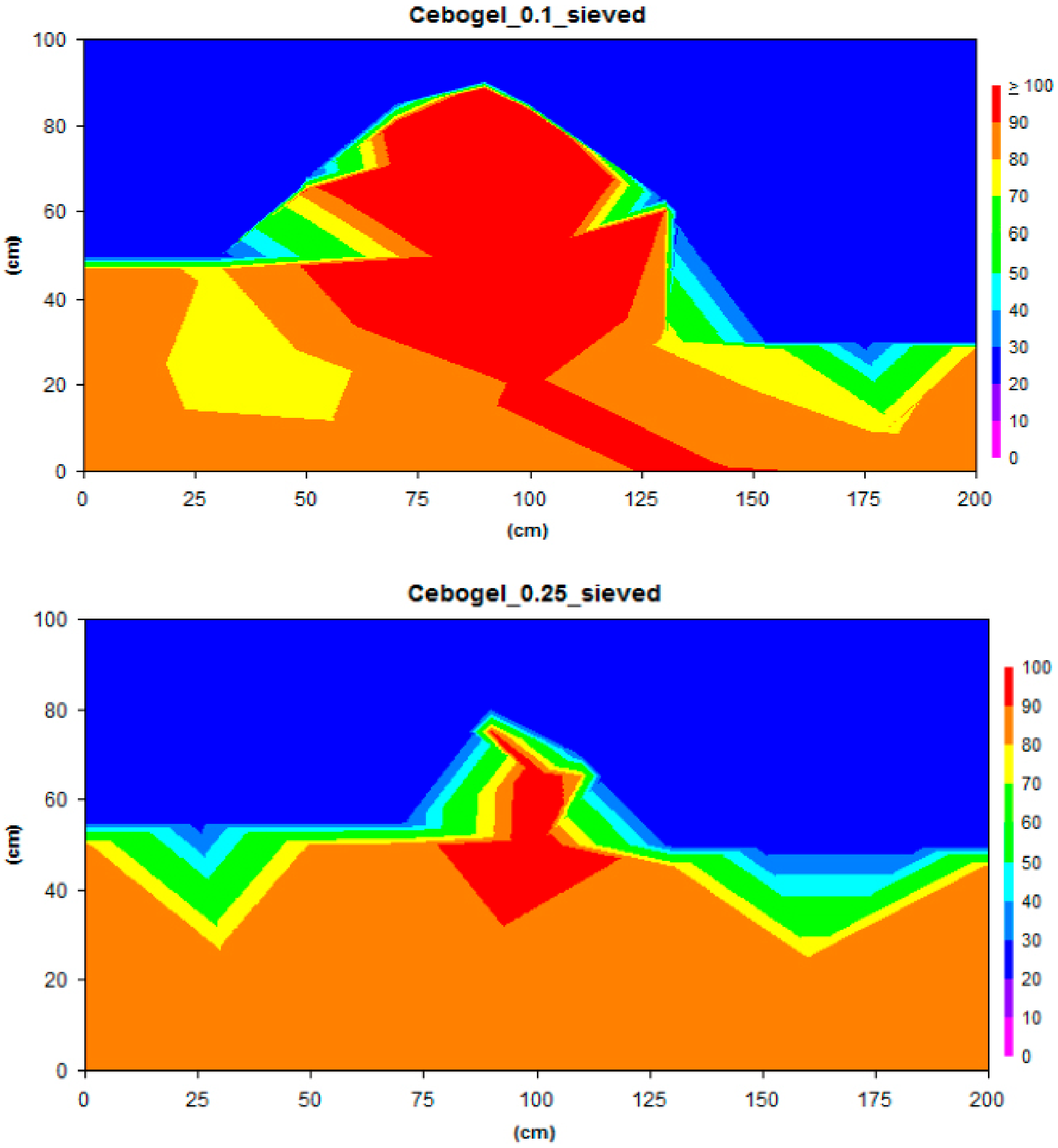


***Figure 4-19.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.1_0 (Cebogel, 0.1 l/min and sieved pellets)* ***Lower:*** *CL_0.25_0 (Cebogel, 0.25 l/min and sieved pellets).*

The wetting behaviour for the tests performed with higher inflow rates, 0.5 and 0.75; Figure 4-20, is however exactly like filling a tub i.e. all water flows downwards from the inflow point and then an even water level rises up. The corresponding contour plots showing the water content distribution after test termination are provided in Figure 4-21.

Assuming that the test equipment simulates a part of the pellet filling between the rock wall and the block stack, this wetting behaviour will lead to that water flowing in from the rock wall, will flow downwards to the floor and then directly out to the backfill front. This behaviour is thus assessed to be problematic during an ongoing backfill installation process. All four tests show a similar behaviour almost independent of the water inflow rate.

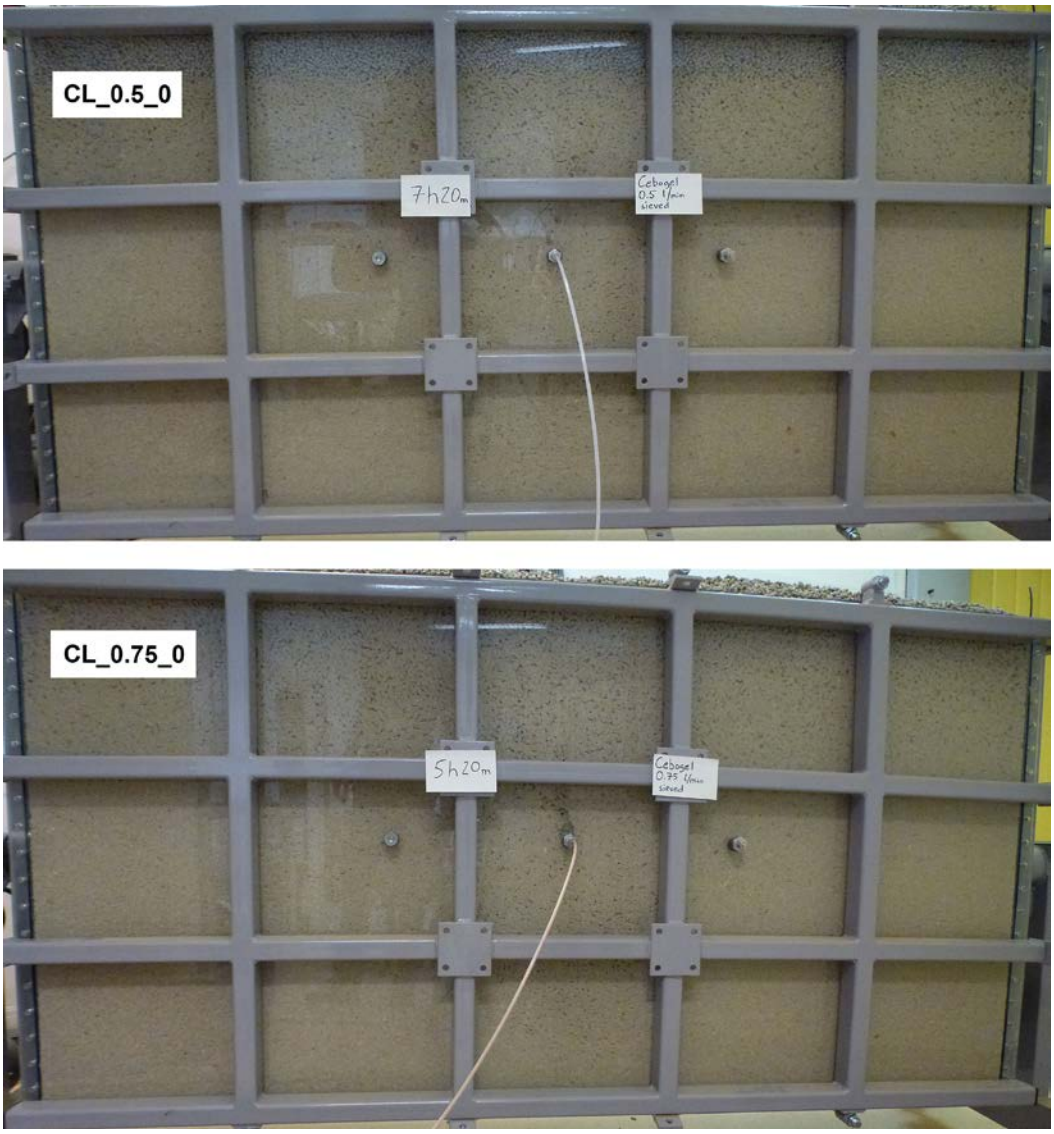
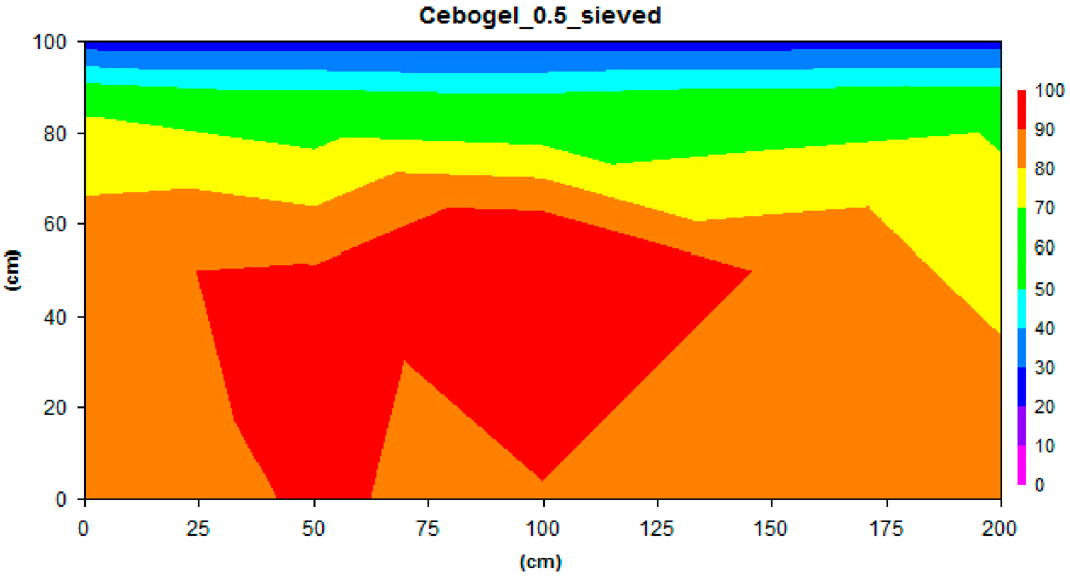


***Figure 4-20.** Photos showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.5_0 (Cebogel, 0.5 l/min and sieved pellets)* ***Lower:*** *CL_0.75_0 (Cebogel, 0.75 l/min and sieved pellets).*



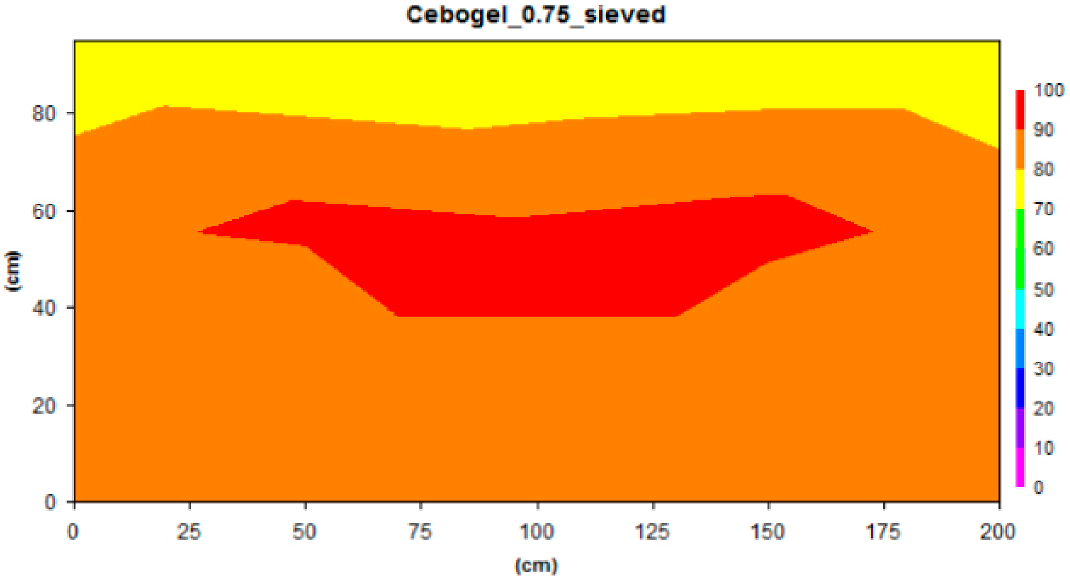


***Figure 4-21.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.5_0 (Cebogel, 0.5 l/min and sieved pellets)* ***Lower:*** *CL_0.75_0 (Cebogel, 0.75 l/min and sieved pellets).*

Two tests were performed with Cebogel pellets and with fines placed in layers. Photos from the tests are provided in Figure 4-22 and close-ups of the layers at time for installation and after that the water inflow has been stopped are provided in Figure 4-23 and 4-24. The corresponding contour plots showing the water content distribution after test termination are provided in Figure 4-25. The wetting behaviour was similar for the two tests i.e. the lower layer stops largely the inflowing water from reaching the floor but when the water level rises upwards over the whole slot cross section the top layer cannot stop the wetting upwards. As shown in the photos, the inflowing water also found some ways downwards pass the lower layer of fines.

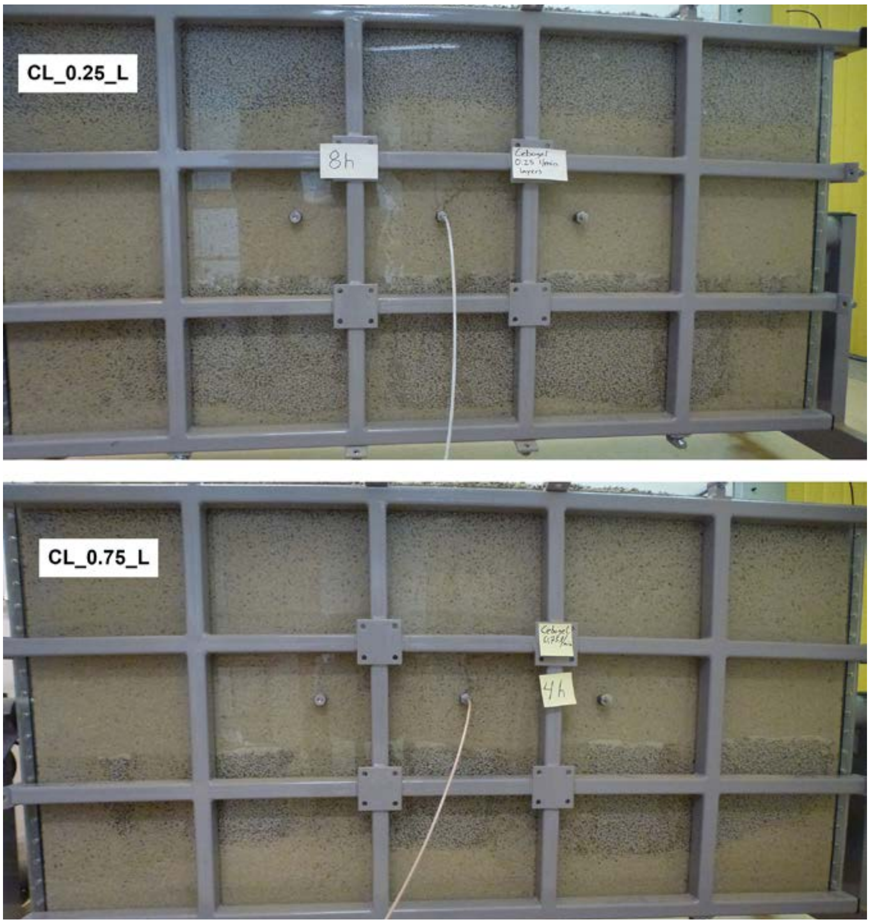


***Figure 4-22.*** *Photos showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.25_L (Cebogel, 0.25 l/min with layers)* ***Lower:*** *CL_0.75_L (Cebogel, 0.75 l/min with layers).*

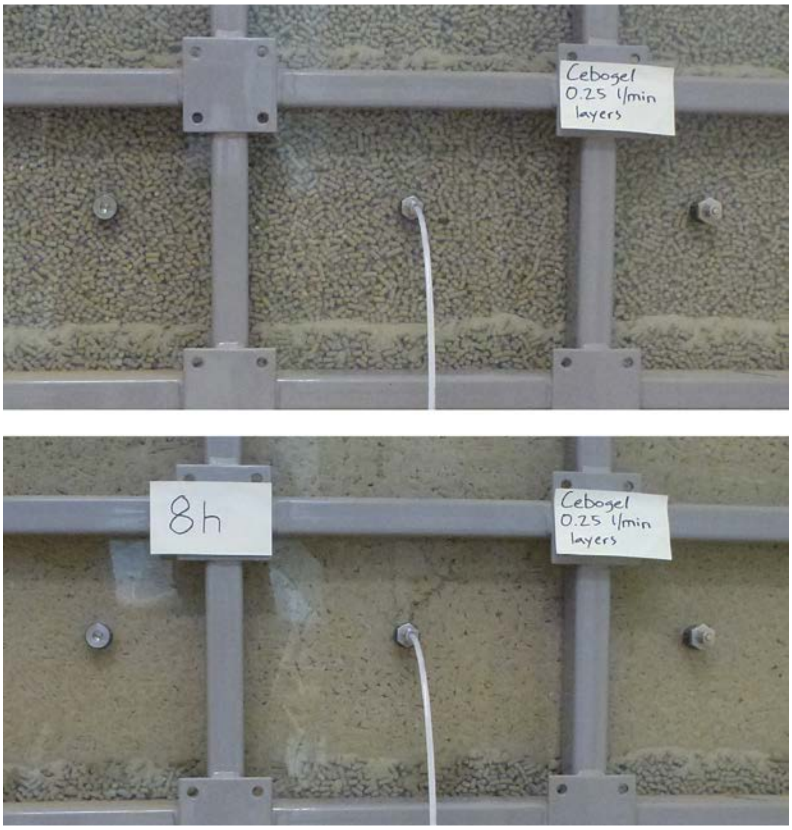


***Figure 4-23.*** *Photos showing close-ups of the test performed with layers, CL_0. 25_L (Cebogel, 0.25 l/min, fines in layers).*
***Upper:*** *After installation*
***Lower:*** *At termination.*

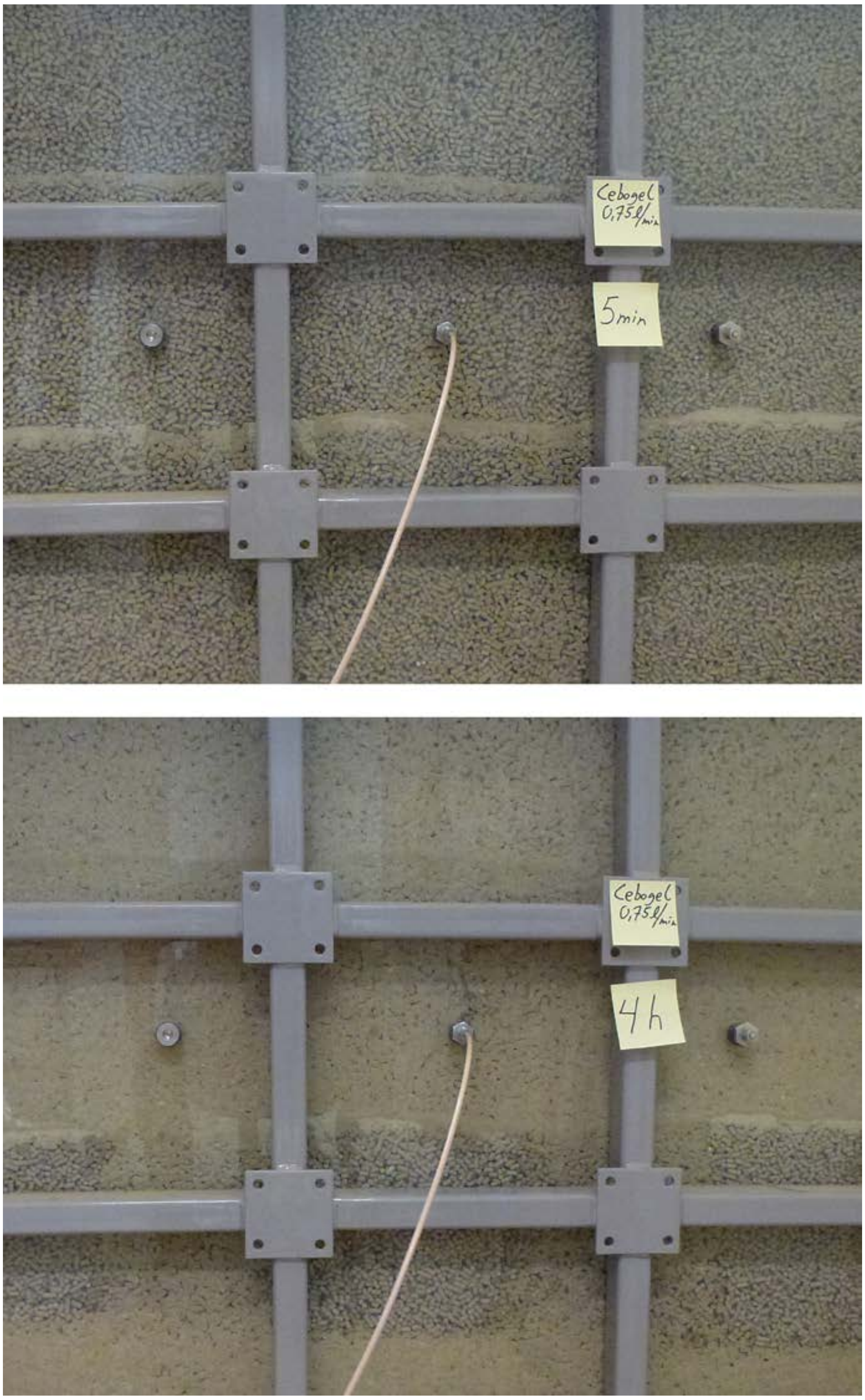
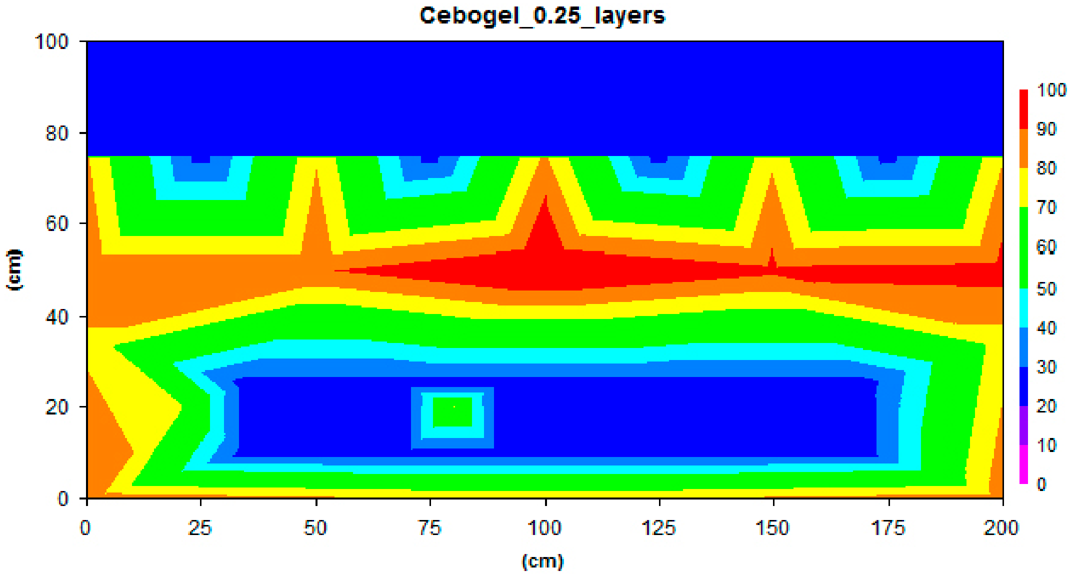


