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System design of backfill

Basic engineering of backfill production system

Peter Eriksson, Svensk Kärnbränslehantering AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

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Abstract

For the backfill of deposition tunnels in the KBS-3 system bentonite blocks and pellets are needed. These blocks and pellets are planned to be produced in a production plant near the repository. This report describes how the production can be performed.

A flow sheet for how the production process will work has been created. Based on this flow sheet process equipment has been suggested which has the capacity that is assumed to be needed. The suggested production is divided into two parts, one in the harbour area where the material is milled and, if needed, dried and one in the production building where the water content is adjusted before block pressing and pellet manufacturing.

Finally a large scale production test was conducted where 1,820 blocks were produced. The production line used resembles the one suggested in this report.

Sammanfattning

I KBS-3 systemet används bentonitblock och -pellets för att återfylla deponeringstunnlarna efter deponering. Dessa block är planerade att produceras i en produktionsbyggnad nära slutförvaret för använt kärnbränsle. I denna rapport beskrivs hur denna produktion skulle kunna gå till.

Ett flödesschema över den tänkta produktionen har skapats och utifrån det har produktionsutrustning som uppfyller kapacitetskraven föreslagits. Den föreslagna produktionen är uppdelad i två delar, en del i hamnen där materialet krossas och torkas, och en del i produktionsbyggnaden där vattenkvot justeras före blockpressning och pellettillverkning.

Slutligen genomfördes även ett storskaligt produktionstest där 1 820 stycken block tillverkades. Dessa block tillverkades i en produktionslina som påminner om den som förslagits i rapporten.

Contents

1 Introduction

SKB's reference method for the final repository for spent nuclear fuel is the KBS-3 method, where the nuclear fuel is placed in copper canisters at 500 meters depth in the bedrock surrounded by swelling bentonite clay, Figure 1-1. The bentonite is installed in the form of compacted buffer blocks, backfill blocks and pellets, as seen in Figure 1-2.

This report will cover the production of backfill blocks and pellets and will present how these components can be produced, and what equipment would be needed for this production. The three topmost buffer blocks are considered as backfill. However they will be produced as a buffer blocks, described in Eriksson (2014).

1.1 Production process of bentonite

The raw material used in the backfill production process is a bentonite clay, mined in open pit mines, Figure 1-3. The raw material is transported to the processing plant after mining, where it is coarsely crushed and sun dried in fields to reduce the water content. Stockpiled bentonite may also be blended with other grades of bentonite to produce a uniform material. Next, the bentonite is dried in rotary or fluid bed dryers, fired with natural gas, oil, or coal to further reduce the moisture content to meet the customer requirement. This is a general description of how the mining works which is not identical in all mines.

Quality control is performed continuously during the described production process.

The bentonite is then transported by bulk ships to the harbour of Hargshamn in Sweden, where the material is unloaded into large storage buildings and delivery control is performed. Next, the bentonite is crushed to the specified granule size distribution and, if needed dried, before being placed in silos. The bentonite cannot have too high water content because it might then stick in the storage and transportation system.

Transportation of the raw material to the production facility is done using bulk trucks which are unloaded pneumatically or by a conveyor system into storage silos within the production facility. In the production building the bentonite is mixed with water to obtain the desired water content before compression to the desired components. For a summary of the process see Figure 1-4.