*Figure 4-24. Photos showing close-ups of the test performed with layers, CL_0. 75_L (Cebogel, 0.75 l/min, fines in layers).* ***Upper:*** *After installation* ***Lower:*** *At termination.*



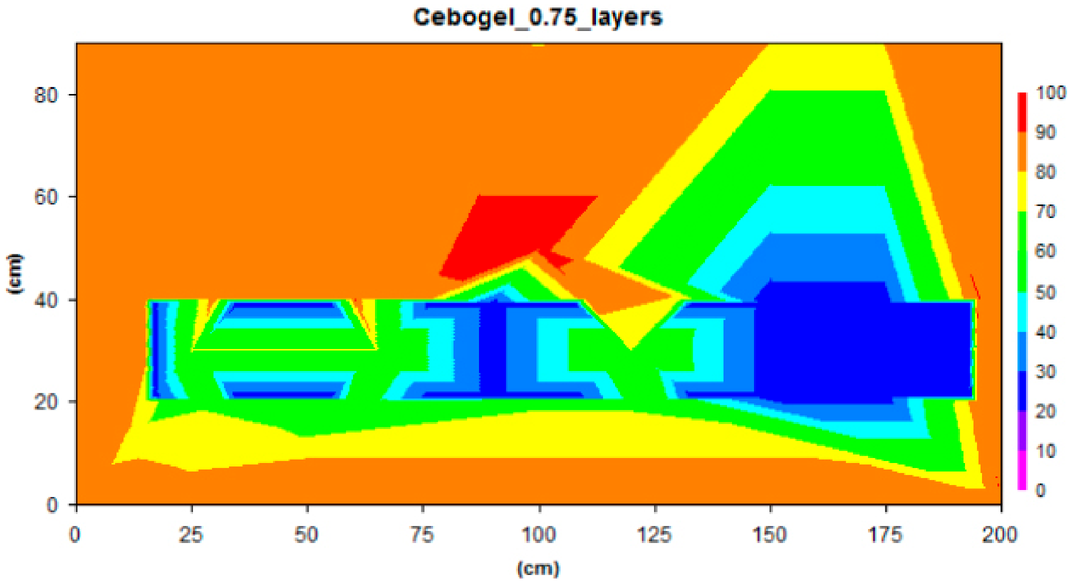


***Figure 4-25.*** *Contour plots showing the wetting pattern at time for termination.* ***Upper:*** *CL_0.5_0 (Cebogel, 0.5 l/min and sieved pellets)* ***Lower:*** *CL_0.75_0 (Cebogel, 0.75 l/min and sieved pellets).*

## 4.4 Comments

The new “Large slot test equipment” has facilitated the possibility to test a pellet filling in large scale regarding e.g. wetting behaviour and water storage capacity. The tests are, however, rather time consuming but they are assessed to give important information. A great advantage with the equipment is that the wetting behaviour is visually available and also that illustrative photos can be taken during the test duration.

From the tests the following conclusions have been drawn:

- One of the objectives with the performed test series was to compare the water storage properties of Asha and Cebogel pellets. Due to the higher water content and lower density of the tested Cebogel pellets, it was not possible to directly compare their wetting behavior to those of the Asha pellets. An important conclusion is, however, that requirements regarding the pellets properties for a backfill purpose must be introduced. The first test performed with Cebogel pellets was performed with a mixture of pellets from two batches (batch 2014 that also was used in the tube test and batch 2015 that was used in the rest of the large slot tests). The results from this test illustrated clearly the large difference in behaviour between the two batches.
- The water storage capacity of the sieved Asha pellets was high, also at high inflow rates. Tests were performed with inflow rates between 0.1 to 1.0 l/min resulting in almost similar wetting behaviours i.e. after an initial flow downwards from the inflow point, the pellets swell and seal and the wetting then proceeds upwards and almost symmetrically around the water inflow point.
- Tests were also performed with fines placed in layers (something that have been noted to sometimes occur during installation of pellets) at different heights. The test layout, with two layers of fines, was somewhat excessive but the test results showed clearly the strong influence that a layer of fines will have on the wetting progress in a pellet filling. For the tests performed with Asha pellets it was noted that the lower layer seemed to seal and prevent further flow downwards while the layer above the inflow point after a certain test time was penetrated. This behaviour is believed to depend on the fact that the lower layer had more time to swell and seal and thereby could withstand a higher water pressure. The behaviour is of course also depending on the test time. If the water pressure is high enough, piping can occur in any direction in the pellet filling. It can, however, be concluded that fines present in a layer, seal efficiently and temporary prevent the wetting from proceeding in that direction.
- An extra test was performed where a strip of geotextile was positioned horizontally across the inflow point. The geotextile distributed the water inflow (0.5 l/min) over a larger area and delayed the time to first outflow with 9.5 % compared to the corresponding test performed without geotextile. The effect was thus limited which probably depends on the scale i.e. the water front reached the top of the pellet box and the test had to be terminated. In larger scale the flow resistance upwards would probably increase with time and after a certain time the wetting would instead proceed in horizontal direction.

# 5 Comments and conclusions

## 5.1 Influence of fines in the pellet filling

The main objective with the performed tests was to determine the effect of fines present in the pellet filling. In earlier performed tests it has been noted that fines seems to decrease the water storing capacity of a pellet filling, see e.g. Koskinen and Sandén (2014) and Andersson and Sandén (2012). The performed tests showed that if the fines are reasonably evenly distributed in the pellet filling, the influence on the water storage capacity seems to be small. However, if the fines are positioned in layers they seem to prevent the wetting in a certain direction and thereby decreasing the water storage capacity of the filling. In the performed test, only horizontal layers of fines have been tested but it is probable that also inclined layers will have the same effect on the wetting process. The problem is that the position of a layer cannot be controlled during the installation. It should be mentioned that a technique to position layers of fine material in a pellet filling also could be used to direct the wetting in a certain direction.

## 5.2 Water storage capacity

When installing bentonite pellets as a part of the backfill installation i.e. in the gap between rock and blocks, it will be important to prevent early horizontal flow without any flow resistance in the pellet filling. This will lead to that water very soon will reach the backfill front. If the wetting front instead is proceeding upwards or symmetrically around the inflow point the time to first outflow at the front will be delayed.

The performed test with sieved Asha pellets showed that the water storage capacity of these pellets is large. With inflow rates up to 1 l/min there will be continuous water storage almost symmetrically around the inflow point i.e. no channel flows seems to occur, which is important since a channel flow out to the backfill front may affect the stability of the backfill installation and also may cause erosion of backfill material.

The results from the tests performed with Cebogel pellets are not entirely fair since the pellets properties of this batch (batch 2015) were different, see description in Chapter 2 and in Section 5.3. The first performed Tube tests were performed using pellets from another batch (batch 2014) resulting in completely different behaviour, more similar to the Asha pellets. This similar behaviour of the Cebogel pellets have also been seen in e.g. Dixon et al. (2008a) and Dixon et al. (2008b) and it is therefore believed that if the pellets' properties regarding water content and density can be held at the right level, also these pellets will have similar water storage capacity as the Asha pellets.

## 5.3 Pellet properties

The results from the tests have shown that it will be necessary to put up requirements regarding the pellet properties regarding water content and density. The Cebogel batch delivered in 2015 was found to have completely different properties regarding water storing behaviour and later laboratory tests showed that the properties of these pellets were completely different, Table 5-1.

When manufacturing pellets with the extrusion method (the pellets type used in this investigation) it is important to have an optimal water content of the raw bentonite. If the water content is too high, it will be impossible to reach the high densities that are necessary in order to achieve the pellet properties needed.

In earlier performed test with Asha and Cebogel pellets, where the water storage properties have been assessed to be high, the water content have been between 12 and 20 % and the dry density of the individual pellets has been between 1 810–2 000 kg/m$^3$, see e.g. Dixon et al. (2008a, b) and Andersson and Sandén (2012). These figures should serve as a guideline for the requirements on the pellet properties.

**Table 5-1. Compilation of data from the investigation of the pellet properties used in the tests. The table shows the average data (see also data provided in Chapter 2).**

| Material | Water content<br>% | Bulk density (average)<br>kg/m³ | Dry density (average)<br>kg/m³ | Void ratio<br>– | Degree of sat.<br>% |
|---|---|---|---|---|---|
| Asha (Äspö HRL 2015) | 15–17 | 2234 | 1924 | 0.502 | 92.7 |
| Cebogel (B+tech 2015) | 12.0–12.2 | 2199 | 1963 | 0.426 | 78.9 |
| Cebogel (Posiva 2015) | 24.1–25.1 | 2000 | 1612 | 0.737 | 91.6 |

## 5.4 Discussion and further work

The most important outcomes from the performed investigations are:

- The presence of fines in a pellet filling depends on if it is present already in the delivered batch or if it is created during installation. To be sure that one get such a functional pellet filling as possible, it is recommended that all pellets manufactured should be sieved before installation. It is also recommended that the pellet installation equipment (blower, conveyor etc.), should be set so that as little fines as possible is created during installation.
- The properties of the backfill pellets are important in order to achieve a pellet filling with great capacity to store inflowing water. A recommended guideline is that the water content should be between 12 and 20 % and the dry density of the individual pellets between 1 810 and 2 000 kg/m$^3$. The specified figures are based on results from a large number of tests with pellets.
- A simple "Method description" describing a test of manufactured backfill pellets regarding water storage capacity should be developed. The test may advantageously be based on the tube tests described in Chapter 3 in this report.
- The tests have shown that fines positioned as layers in a pellet filling temporarily will seal very efficiently, within a pellet filling, when water reaches the layer and thereby prevent water from flowing in that direction. This is a technique that could be used to direct the wetting in a certain direction. It has e.g. been discussed to use wetted layers of pellets to prevent water flow but an alternative could be to instead use layers of fines.

# References

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

**Andersson L, Sandén T, 2012.** Optimization of backfill pellet properties. ÅSKAR DP2. Laboratory tests. SKB R-12-18, Svensk Kärnbränslehantering AB.

**Dixon D, Anttila S, Viitanen M, Keto P, 2008a.** Tests to determine water uptake behavior of tunnel backfill. SKB R-08-134, Svensk Kärnbränslehantering AB.

**Dixon D, Lundin C, Örtendahl E, Hedin M, Ramqvist G, 2008b.** Deep repository – engineered barrier system. Half scale tests to examine water uptake by bentonite pellets in a block-pellet backfill system. SKB R-08-132, Svensk Kärnbränslehantering AB.

**Koskinen V, Sandén T, 2014.** System design of backfill. Distribution of inflowing water by using geotextile. SKB R-14-10, Svensk Kärnbränslehantering AB.

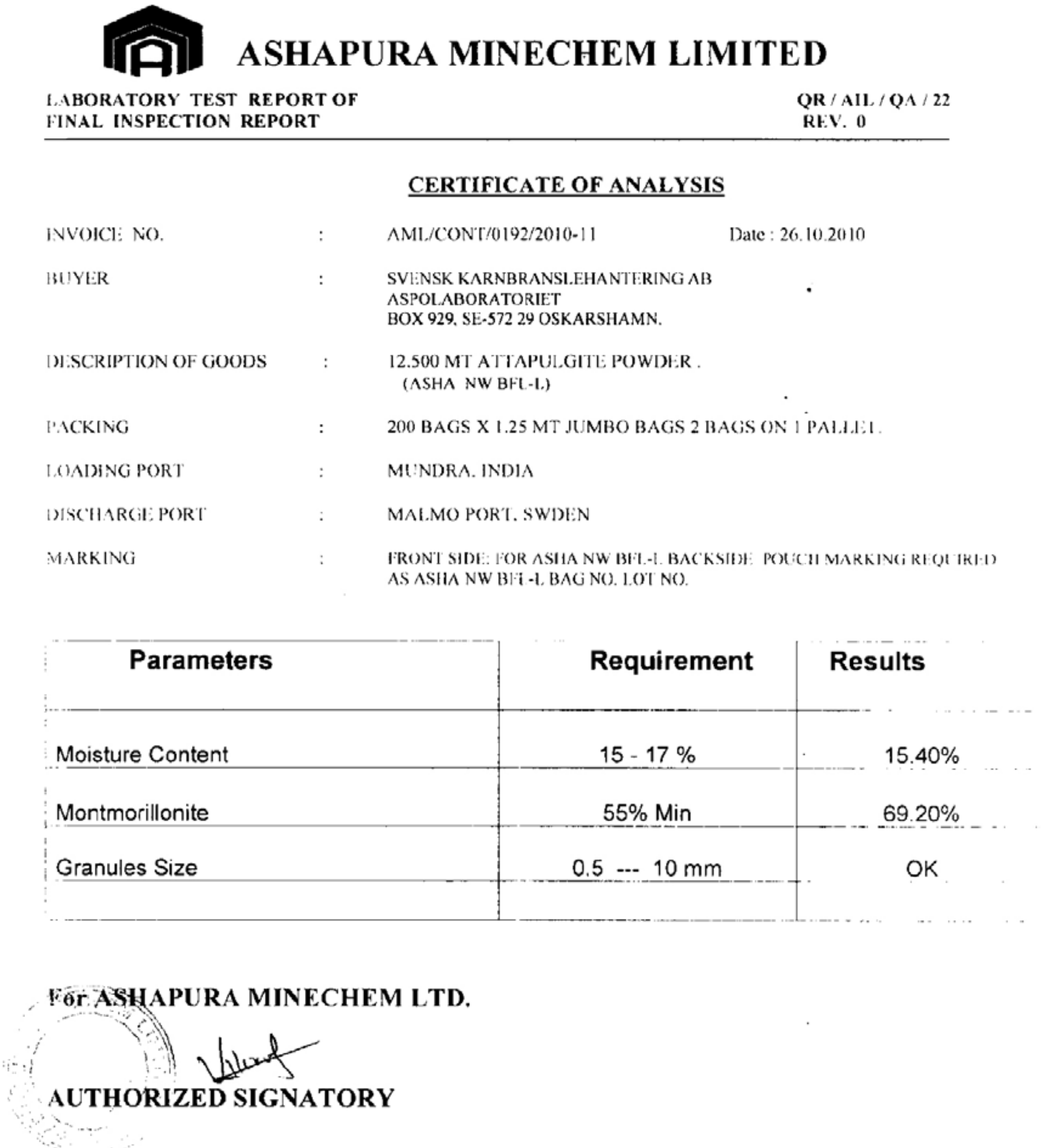
**Sandén T, Börgesson L, 2014.** System design of backfill. Methods for water handling. SKB R-14-09, Svensk Kärnbräsnlehantering AB.

**Sandén T, Börgesson L, Dueck A, Goudarzi R, Lönnqvist M, 2008.** Deep repository – Engineered barrier system. Erosion and sealing processes in tunnel backfill materials investigated in laboratory. SKB R-08-135, Svensk Kärnbränslehantering AB.

**Åkesson M, Sandén T, Börgesson L, 2017.** Water handling during backfill installation. Conceptual and mathematical models of water storage and spreading. SKB R-16-12, Svensk Kärnbränslehantering AB.

## Material data sheet Asha NW BFL-L 2010

Note: Under the heading “Description of goods” the wrong material is described. The right material is within parenthesis.



**ASHAPURA MINECHEM LIMITED**

LABORATORY TEST REPORT OF
FINAL INSPECTION REPORT

QR / AIL / QA / 22
REV. 0

**CERTIFICATE OF ANALYSIS**

INVOICE NO. : AML/CONT/0192/2010-11 Date : 26.10.2010

BUYER : SVENSK KARNBRANSLEHANTERING AB
ASPOLABORATORIET
BOX 929, SE-572 29 OSKARSHAMN.

DESCRIPTION OF GOODS : 12.500 MT ATTAPULGITE POWDER .
(ASHA NW BFL-L)

PACKING : 200 BAGS X 1.25 MT JUMBO BAGS 2 BAGS ON 1 PALLET .

LOADING PORT : MUNDRA, INDIA

DISCHARGE PORT : MALMO PORT, SWDEN

MARKING : FRONT SIDE: FOR ASHA NW BFL-L BACKSIDE POUCH MARKING REQUIRED AS ASHA NW BFL-L BAG NO. LOT NO.

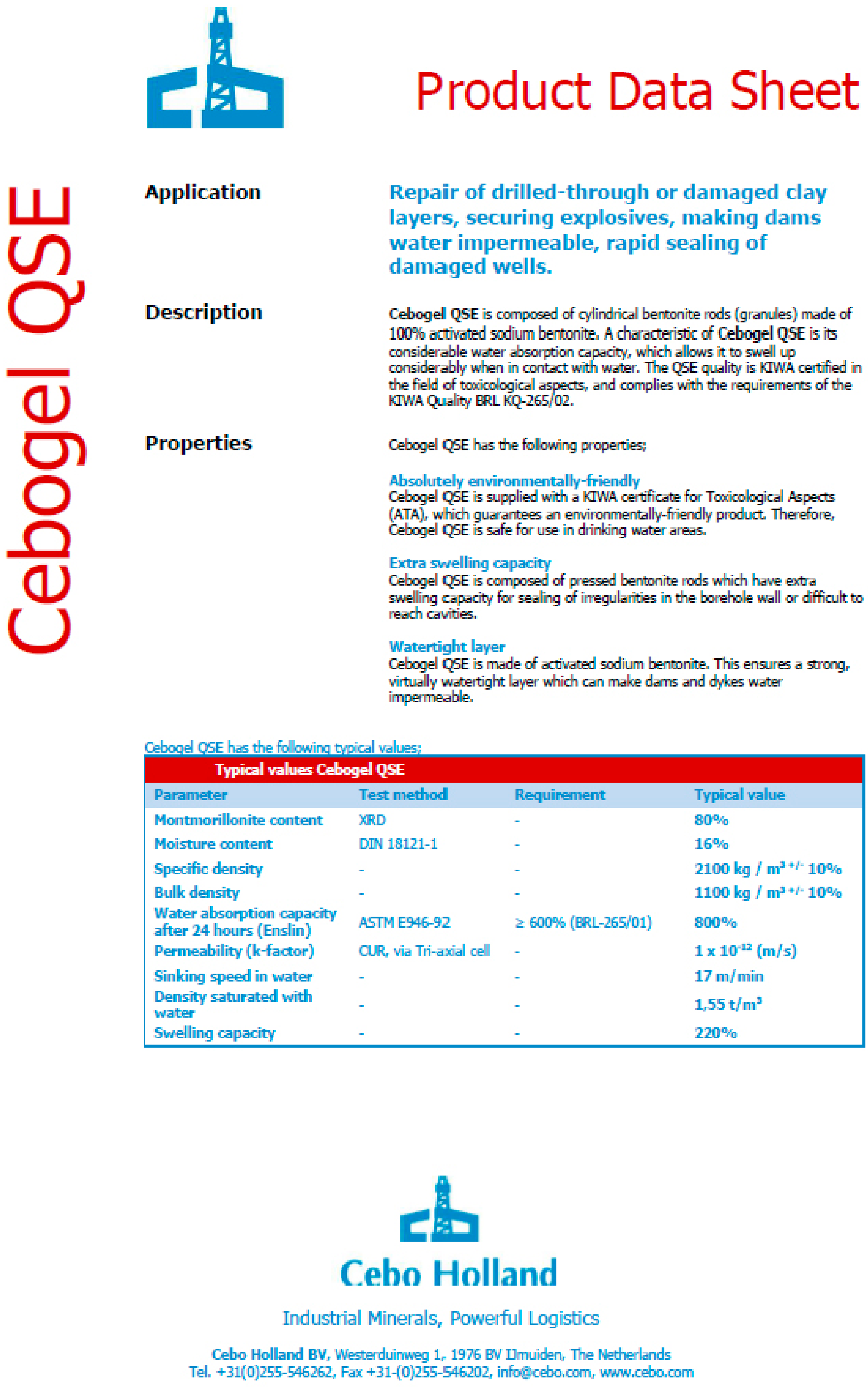
| Parameters | Requirement | Results |
|---|---|---|
| Moisture Content | 15 - 17 % | 15.40% |
| Montmorillonite | 55% Min | 69.20% |
| Granules Size | 0.5 --- 10 mm | OK |
| | | |

**For ASHAPURA MINECHEM LTD.**

**AUTHORIZED SIGNATORY**

# Appendix 2

## Product data sheet Cebogel QSE page 1



# Product Data Sheet

Cebogel QSE

**Application**

**Repair of drilled-through or damaged clay layers, securing explosives, making dams water impermeable, rapid sealing of damaged wells.**

**Description**

**Cebogel QSE** is composed of cylindrical bentonite rods (granules) made of 100% activated sodium bentonite. A characteristic of **Cebogel QSE** is its considerable water absorption capacity, which allows it to swell up considerably when in contact with water. The QSE quality is KIWA certified in the field of toxicological aspects, and complies with the requirements of the KIWA Quality BRL KQ-265/02.

**Properties**

Cebogel QSE has the following properties;

**Absolutely environmentally-friendly**
Cebogel QSE is supplied with a KIWA certificate for Toxicological Aspects (ATA), which guarantees an environmentally-friendly product. Therefore, Cebogel QSE is safe for use in drinking water areas.

**Extra swelling capacity**
Cebogel QSE is composed of pressed bentonite rods which have extra swelling capacity for sealing of irregularities in the borehole wall or difficult to reach cavities.

**Watertight layer**
Cebogel QSE is made of activated sodium bentonite. This ensures a strong, virtually watertight layer which can make dams and dykes water impermeable.

Cebogel QSE has the following typical values;

**Typical values Cebogel QSE**

| Parameter | Test method | Requirement | Typical value |
|---|---|---|---|
| Montmorillonite content | XRD | - | 80% |
| Moisture content | DIN 18121-1 | - | 16% |
| Specific density | - | - | 2100 kg / $m^3$ $^{+/-}$ 10% |
| Bulk density | - | - | 1100 kg / $m^3$ $^{+/-}$ 10% |
| Water absorption capacity after 24 hours (Enslin) | ASTM E946-92 | ≥ 600% (BRL-265/01) | 800% |
| Permeability (k-factor) | CUR, via Tri-axial cell | - | $1 \times 10^{-12}$ (m/s) |
| Sinking speed in water | - | - | 17 m/min |
| Density saturated with water | - | - | 1,55 t/$m^3$ |
| Swelling capacity | - | - | 220% |

**Cebo Holland**

Industrial Minerals, Powerful Logistics

**Cebo Holland BV**, Westerduinweg 1, 1976 BV IJmuiden, The Netherlands
Tel. +31(0)255-546262, Fax +31-(0)255-546202, info@cebo.com, www.cebo.com

## Product data sheet Cebogel QSE page 2

# Product Data Sheet

Cebogel QSE

**Recommended use**

Careful and even dosing are required for an optimal result. Bridge formation can occur in the event of dosing too rapidly.

Cebogel QSE has the following chemical and physical properties;

| Chemical and physical properties Cebogel QSE | |
|---|---|
| Composition | High quality activated sodium bentonite |
| Colour | Grey/yellow |
| Form | Cylindrical rods |
| Dimensions | Diameter 6,5 mm<br>Length 5 – 20 mm |

**Packaging**

Cebogel QSE is available in the following packaging;

- 1050 kg packed in 25 kg bags on a pallet with shrink film
- 1000 kg big bag

Revision date : 10.11.2014
Document number : 102701GB

In so far as we can ascertain the above-stated information is correct. However, we are unable to provide any guarantees with regard to the results that you will achieve with this. This specification is provided on the condition that you determine yourself to what degree it is suitable for your purposes.

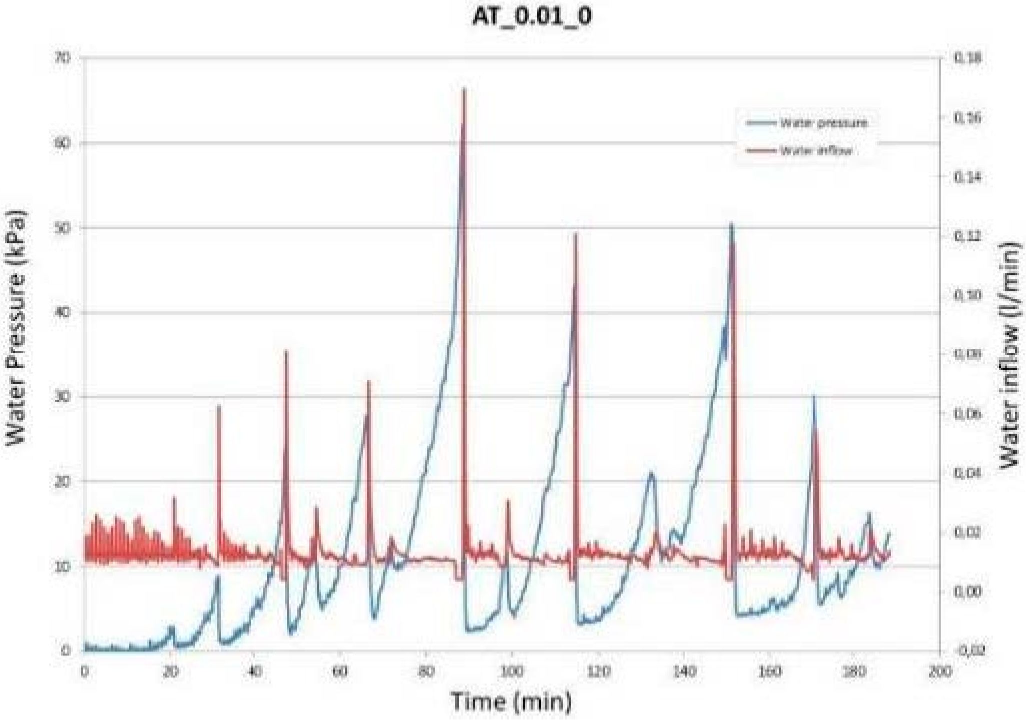
Cebo Holland

Industrial Minerals, Powerful Logistics

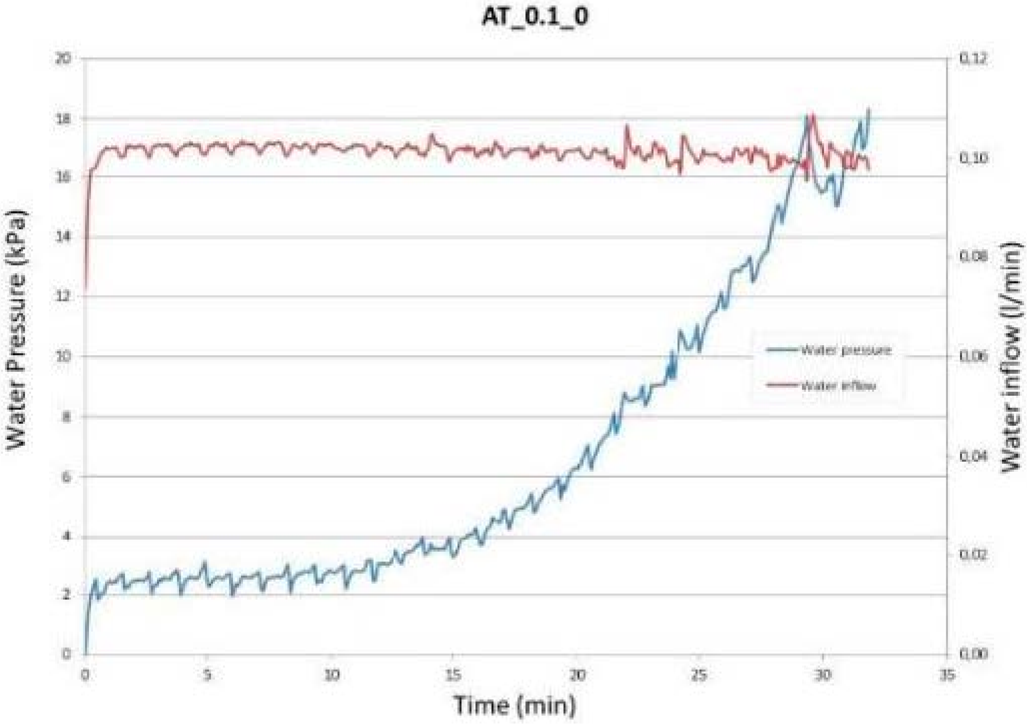
Cebo Holland BV, Westerduinweg 1, 1976 BV IJmuiden, The Netherlands
Tel. +31(0)255-546262, Fax +31-(0)255-546202, info@cebo.com, www.cebo.com

# Appendix 4

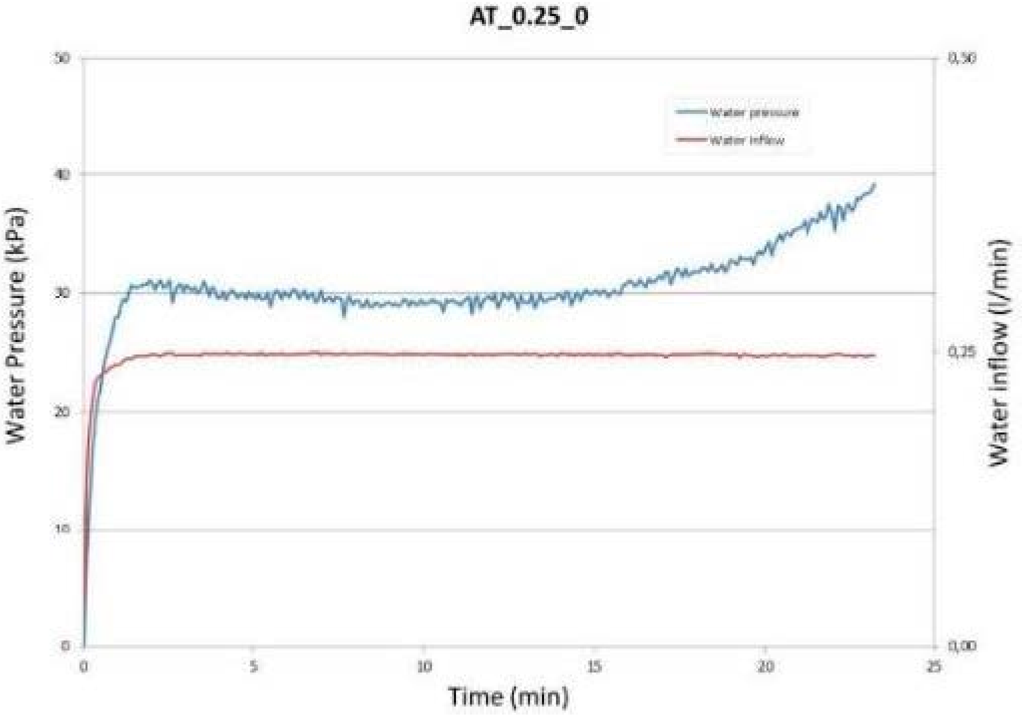
## Tube tests water pressure and inflow rate graphs, Asha



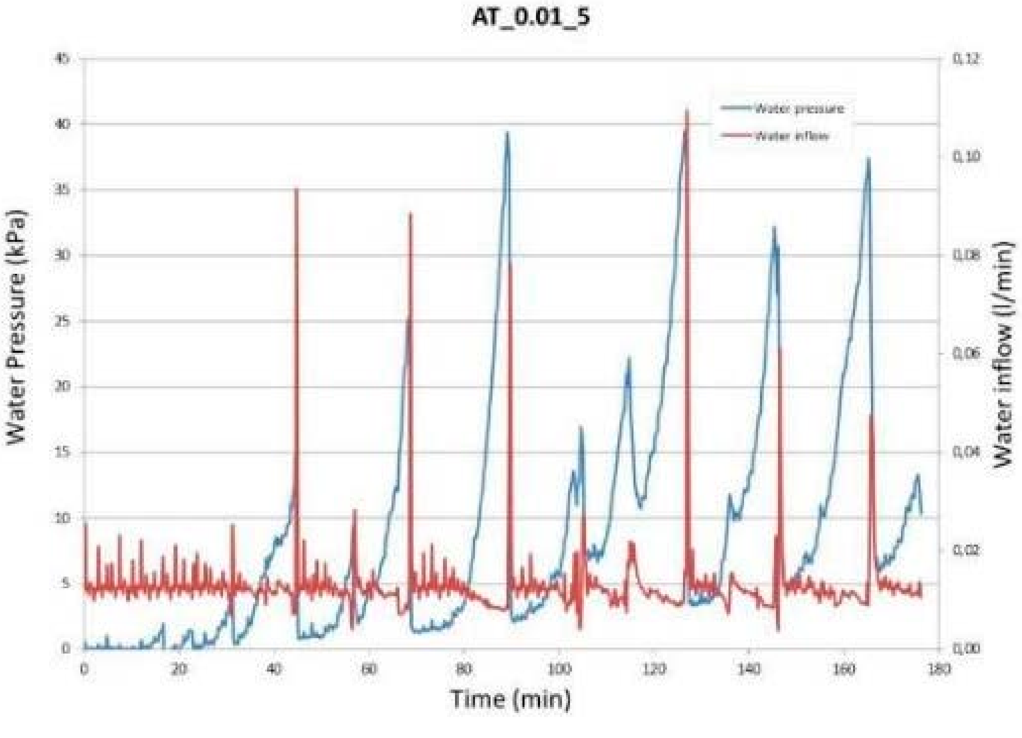
***A4-1.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.01 l/min.*



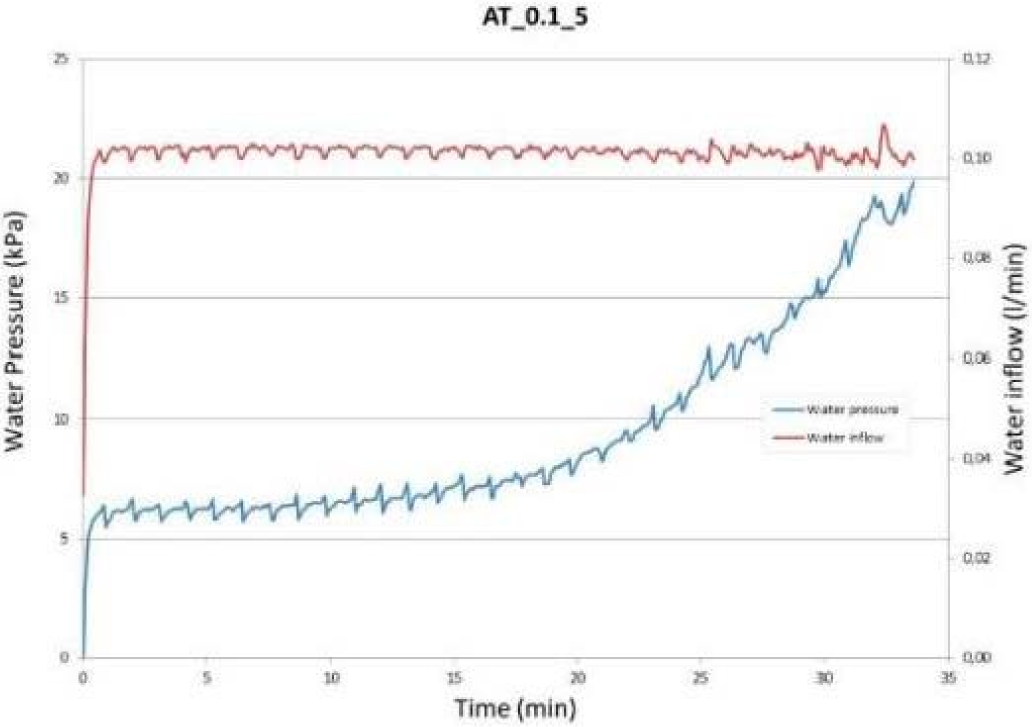
***A4-2.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.1 l/min.*



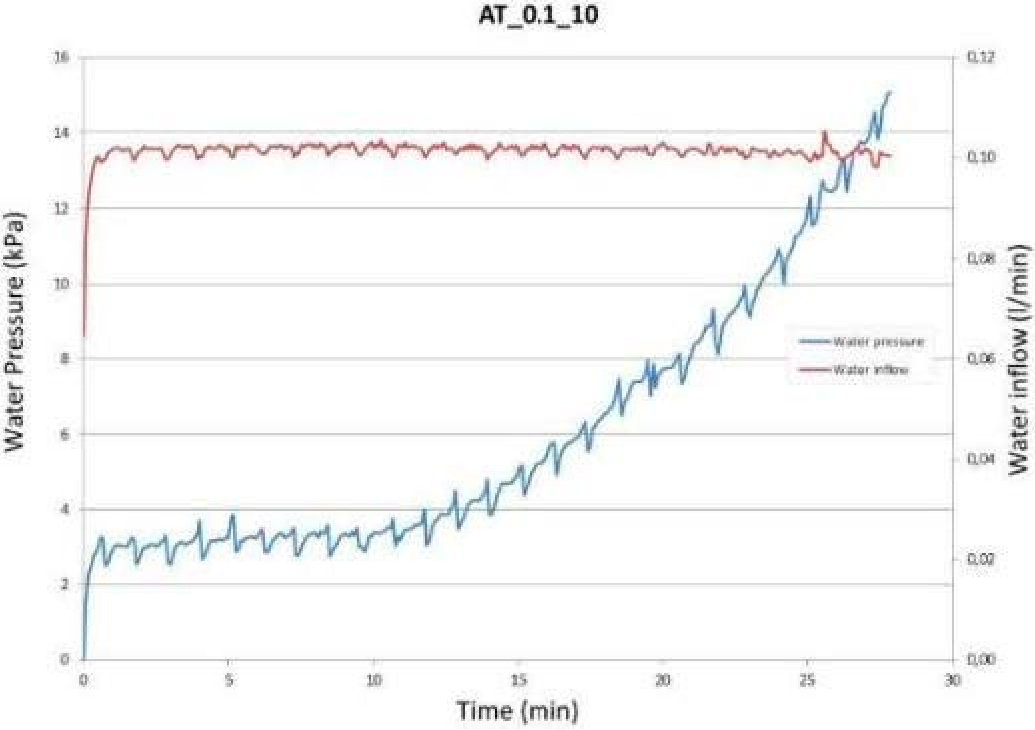
*A4-3.* Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.25 l/min.



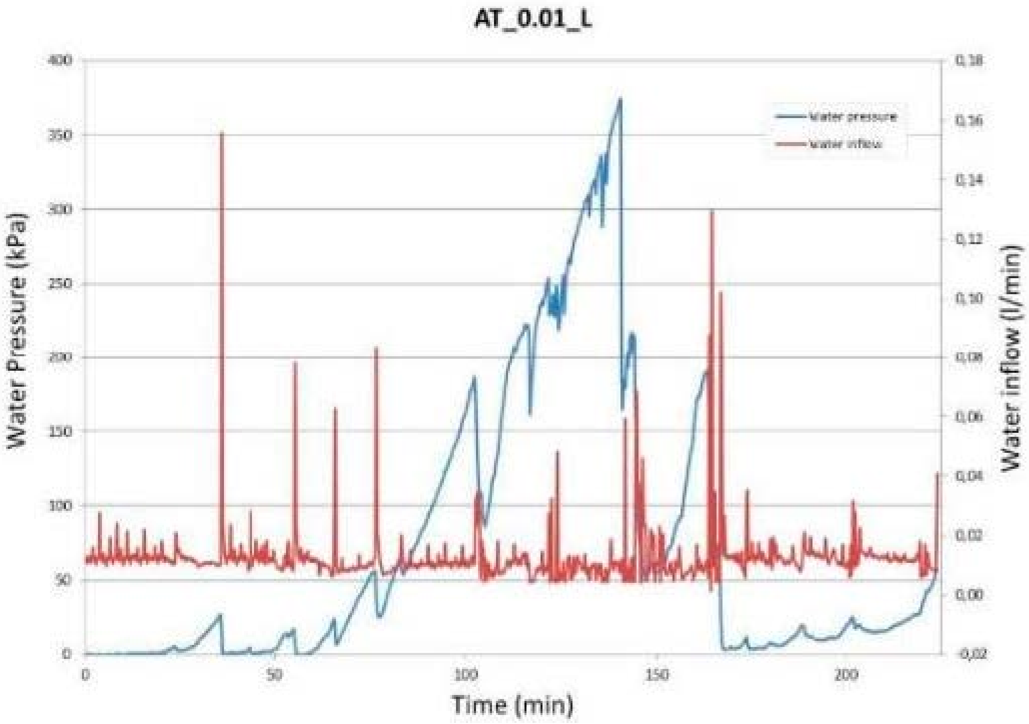
*A4-4.* Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.01 l/min. 5 % fines are mixed with the pellets.