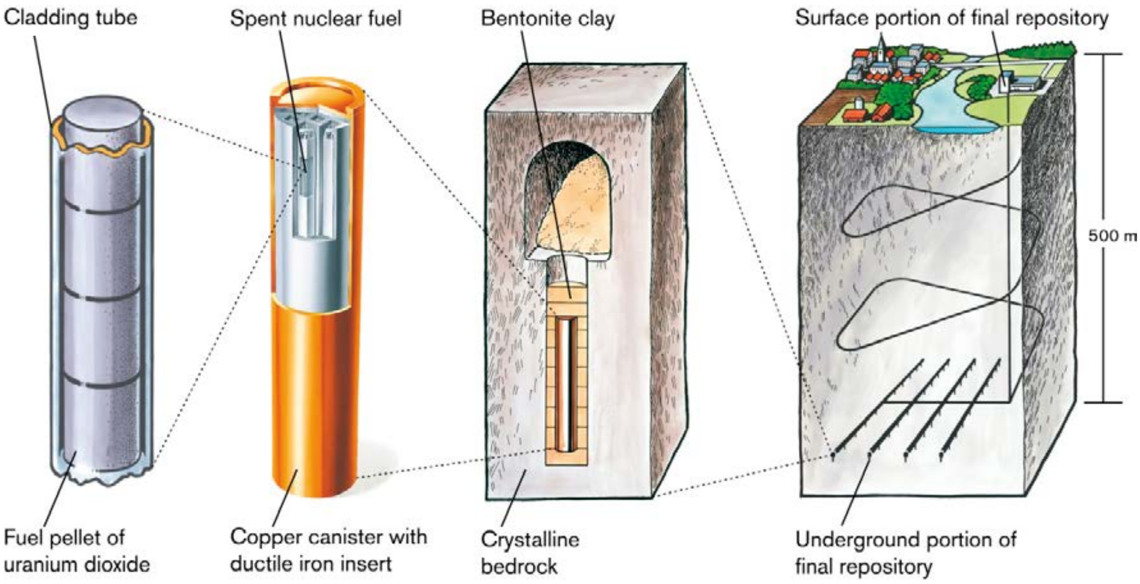

Figure 1-1. *The barriers in the planned repository.*

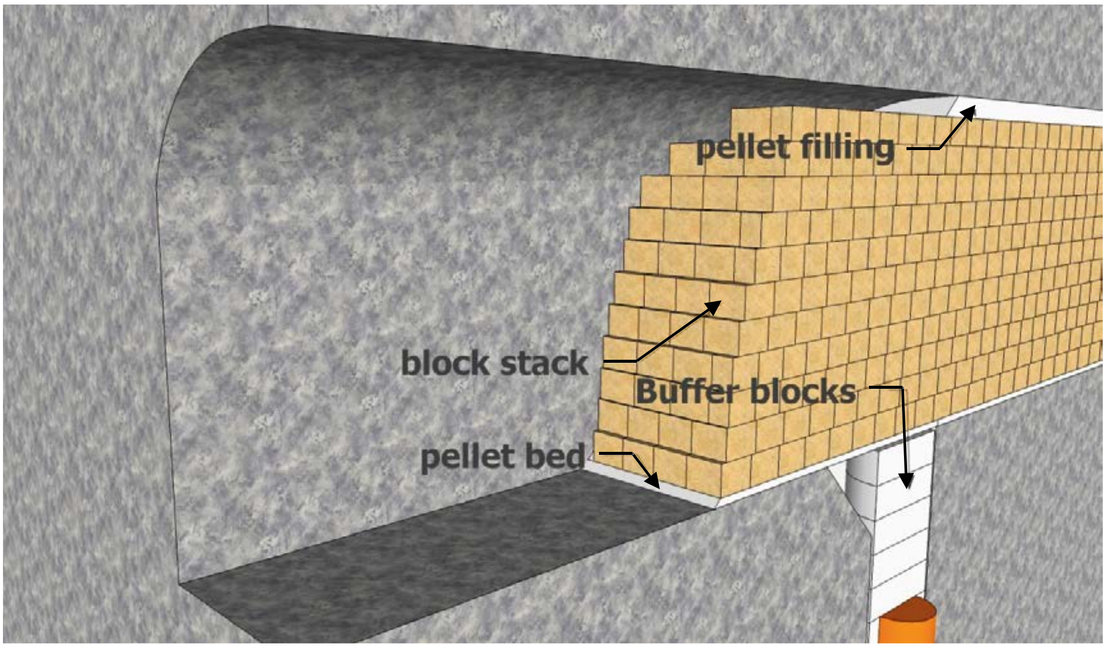

Figure 1-2. *Illustration of the components of the backfill.*

Figure 1-3. *A bentonite mine on the island of Milos.*

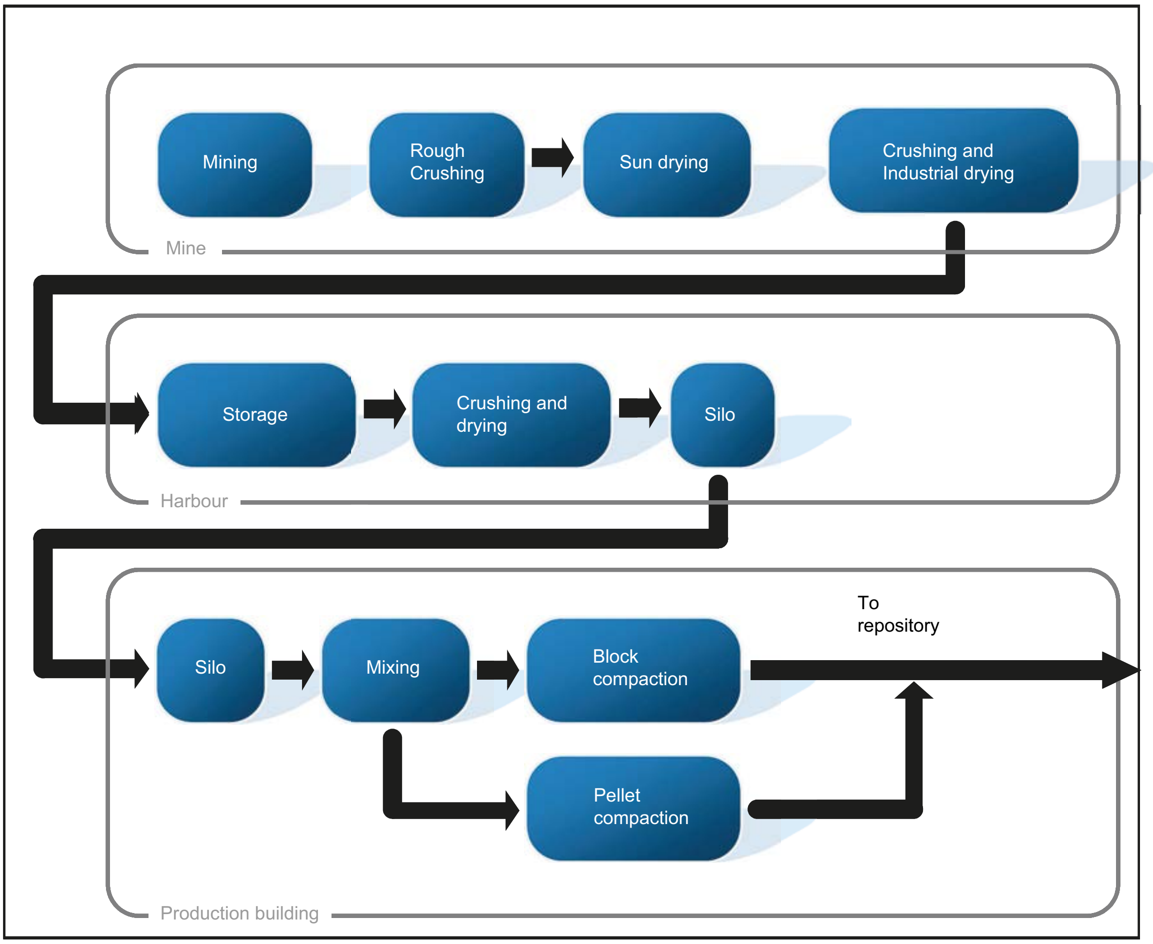

***Figure 1-4.** Process steps from mining to finished bentonite products*

2 Objective and scope

This report covers the production chain for the harbour area and production building at the site for the final repository for spent nuclear fuel in accordance with Figure 1-4.

A suggestion regarding equipment needed for production of backfill components with sufficient capacity and quality is made based on the experiences gained during previous backfill block test production (Sandén et al. 2014b) and the large scale production described in Chapter 8. In addition a process description and specifications for the different machines needed to produce backfill blocks and pellets are also presented.

Additionally a large scale production of approximately 1,800 backfill blocks has been performed in which enough blocks to backfill 12 meters of a deposition tunnel were produced. The experiences and results from this production are reported in this report.

3 Assumptions and requirements

This chapter describes the assumptions made in this report and the requirements which the production system needs to fulfil.

The design requirements for the backfill production system used in this report are:

- The production system needs to be able to produce components for 200 deposited canisters per year. This means that approximately 200 tonnes of blocks and 40 tonnes of pellets need to be produced each day. This assumes that the overbreak, the rock excavated outside the nominal tunnel dimension, is on average 20%. It also assumes 226 working days per year and a distance between the deposition holes of 6.8 meters.
- The material should be possible to transport pneumatically into the production building.
- The production system needs to have the capacity to produce components according to the specification in Chapter 4. The production system should be flexible in order to be able to different types of raw materials. However, it is assumed that the maximum compaction pressure for backfill blocks is 50 MPa. Blocks can be produced according to specification with all materials tested so far, with a compaction pressure less than 50 MPa. Therefore 50 MPa pressing force is used to design the press.
- The blocks need to be protected to ensure that they are not exposed to a relative humidity that differ from that in which the blocks are in equilibrium with the surrounding air. Equilibrium point for the relative humidity is approximately 75% for a block with 20% water content made out of ASHA NW BFL-L clay (Sandén et al. 2014a). It would be advantageous if a special protection could be avoided during production and storage. Further studies are needed to find out which environment could be accepted.
- The pellets are assumed to be produced by extrusion.