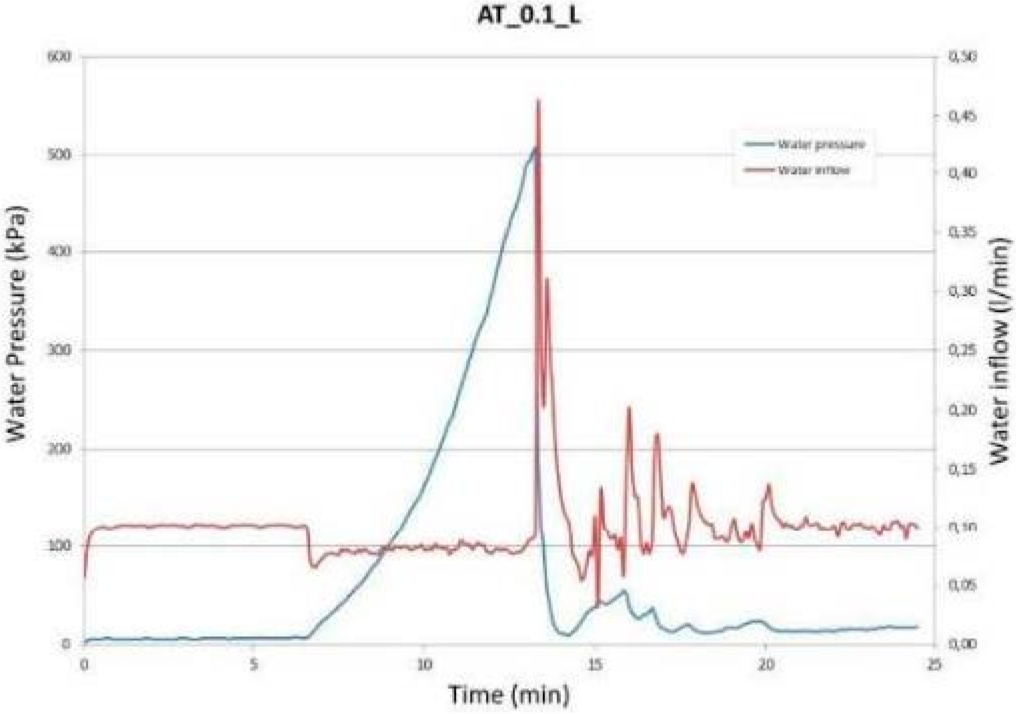
***A 4-5.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. 5 % fines are mixed with the pellets.*



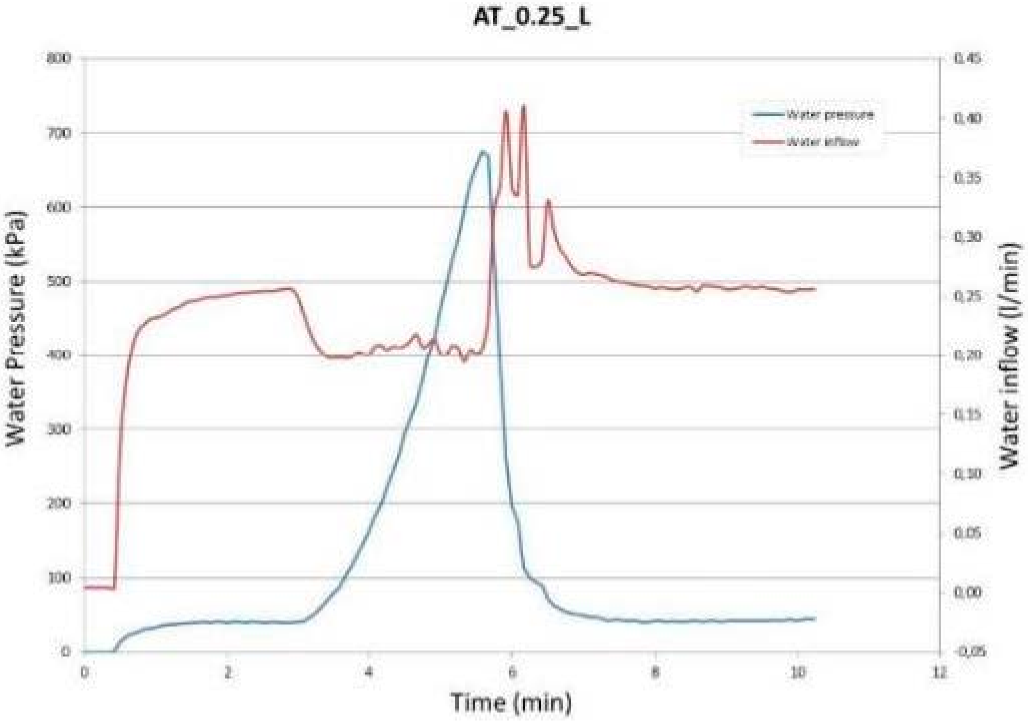
***A4-6.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. 10 % fines are mixed with the pellets.*



***A4-7.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.01 l/min. Fines are positioned in layers in the pellet filling.*



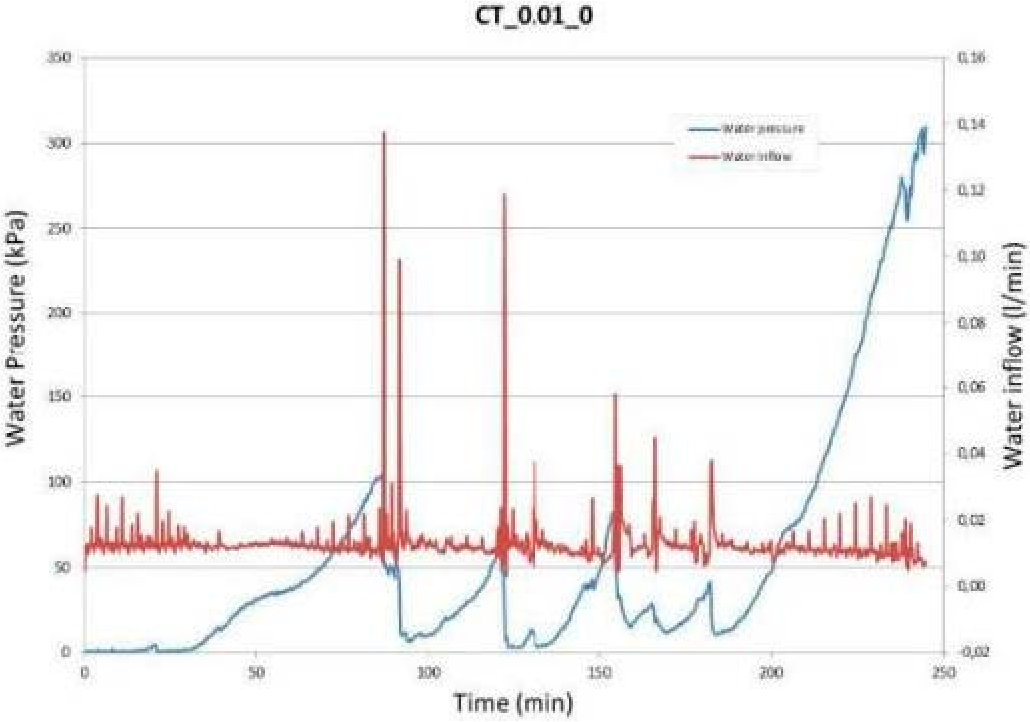
***A4-8.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. Fines are positioned in layers in the pellet filling.*



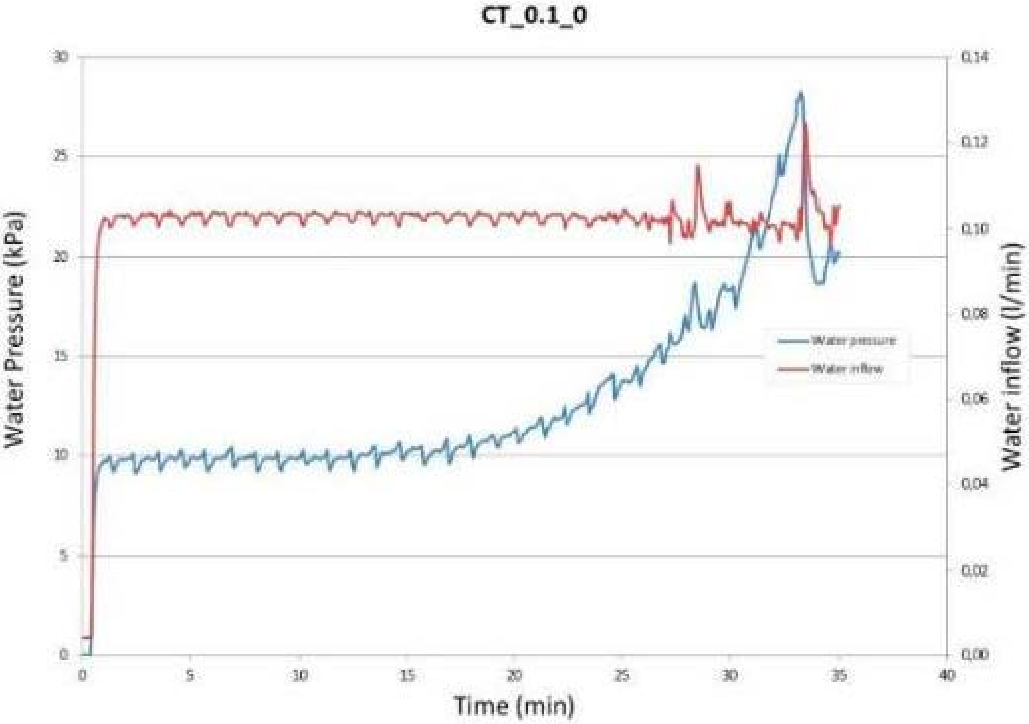
***A4-9.*** *Water pressure for Asha Tube tests with 1 % salinity and water inflow rate of 0.25 l/min. Fines are positioned in layers in the pellet filling.*

# Appendix 5

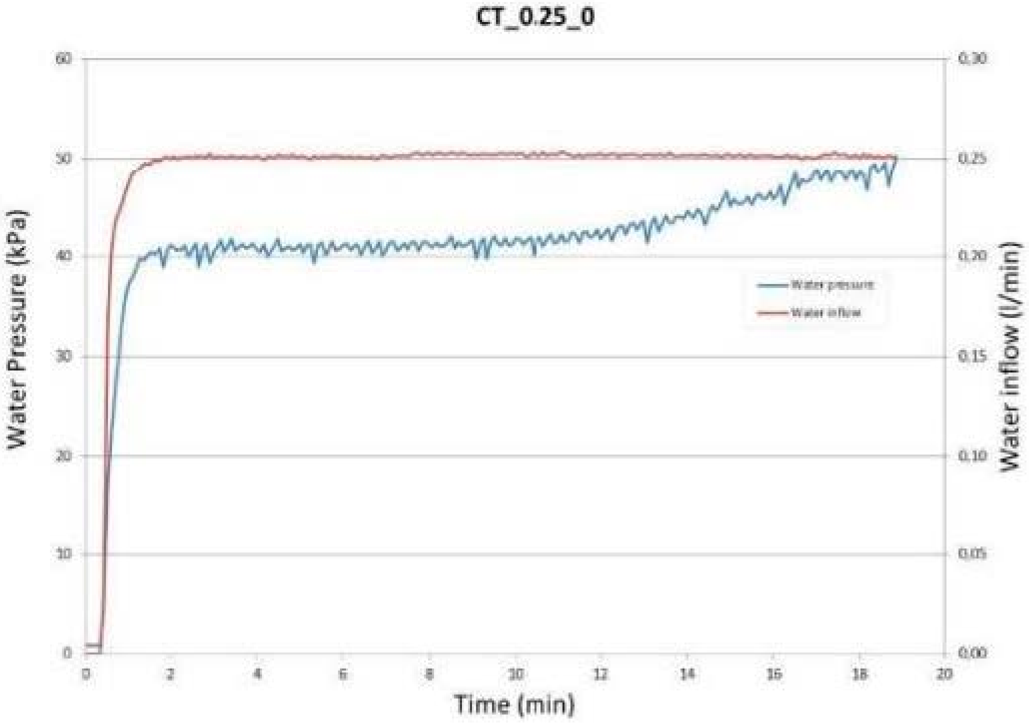
## Tube tests water pressure and inflow rate graphs, Cebogel



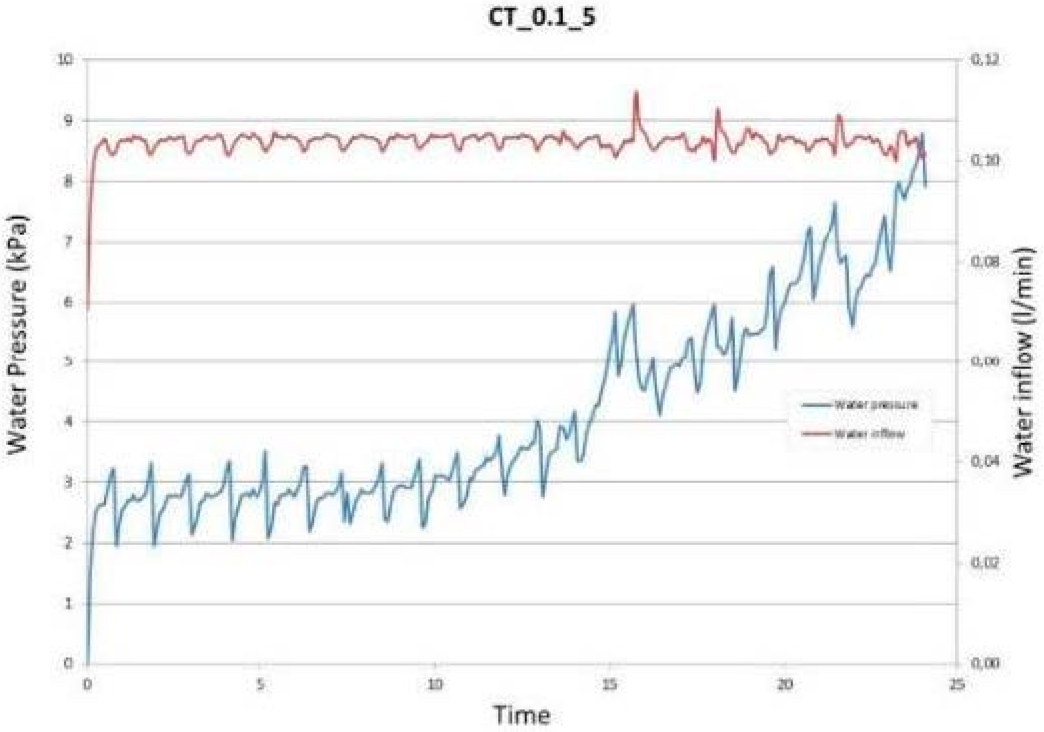
***A5-1.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.01 l/min.*



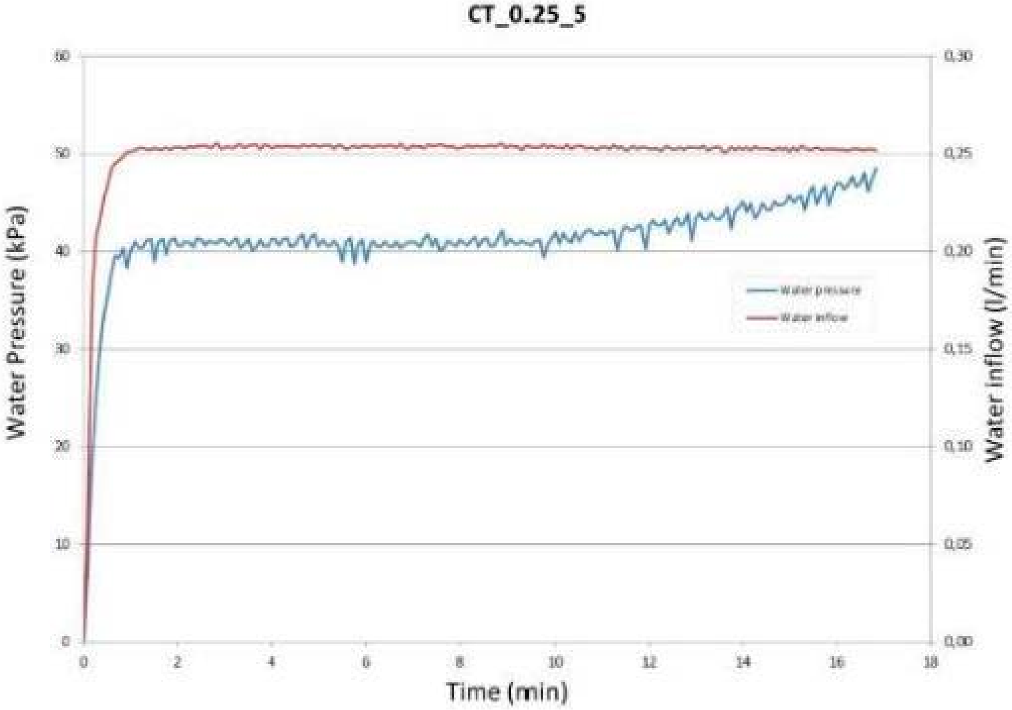
***A5-2.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.1 l/min.*



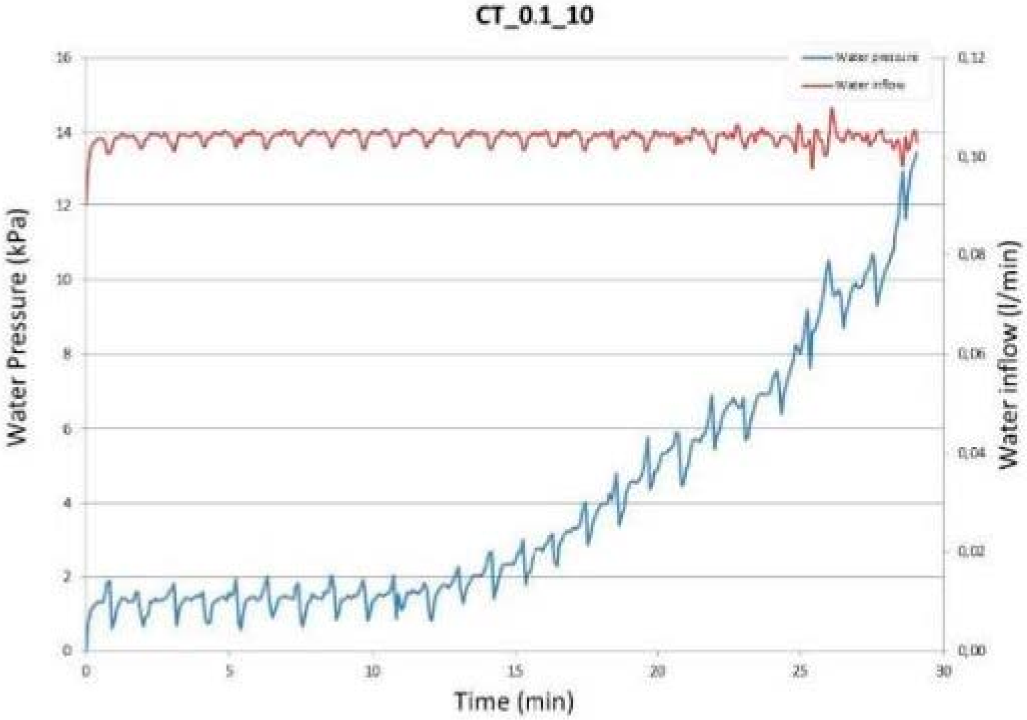
***A5-3.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.25 l/min.*



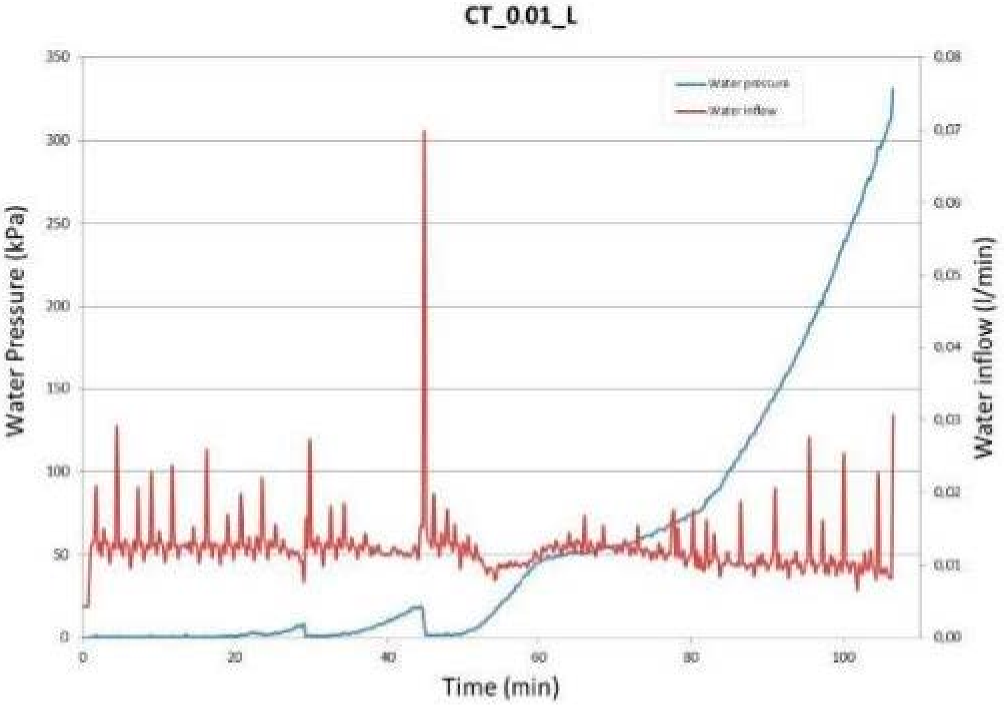
***A5-4.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. 5 % fines are mixed with the pellet.*



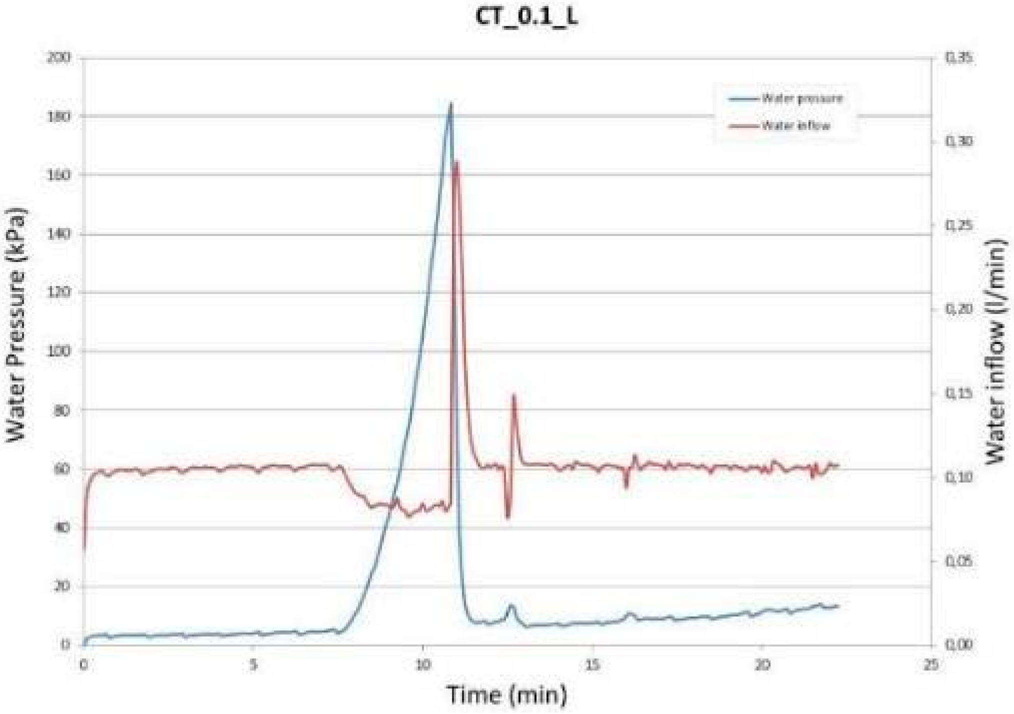
***A5-5.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.25 l/min. 5 % fines are mixed with the pellet.*



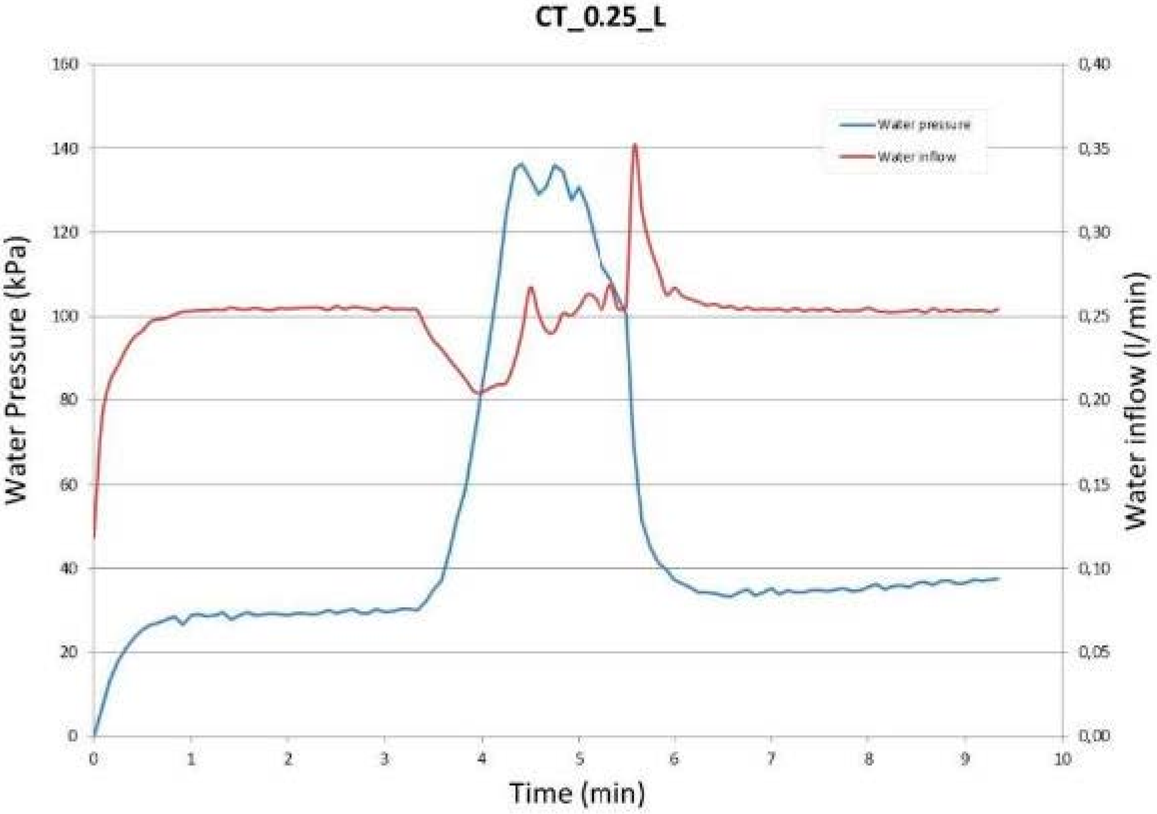
***A5-6.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. 10 % fines are mixed with the pellet.*



***A5-7.** Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.01 l/min. Fines are placed in layers in the pellet filling.*



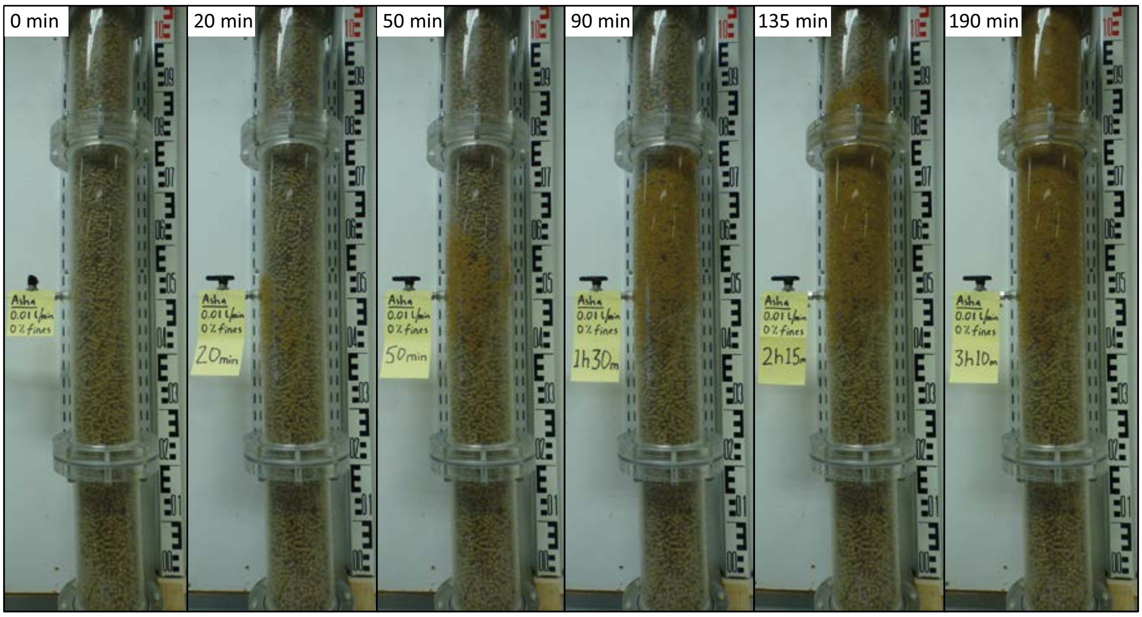
***A5-8.** Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.1 l/min. Fines are placed in layers in the pellet filling.*



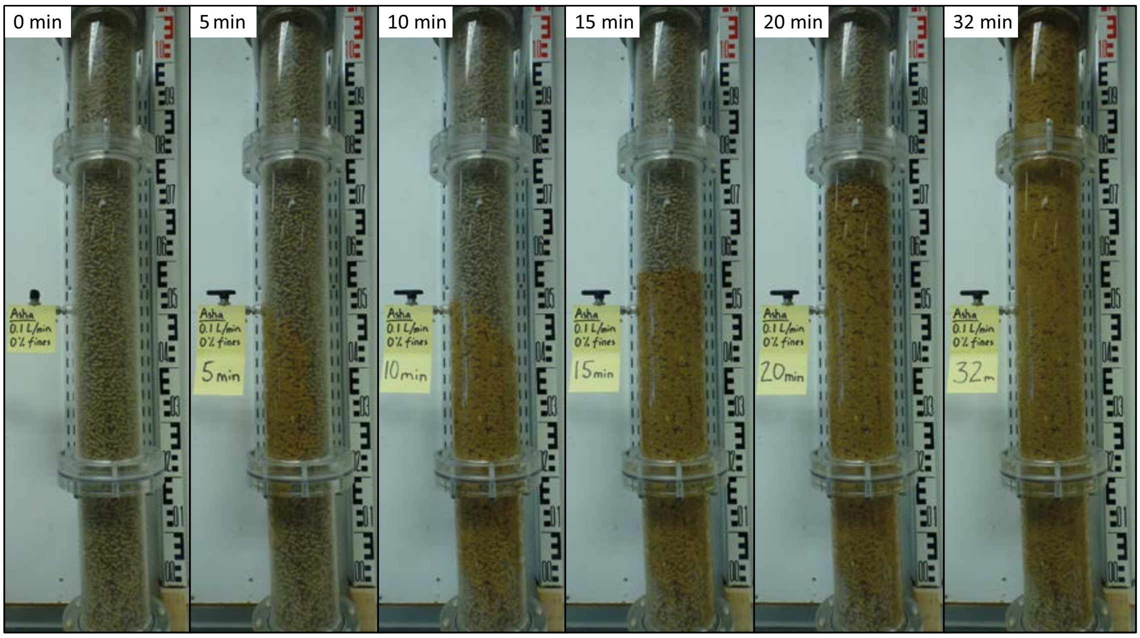
***A5-9.*** *Water pressure for Cebogel Tube tests with 1 % salinity and water inflow rate of 0.25 l/min. Fines are placed in layers in the pellet filling.*

# Appendix 6

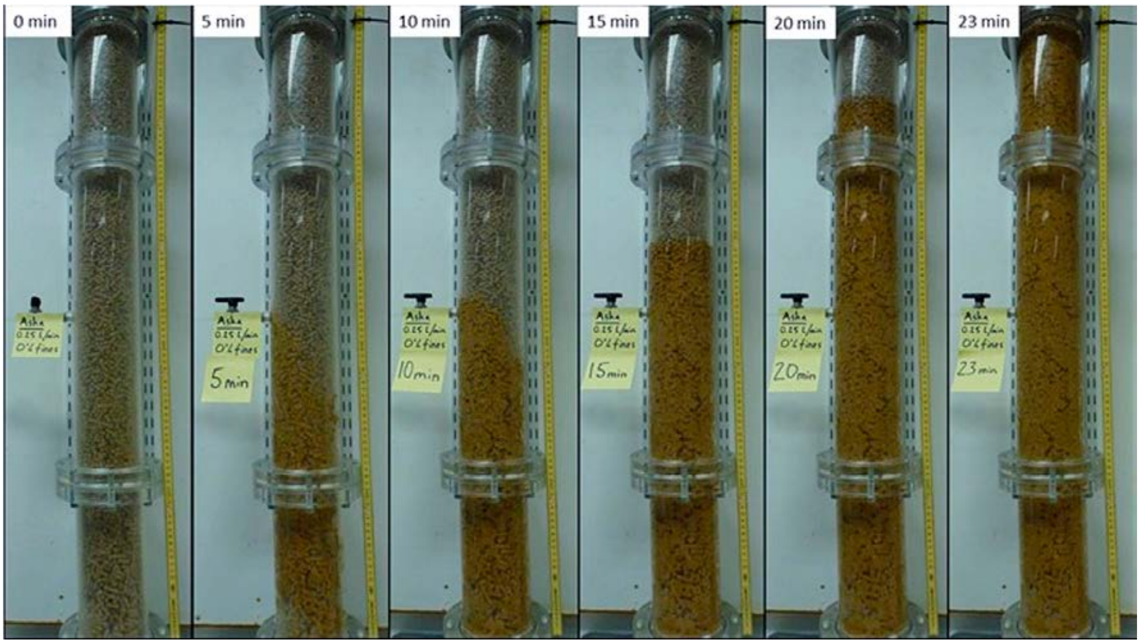
## Tube tests water front evolution, Asha



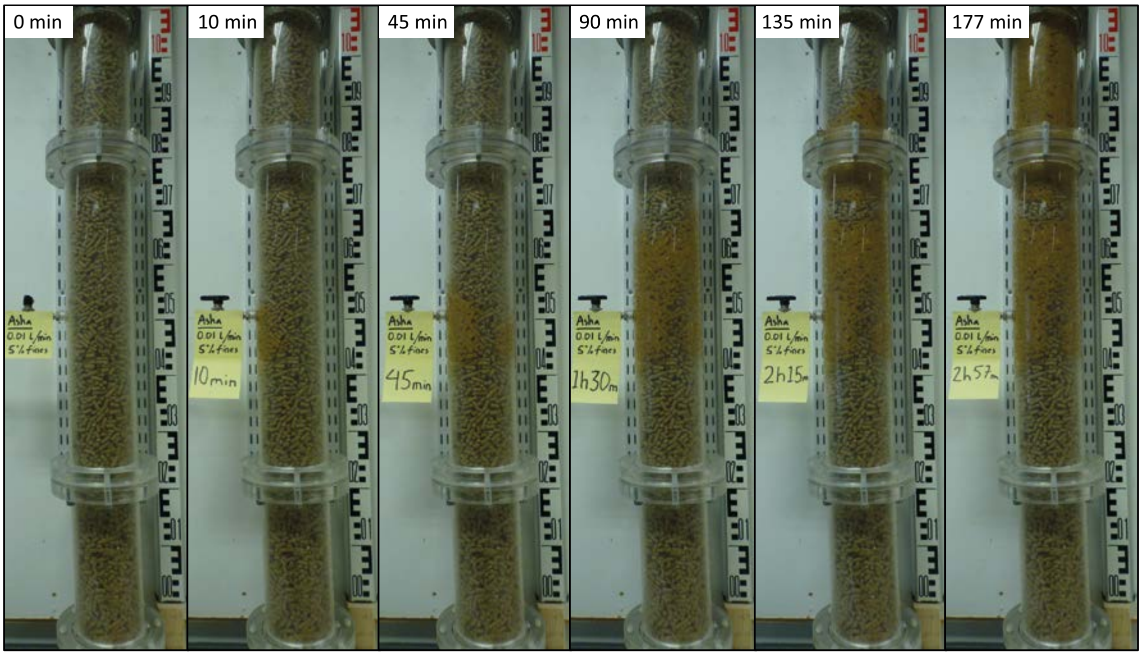
***A6-1.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.01 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



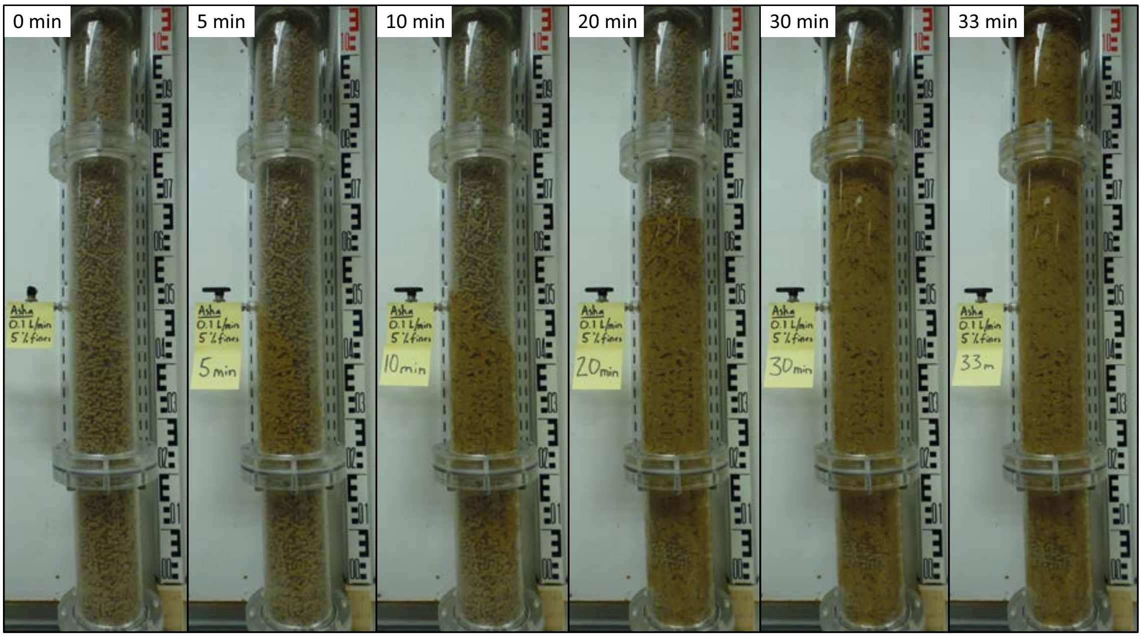
***A6-2.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.1 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



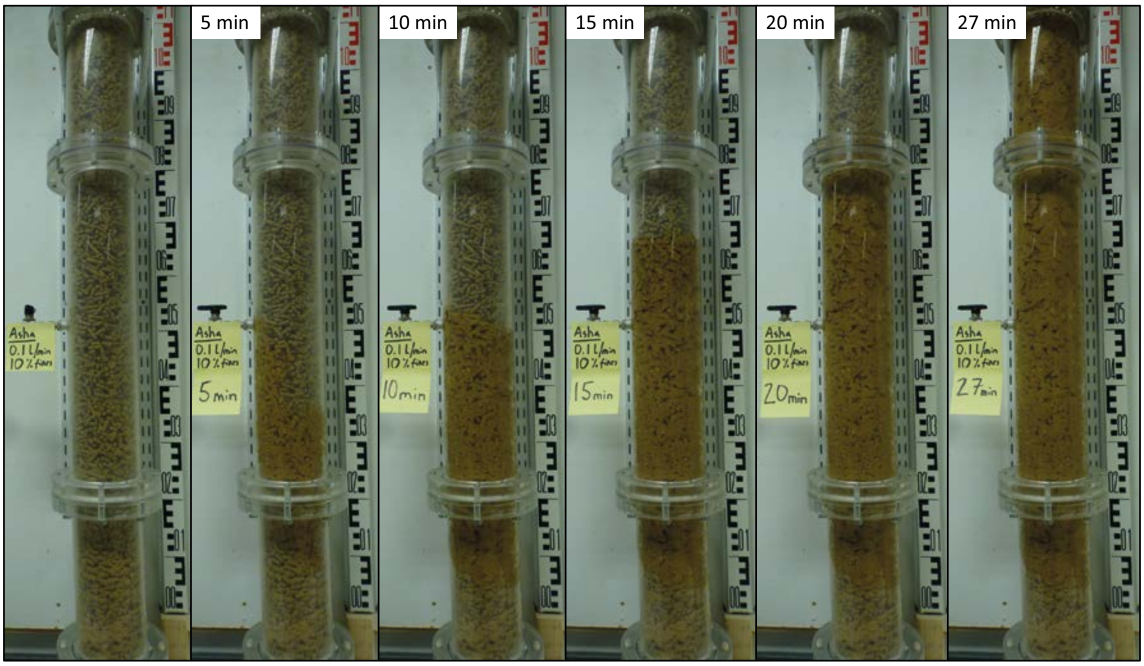
***A6-3.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.25 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



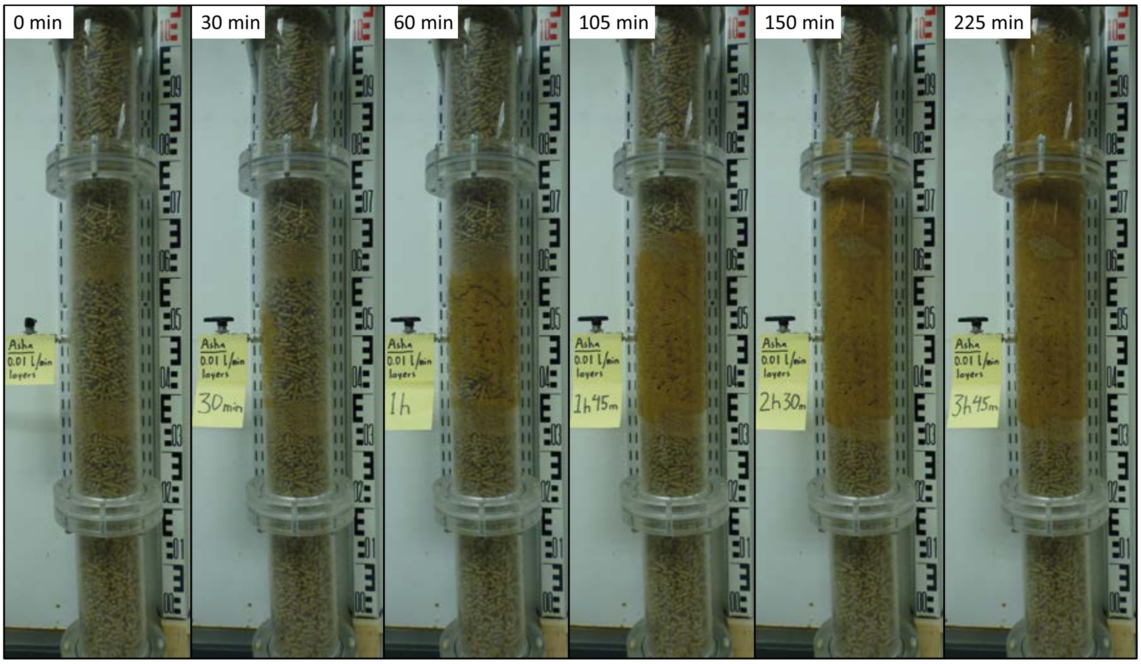
***A6-4.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.01 l/min and 5 % fines in the pellets. The photos are taken at different times after test start.*