4 Components to be produced

Two different bentonite backfill components need to be produced for the repository. These components are backfill blocks and pellets. The blocks should fulfil the specifications in Table 4-1. The block specifications have been updated compared to the reference design due to development of the installation technique. The block dimensions have been optimized with respect to:

- Size of the deposition tunnel.
- The developed pattern of the stacked blocks.
- The capacity of the robot that will be used for emplacement.
- The capacity of available press for backfill blocks manufacturing.

The pellet properties have been optimized and 6 mm extruded pellets are assessed to work best for this application. The specifications for the pellets are shown in Table 4-2.

Table 4-1. Backfill block specifications.

Block specifications		
	Nominal	Tolerance
Length	571 mm	± 2 mm
Depth	500 mm	± 2 mm
Height	400 mm	± 2 mm
Dry density	1,700 kg/m^3	± 50 kg/m^3

Figure 4-1. *Backfill block.*

Table 4-2. Pellet specifications.

Pellet specifications	
Dry density	< 850 kg/m^3
Diameter	6 mm
Length	6–22 mm

Figure 4-2. *Bentonite pellets produced by extrusion.*

5 Process description

5.1 General

The backfill blocks are planned to be produced with uni-axial compaction. Uni-axial compression is when the material is compacted in one direction in a rigid mould. This can be done with commercial presses that are used for example in the refractory industry. Tests have shown that it is possible to use these methods on the block sizes that have been suggested for the backfill. The general process steps for the production of backfill blocks and pellets in a production facility in the final repository are shown in Figure 5-1. A more detailed flow sheet, on which the process description is based, can be found in Appendix 1.

5.2 Storage

The raw material is delivered by bulk ships and will initially be stored in storage buildings before being fed into the process. The capacity of the storage buildings should be dimensioned after the types of ships that are expected to be used for bentonite transport. The total yearly delivery of bentonite is assessed to be approximately 50,000 tonnes.

5.3 Crushing and drying

As the material is assumed to be delivered as a coarsely grinded material it needs to be milled to the specified granule size distribution. There are currently no requirements on granule size distribution. However it is known that this will affect the properties of the compacted blocks. Therefore work is ongoing trying to set requirements for the granule size distribution. The milling and possibly drying needs to take place in the harbour area since the material is to be transported by bulk trucks and pneumatically blown into silos adjacent to the production building.