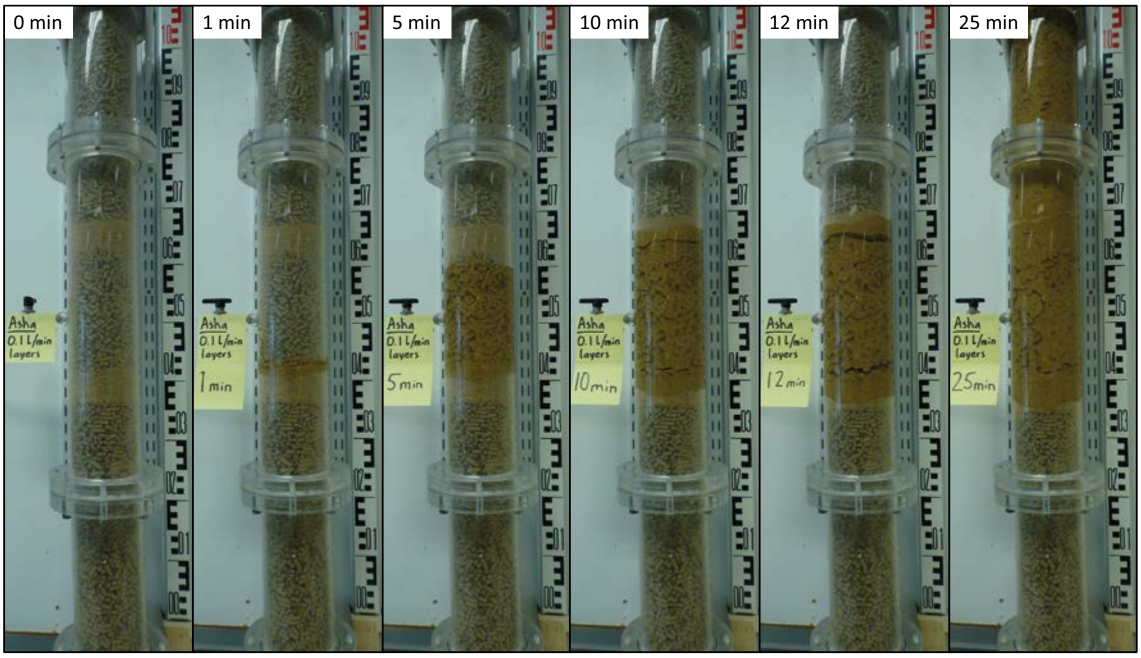
***A6-5.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.1 l/min and 5 % fines in the pellets. The photos are taken at different times after test start.*



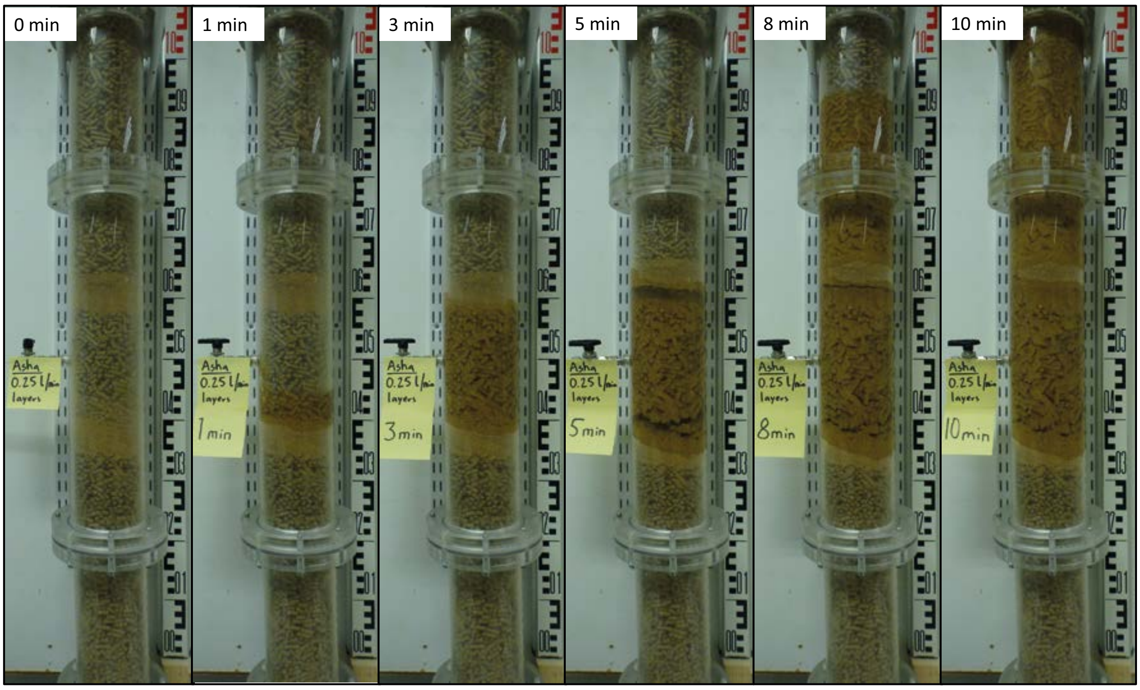
***A6-6.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.1 l/min and 10 % fines in the pellets. The photos are taken at different times after test start.*



*A6-7. Photos of the test performed with Asha pellets, an inflow rate of 0.01 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.*



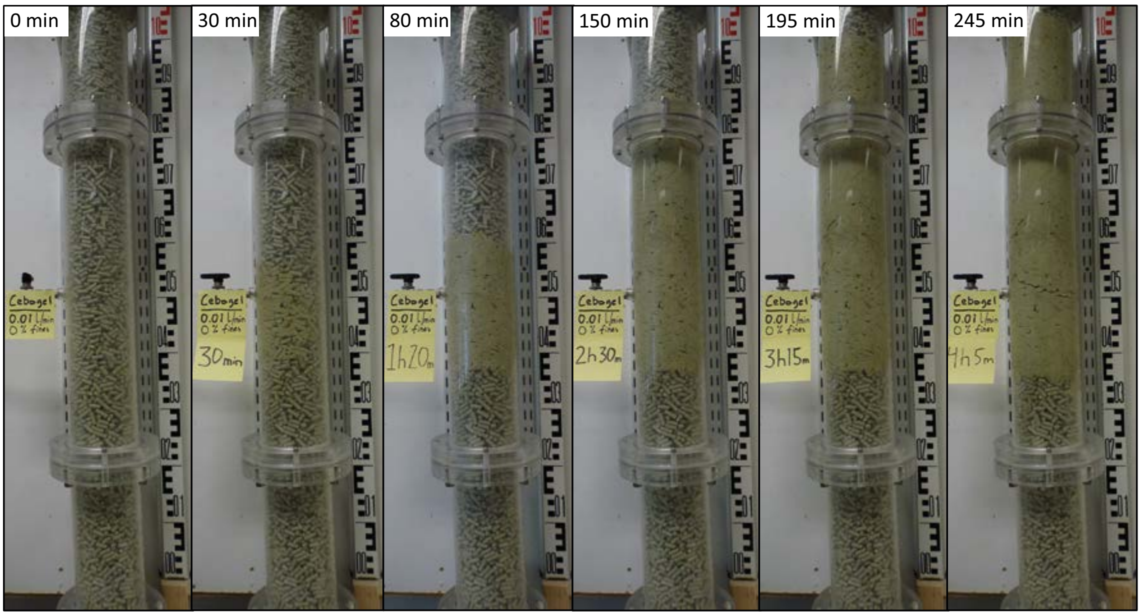
*A6-8. Photos of the test performed with Asha pellets, an inflow rate of 0.1 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.*



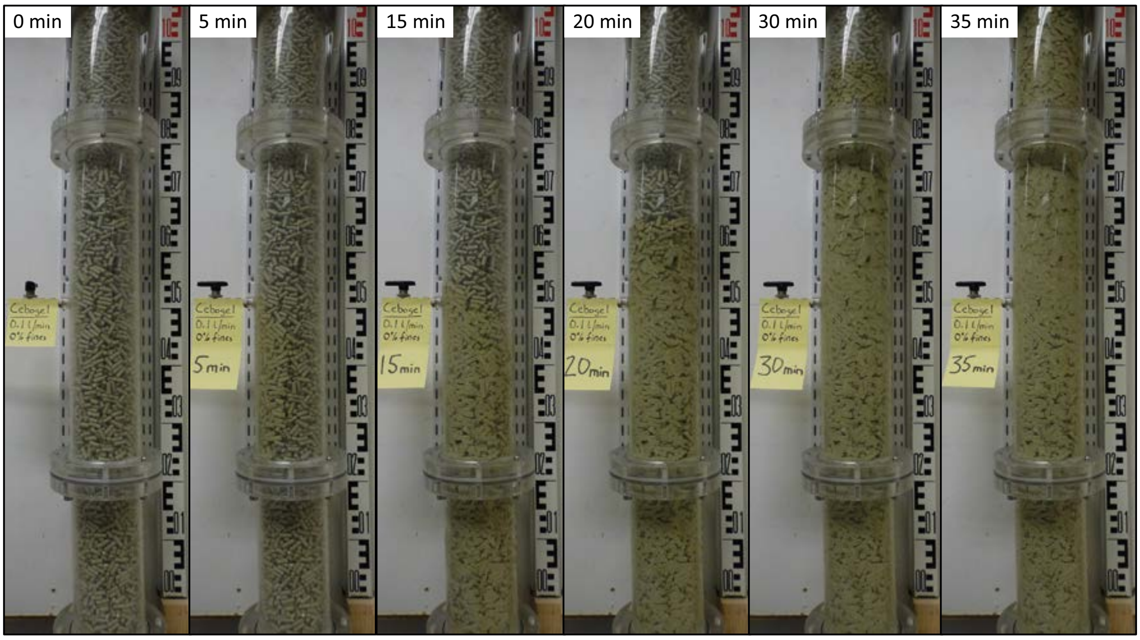
***A6-9.*** *Photos of the test performed with Asha pellets, an inflow rate of 0.25 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.*

# Appendix 7

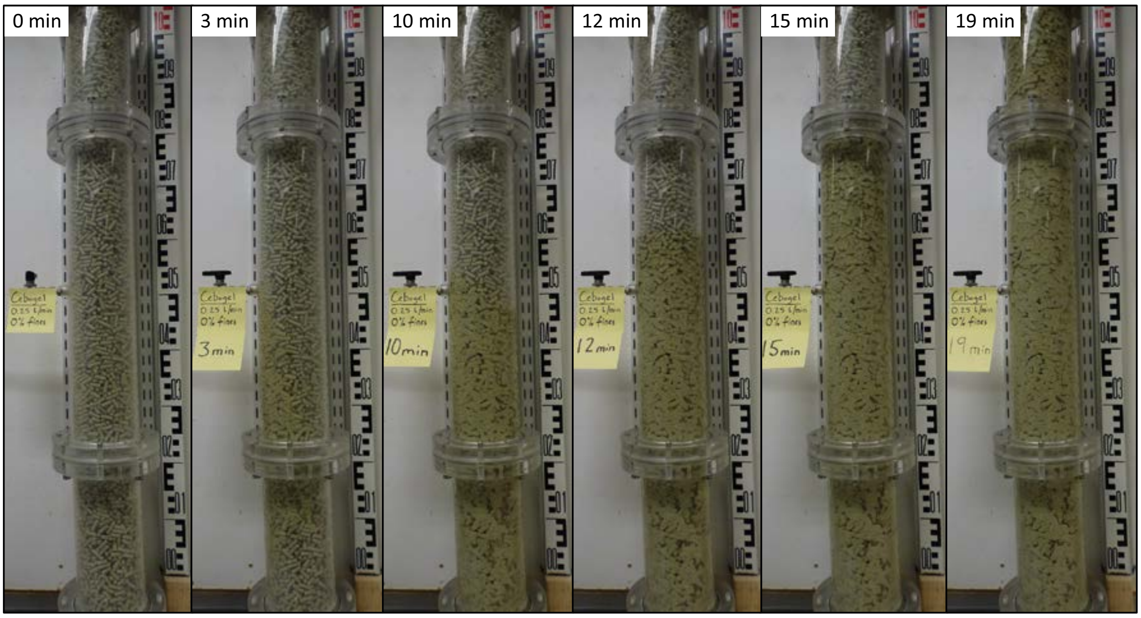
## Tube tests water front evolution, Cebogel



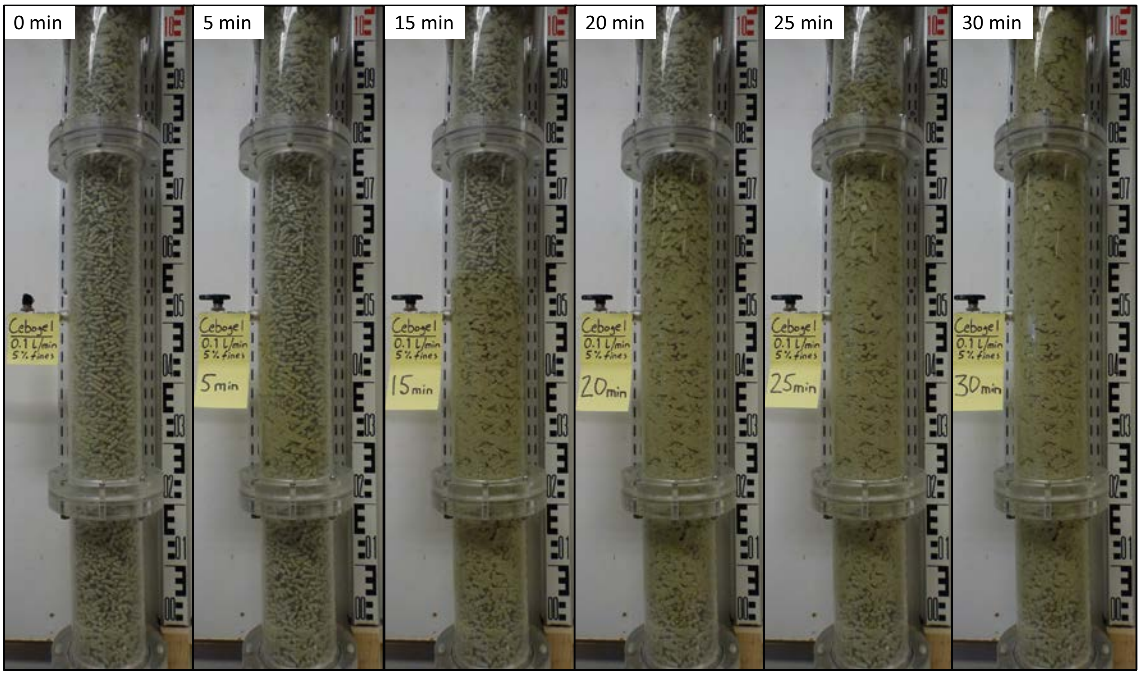
***A7-1.*** *Photos of the test performed with Cebogel pellets, an inflow rate of 0.01 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



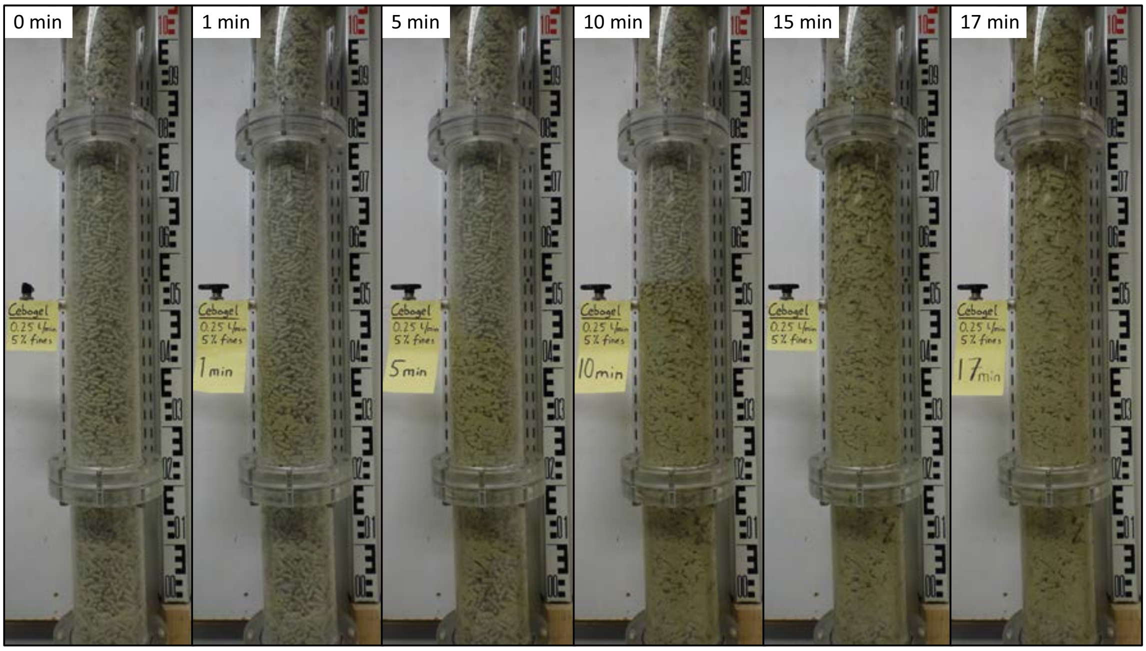
***A7-2.*** *Photos of the test performed with Cebogel pellets, an inflow rate of 0.1 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



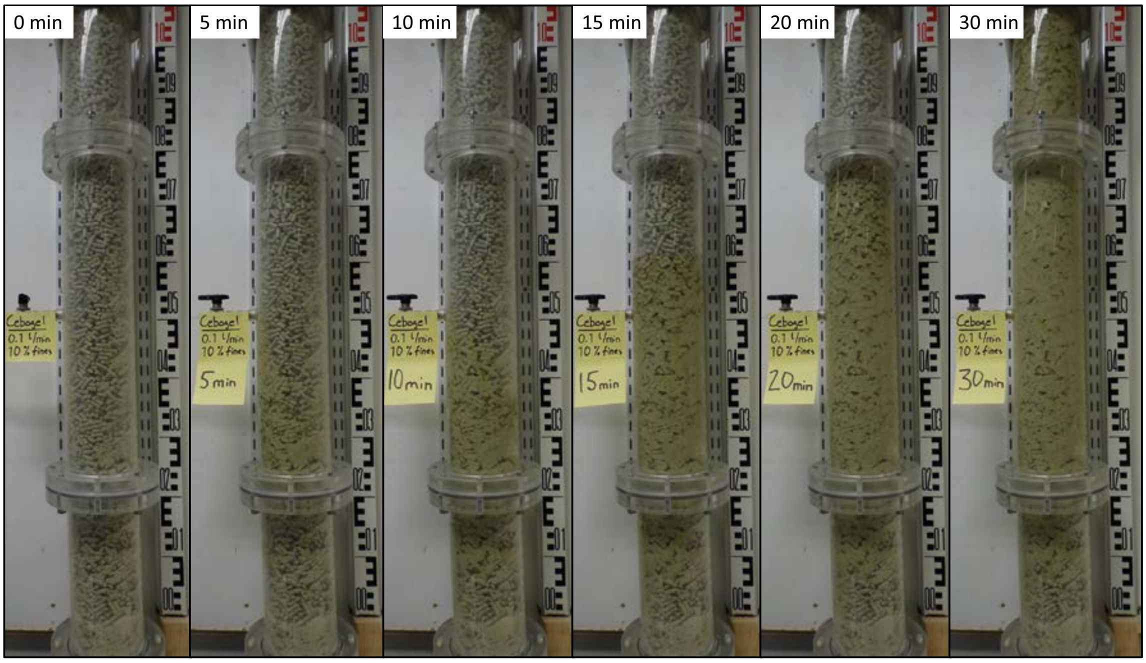
***A7-3.*** *Photos of the test performed with Cebogel pellets, an inflow rate of 0.25 l/min and 0 % fines in the pellets. The photos are taken at different times after test start.*



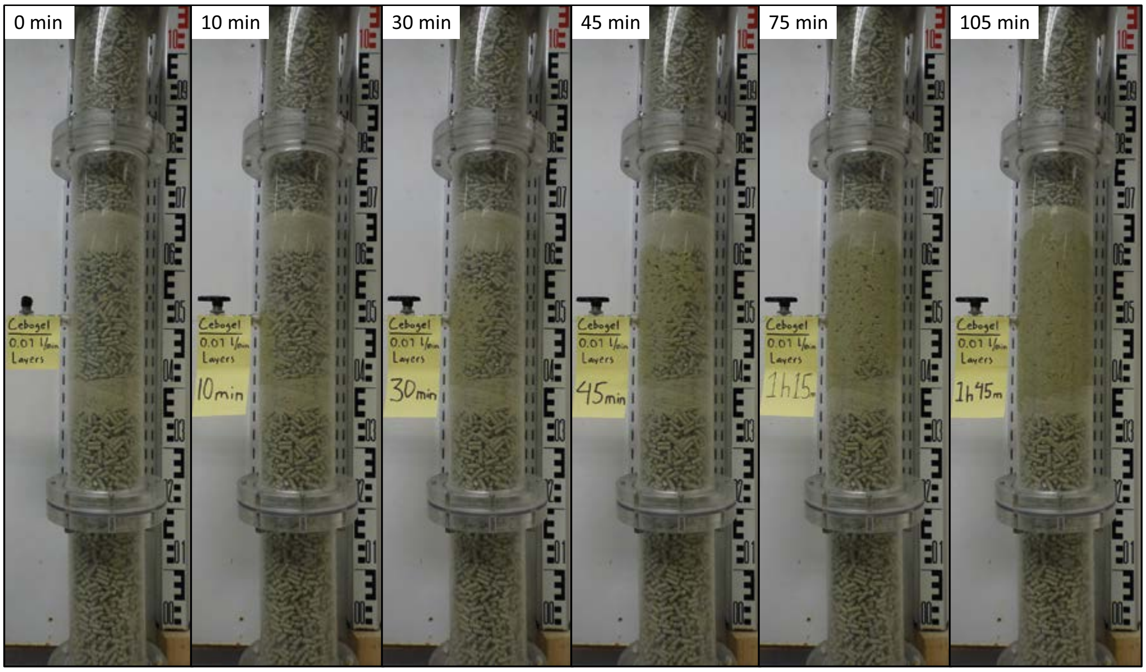
***A7-4.*** *Photos of the test performed with Cebogel pellets, an inflow rate of 0.1 l/min and 5 % fines in the pellets. The photos are taken at different times after test start.*



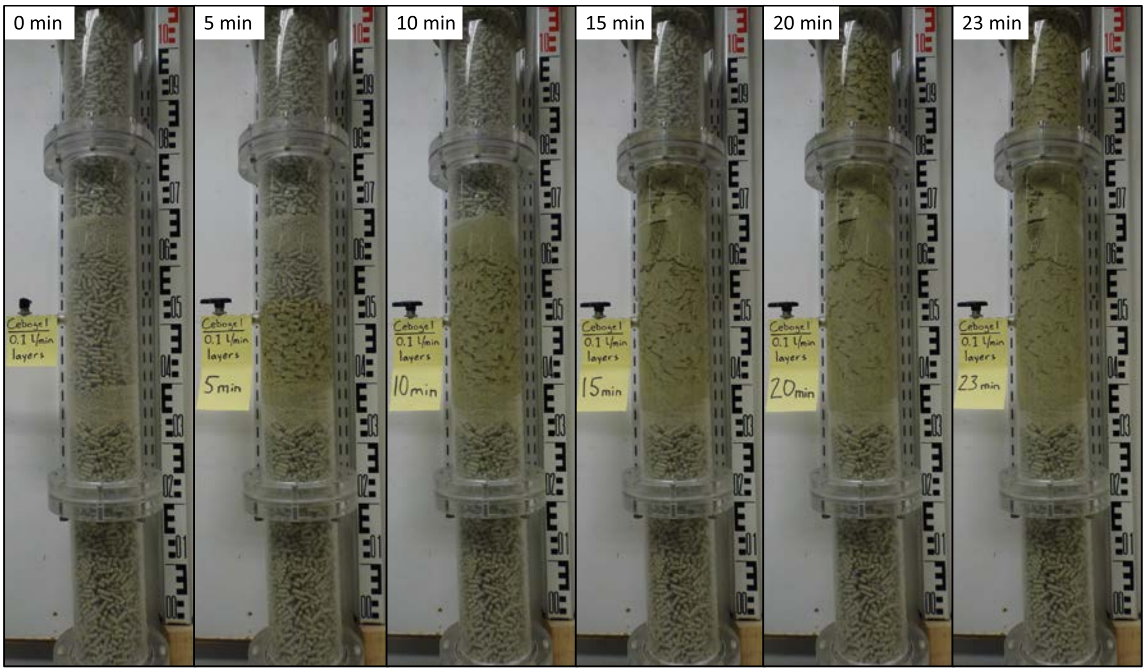
***A7-5.** Photos of the test performed with Cebogel pellets, an inflow rate of 0.25 l/min and 5 % fines in the pellets. The photos are taken at different times after test start.*



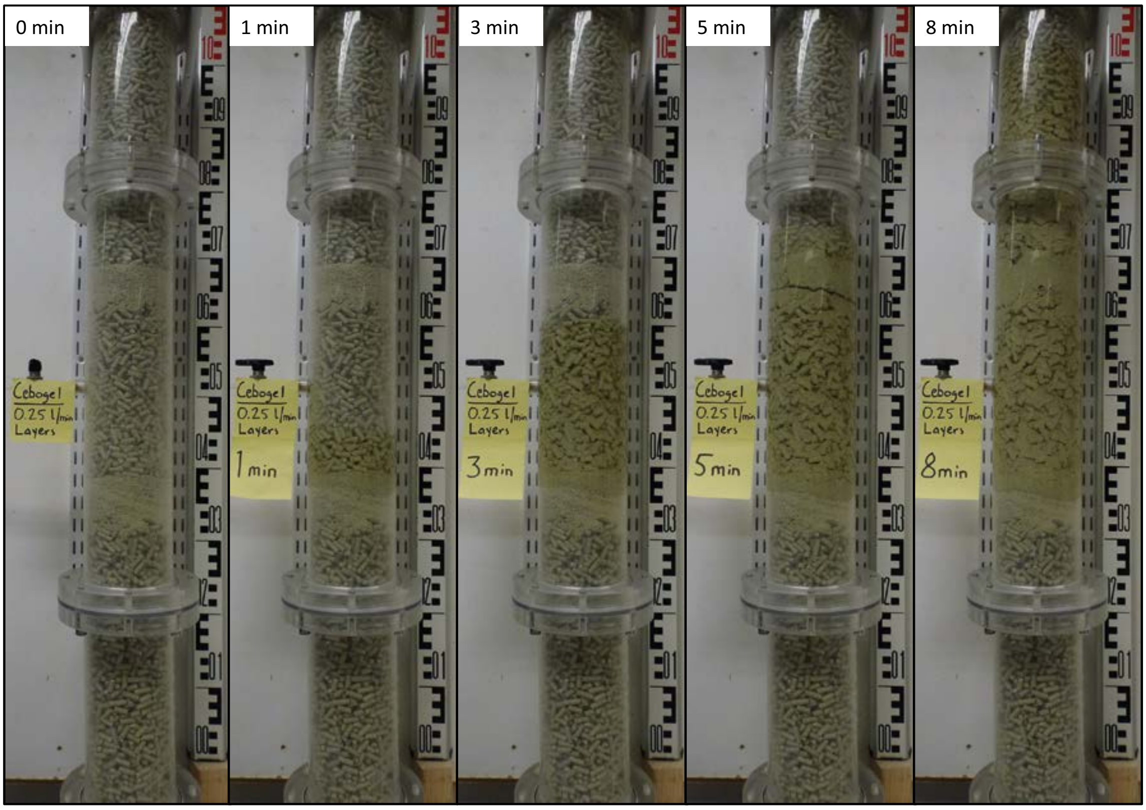
***A7-6.** Photos of the test performed with Cebogel pellets, an inflow rate of 0.1 l/min and 10 % fines in the pellets. The photos are taken at different times after test start.*



*A7-7.* Photos of the test performed with Cebogel pellets, an inflow rate of 0.01 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.



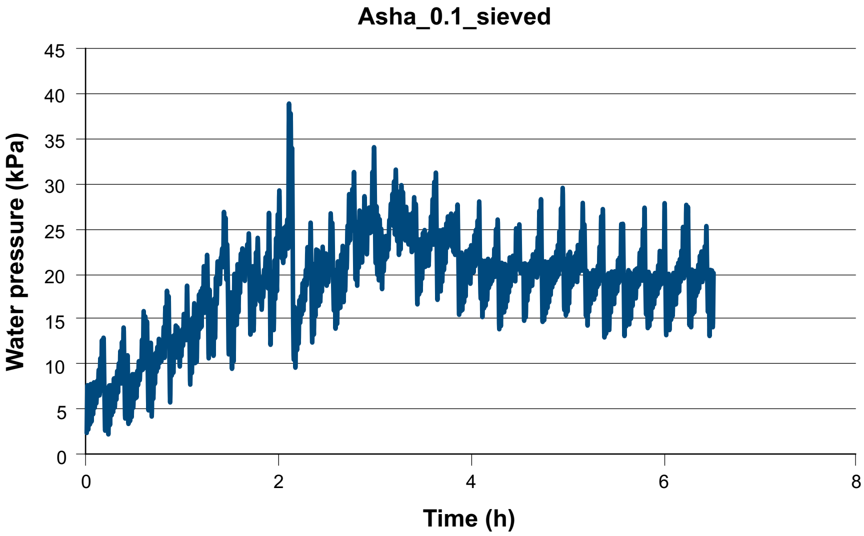
*A7-8.* Photos of the test performed with Cebogel pellets, an inflow rate of 0.1 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.



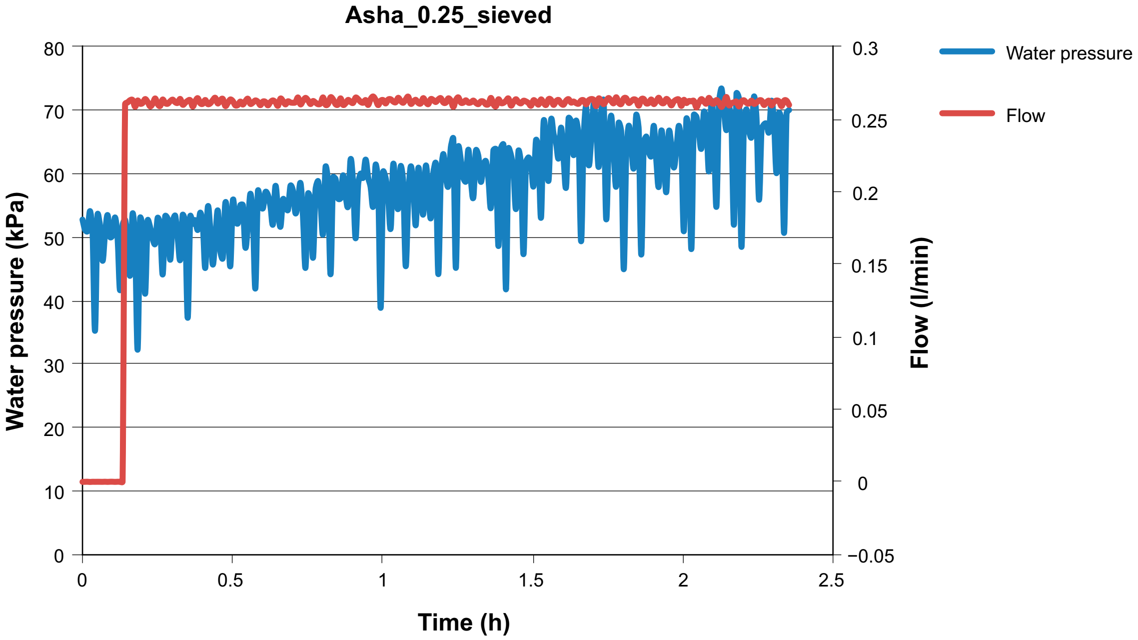
*A7-9. Photos of the test performed with Cebogel pellets, an inflow rate of 0.25 l/min and fines placed in layers in the pellet filling. The photos are taken at different times after test start.*

# Appendix 8

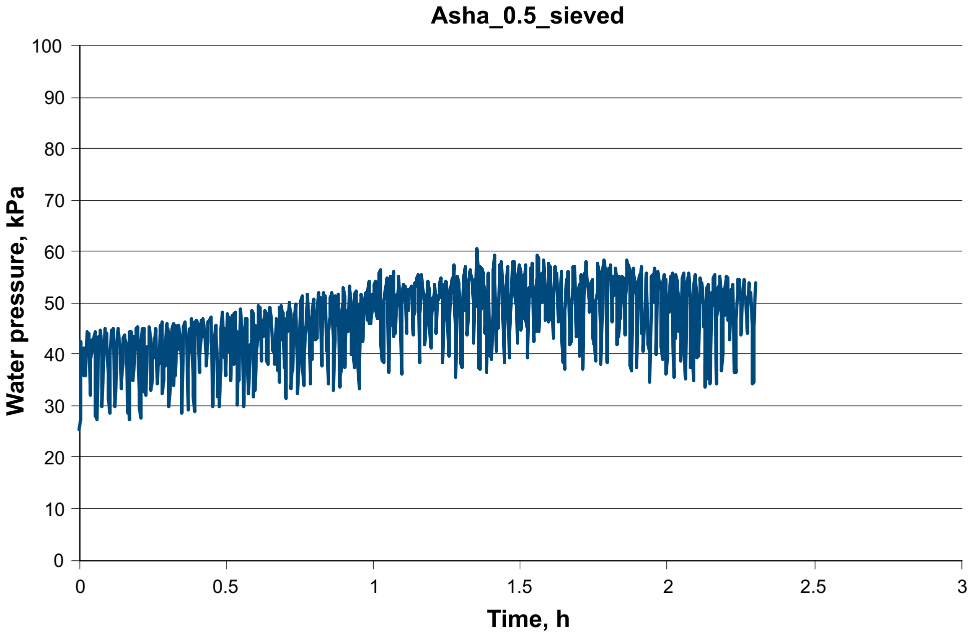
## Large slot tests, water pressure and water inflow rate, Asha



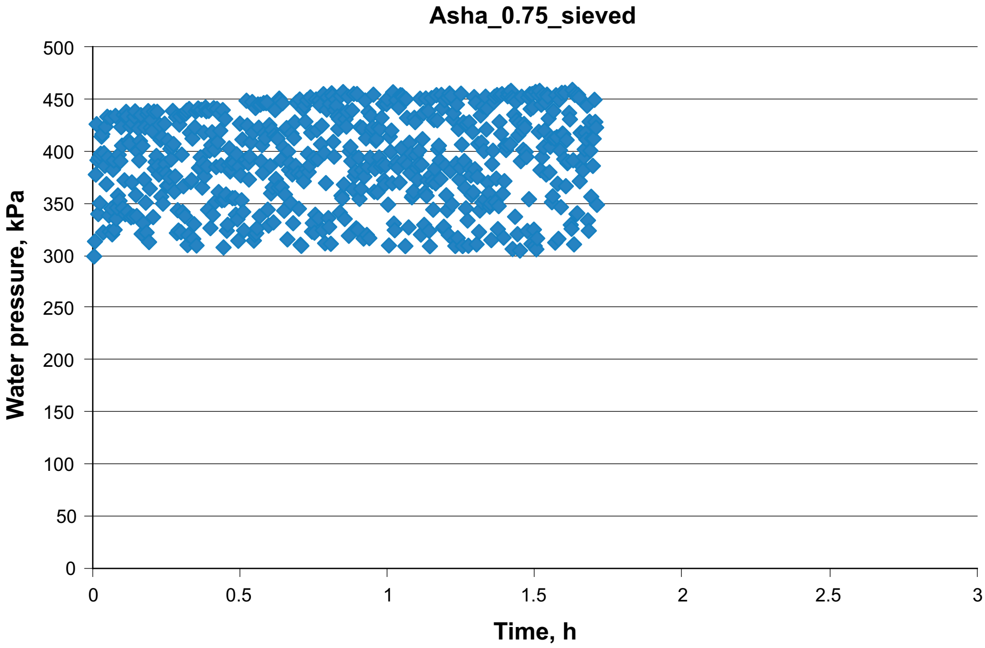
***A8-1.*** *Water pressure for Large slot test performed with sieved Asha pellets and a water inflow rate of 0.1 l/min.*



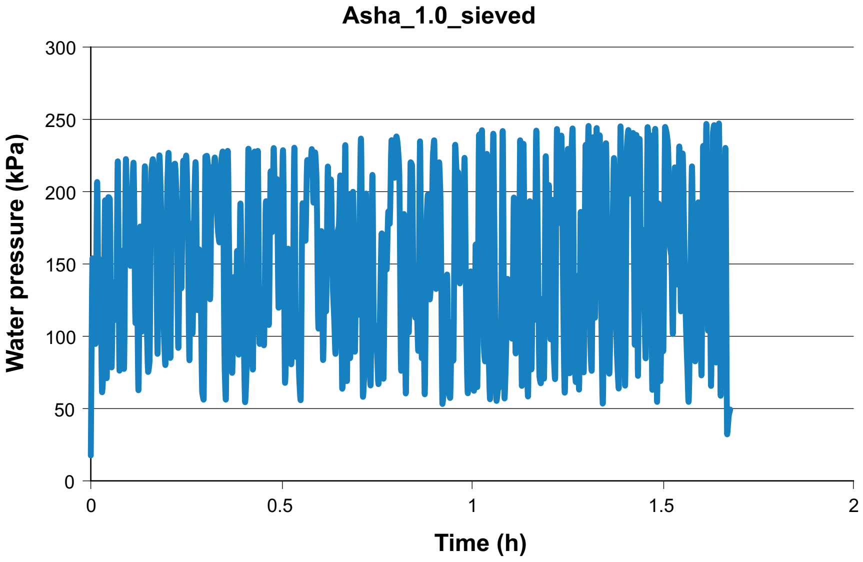
***A8-2.*** *Water pressure for Large slot test performed with sieved Asha pellets and a water inflow rate of 0.25 l/min.*



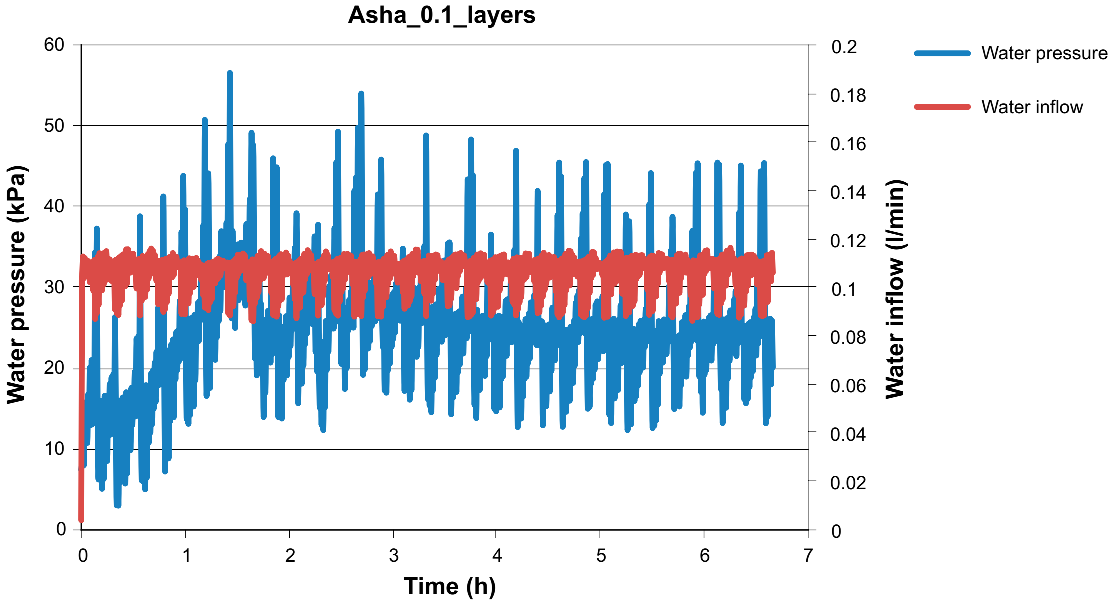
***A8-3.*** *Water pressure for Large slot test performed with sieved Asha pellets and a water inflow rate of 0.5 l/min.*



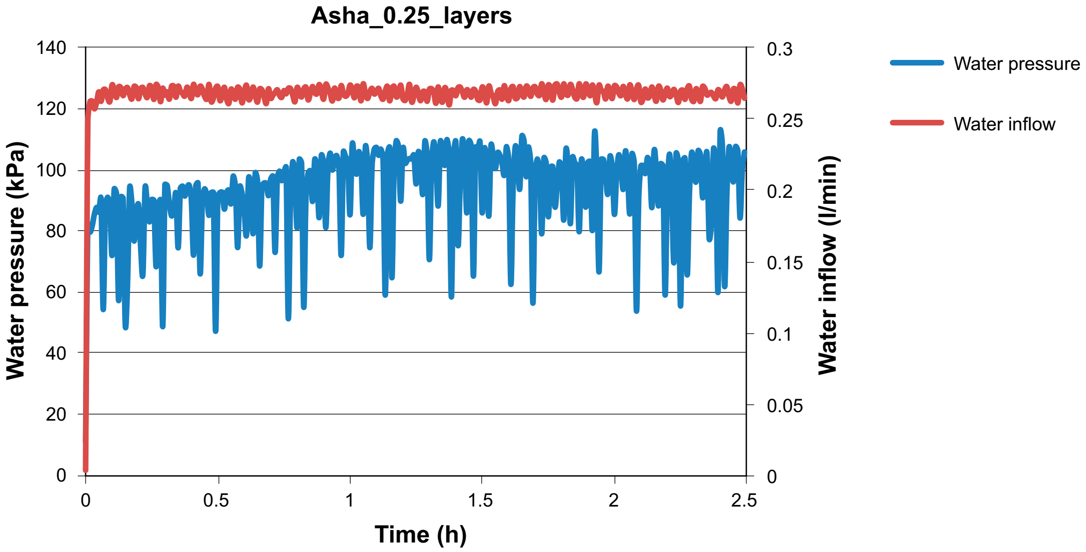
***A8-4.*** *Water pressure for Large slot test performed with sieved Asha pellets and a water inflow rate of 0.5 l/min.*



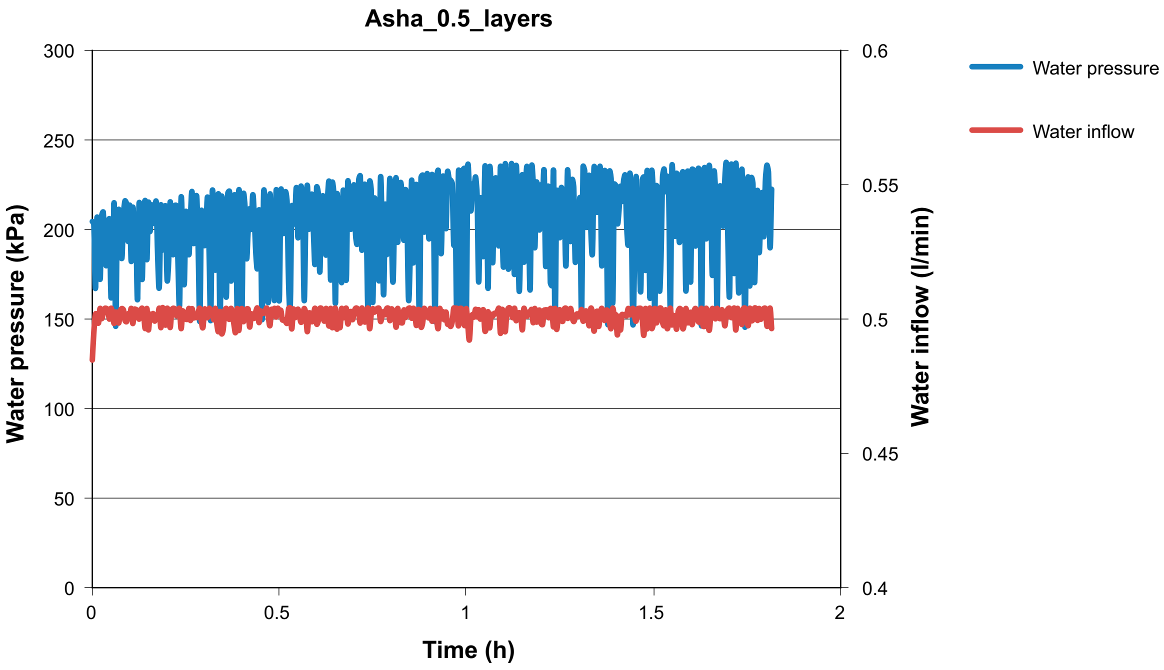
***A8-5.*** *Water pressure for Large slot test performed with sieved Asha pellets and a water inflow rate of 1.0 l/min.*



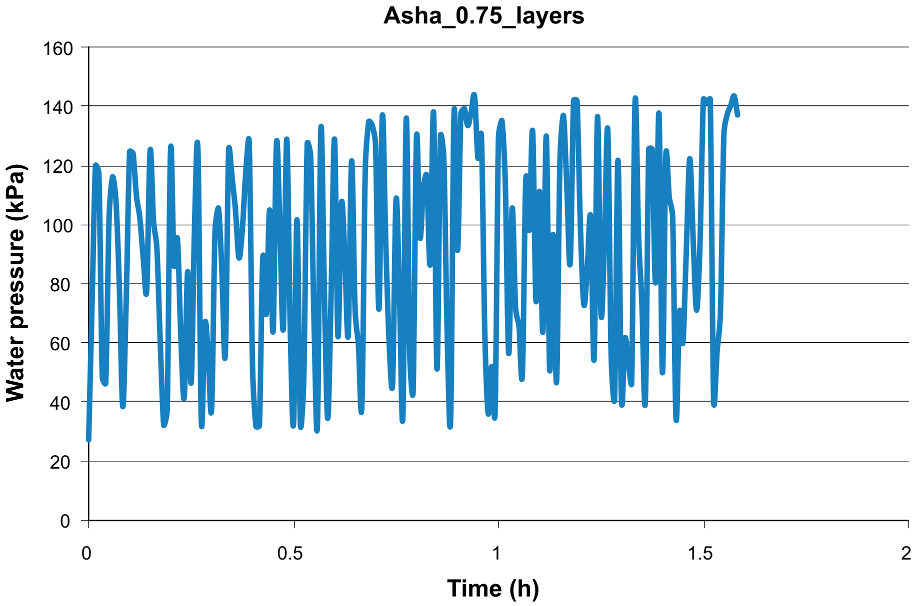
***A8-6.*** *Water pressure for Large slot test performed with sieved Asha pellets and fines placed in layers. The water inflow rate was 0.1 l/min.*



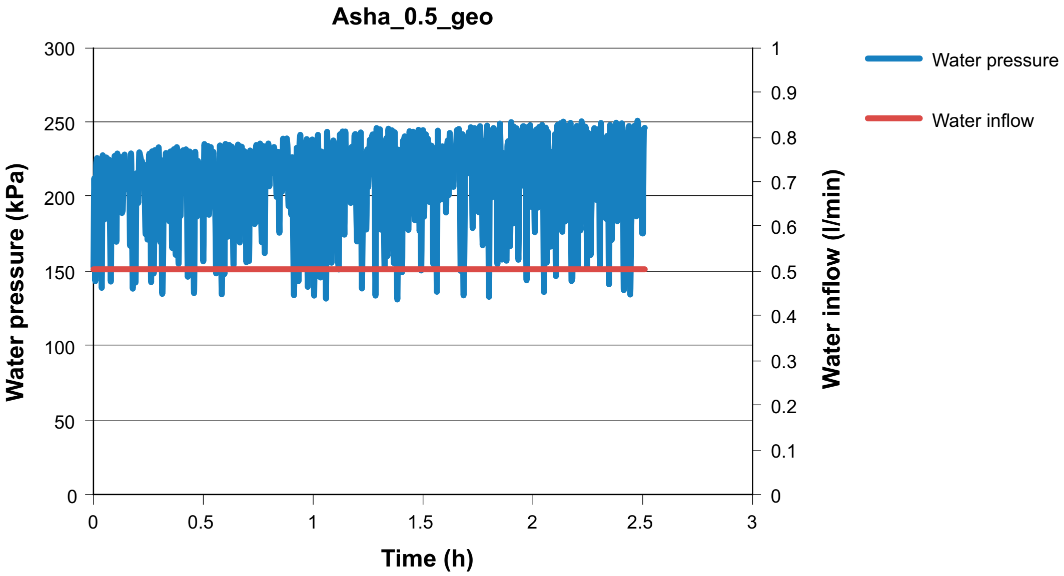
*A8-7. Water pressure for Large slot test performed with sieved Asha pellets and fines placed in layers. The water inflow rate was 0.25 l/min.*



*A8-8. Water pressure for Large slot test performed with sieved Asha pellets and fines placed in layers. The water inflow rate was 0.5 l/min.*



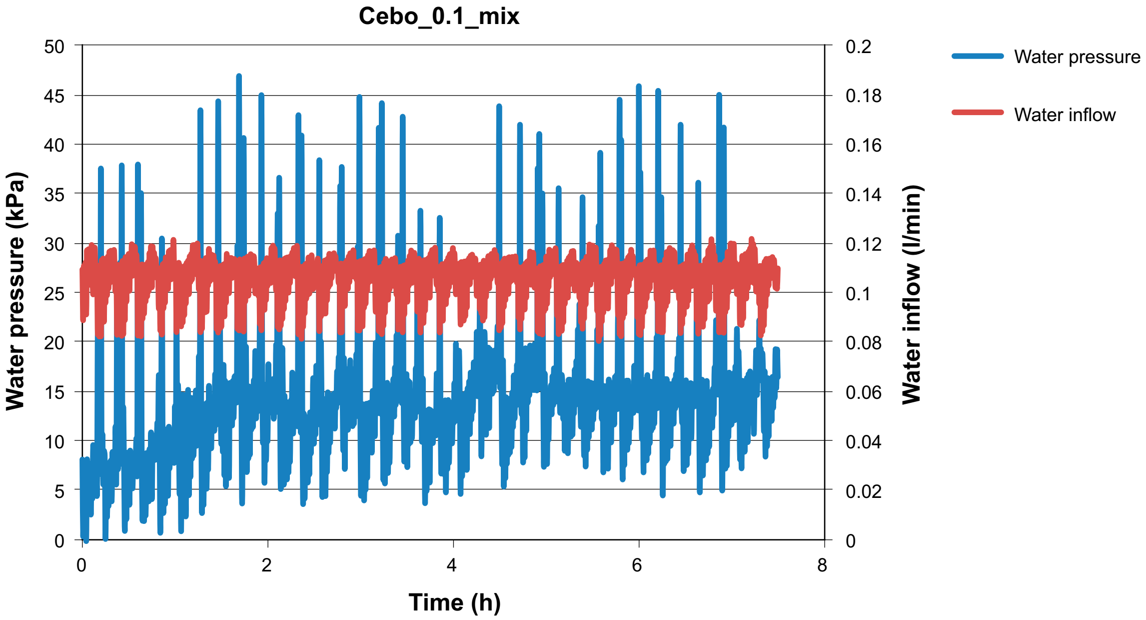
***A8-9.*** *Water pressure for Large slot test performed with sieved Asha pellets and fines placed in layers. The water inflow rate was 0.75 l/min.*



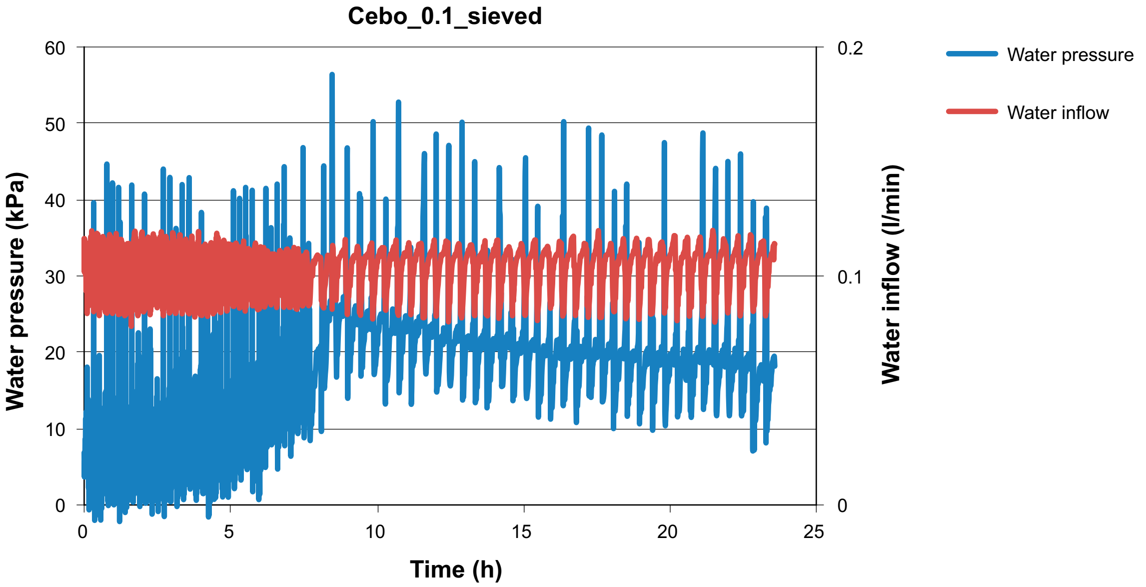
***A8-10.*** *Water pressure for Large slot test performed with sieved Asha pellets and a geotextile for distribution of water. The water inflow rate was 0.5 l/min.*

# Appendix 9

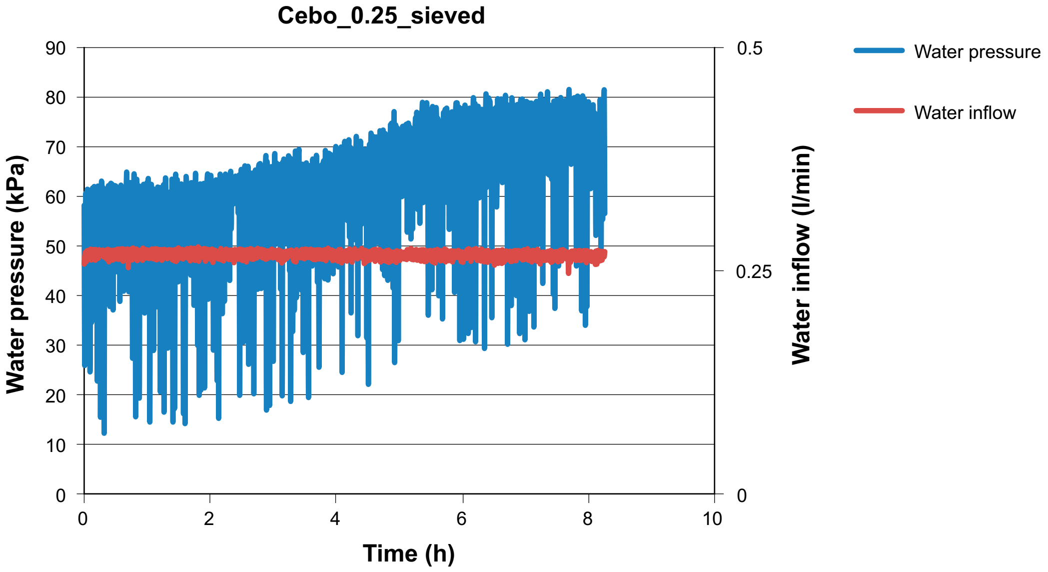
## Large slot tests, water pressure and water inflow rate, Cebogel



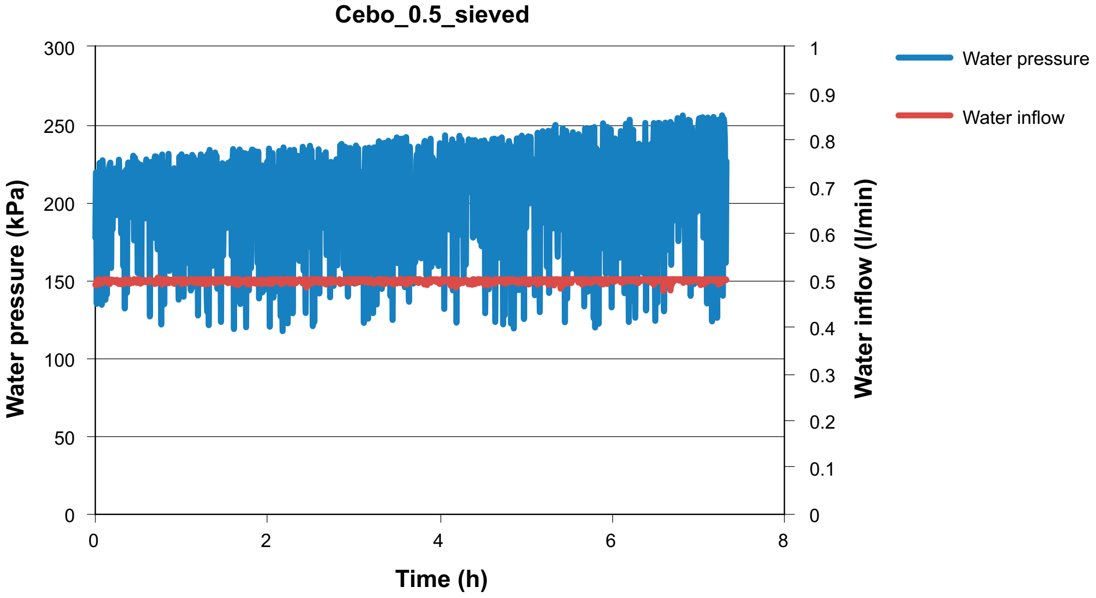
***A9-1.*** *Water pressure for Large slot test performed with sieved Cebogel pellets. Pellets from two different batches were used in this test. The water inflow rate was 0.1 l/min.*



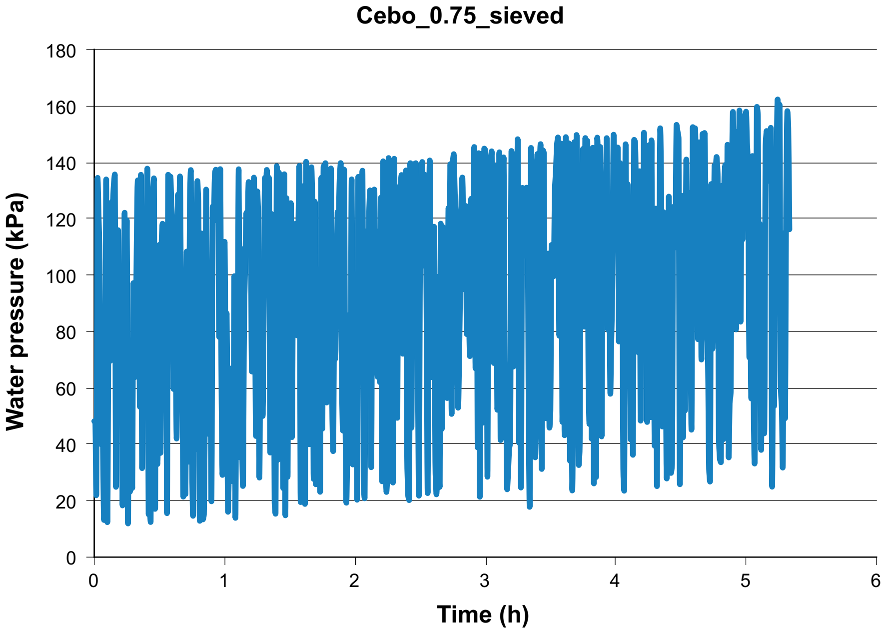
***A9-2.*** *Water pressure for Large slot test performed with sieved Cebogel pellets. The water inflow rate was 0.1 l/min.*



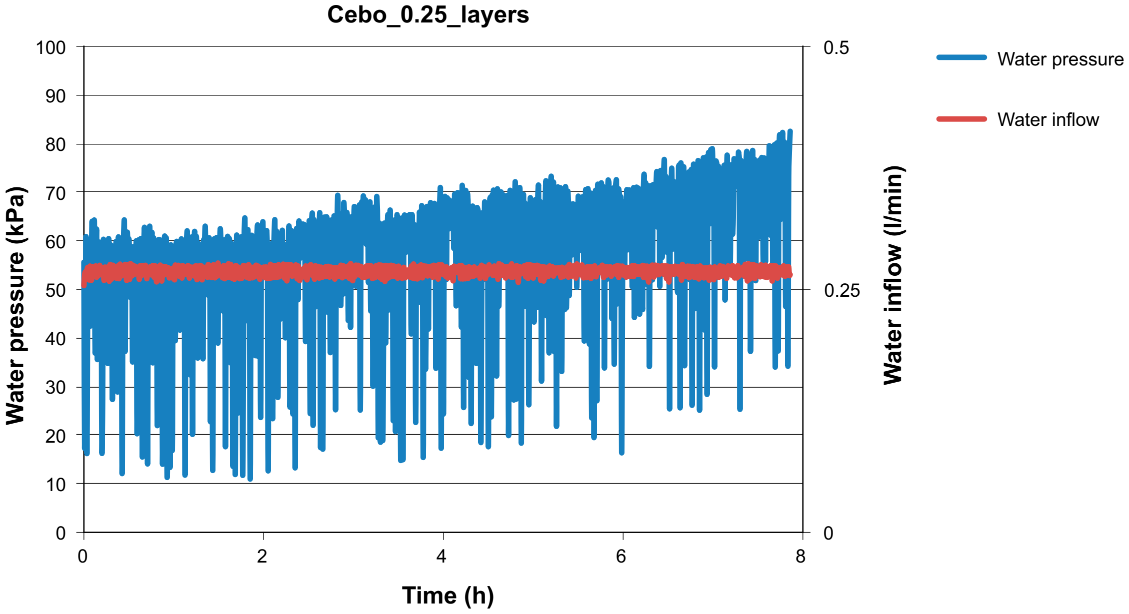
*A9-3. Water pressure for Large slot test performed with sieved Cebogel pellets. The water inflow rate was 0.25 l/min.*



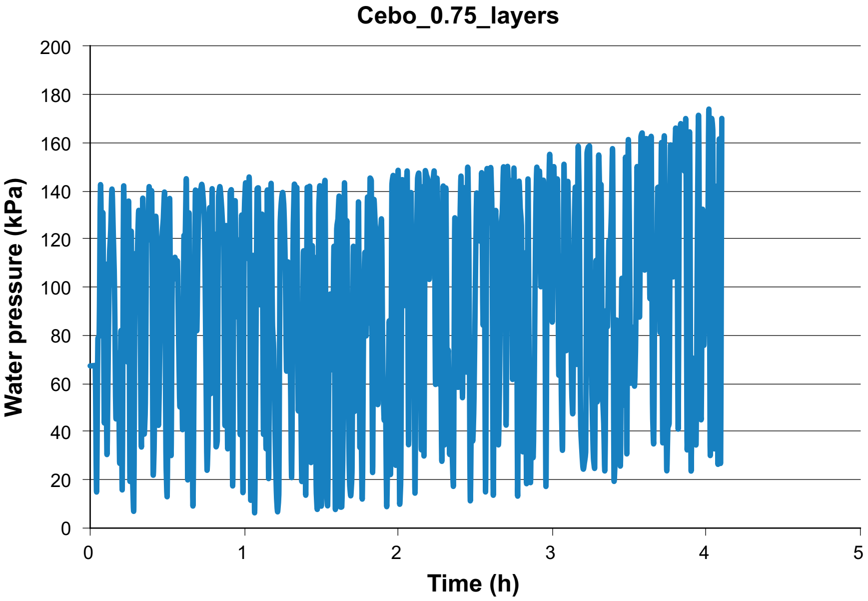
*A9-4. Water pressure for Large slot test performed with sieved Cebogel pellets. The water inflow rate was 0.5 l/min.*



*A9-5.* *Water pressure for Large slot test performed with sieved Cebogel pellets. The water inflow rate was 0.75 l/min.*



*A9-6.* *Water pressure for Large slot test performed with sieved Cebogel pellets and fines placed in layers. The water inflow rate was 0.25 l/min.*



***A9-7.*** *Water pressure for Large slot test performed with sieved Cebogel pellets and fines placed in layers. The water inflow rate was 0.75 l/min.*

Arkitektkopia AB, Bromma, 2018

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waste produced by the Swedish nuclear power plants such that man
and the environment are protected in the near and distant future.

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