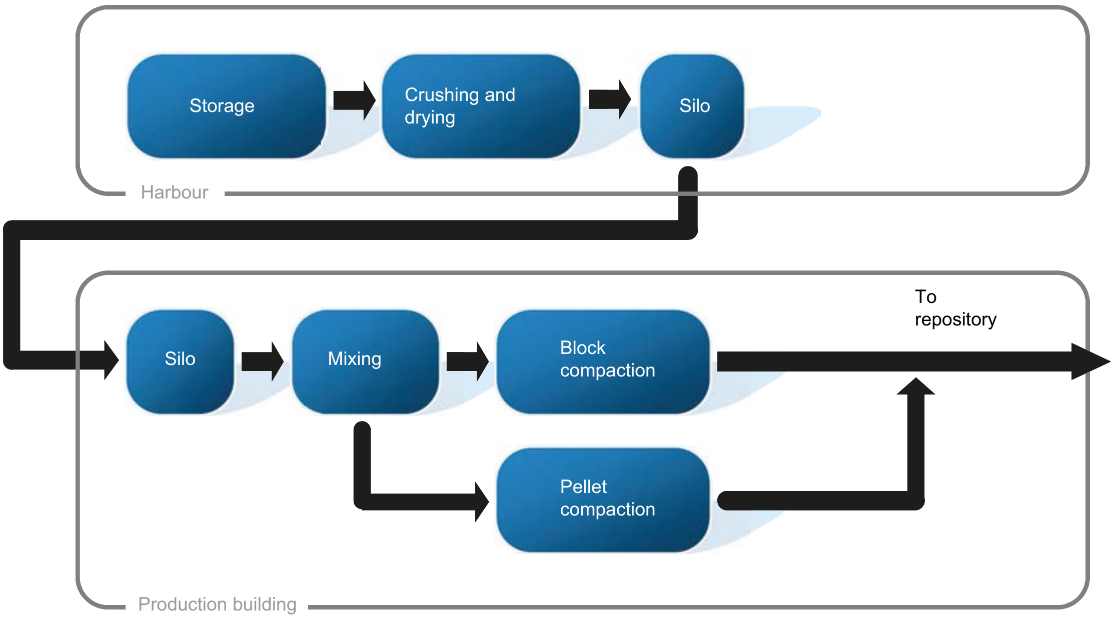

Figure 5-1. General description of the production system.

Transportation by bulk trucks and storage in silos require material with a water content, water mass divided by dry mass, of less than 12%. This value is based on experiences from industries using bentonite, and is lower than what is expected in the delivery.

Suitable equipment for drying and milling the material could be a pendulum mill also known as a Raymond mill. This equipment has the possibility to use a heater to blow hot air through the milled bentonite and thereby drying it at the same time. The maximum temperature should be controlled so it does not exceed a limit were the bentonite will be affected. An example of equipment could be an MO-12 from Molaris which has a drying and crushing capacity of at least 12 tonnes per hour.

5.4 Silos

The crushed and dried raw material will be stored in silos both before transport to the production facility and within the production facility. It should be possible to load and unload the silos pneumatically.

5.5 Mixing

Before the material is ready for compaction water is added to obtain the desired water content. This is done in a mixer where clay material and water is mixed to achieve a water content of approximately 20%. However, the required water content may vary for different raw materials. The mixer will run until the batch has an even water content, which is estimated to be approximately 5 minutes. When the mixing is finished the material is transferred to a hopper underneath the mixer and transported either to the block pressing station or to the pellet extrusion equipment via a table feeder. There are two table feeders, one for blocks and one for pellets, and therefore it is possible to use different water content for the blocks and the pellets.

A mixer that has proved to work well for mixing bentonite during test production at the Äspö HRL, is an intensive mixer from Eirich, Figure 5-2. A similar mixer was used during the large scale production. A suitable model could be the RV-24, which will be able to mix approximately 1.6 tonnes per batch. This mixer would therefore have the capacity to mix 240 tonnes of material in 16 hours or two shifts.

Figure 5-2. *Eirich mixer used at Äspö.*

5.6 Compaction

When compacting the backfill blocks a method with a moving mould has been used. In this method the mould moves independently of the piston. This is the same as having two pistons pushing from both the upper side and the lower side of the block. Therefore it reduces the effect of friction compared to compaction from the upper side only. Therefore it is possible to compact higher blocks with better homogeneity. This independently moving mould also gives the ability to control where in the block the compaction centre should be.

The compaction cycle starts with the mould being filled with material. This filling is done to a predefined height. Because the bulk density of the clay powder changes with grain size distribution it is important to have good control of the grain size distribution to get an even final density. To be able to speed up the compaction time and improve the quality of the blocks the material is de-aired by the use of vacuum which is applied in the mould before the compaction starts. The upper piston is then pushed down and the blocks are compacted with a compaction pressure somewhere in the range 25–50 MPa depending on which material is used. The pressure is then reduced, the mould is retracted and the block is extruded out of the mould.

A term used in the production is the filling factor which is defined as the ratio between the height before compaction and the height after compaction. In Sandén et al. (2014b) the filling factor of different materials has been measured and they vary between 1.42 and 1.78. This suggests that to be able to produce blocks that are 400 mm high a press with a stroke of at least 712 mm is required. It is recommended that a press with a stroke of approximately 800 mm should be used. An example of a suitable press could be the HPF 1600 from Laeis, Figure 5-3, which could be bought with an option of a stroke of 800 mm and equipment for applying vacuum before compaction. It also has enough pressing force to compact the blocks with a pressure of 56 MPa since the maximum pressing force is 1,600 kN and the block area is 0,2855 m^2.

5.7 Maintenance area

A small maintenance area is needed to re-build moulds and repair and refurbish mould components. The mould consists of multiple parts which are shown in Figure 5-4. Spare parts for the mould need to be kept in storage.

Figure 5-3. *A HPF 1600 press from Laeis.*

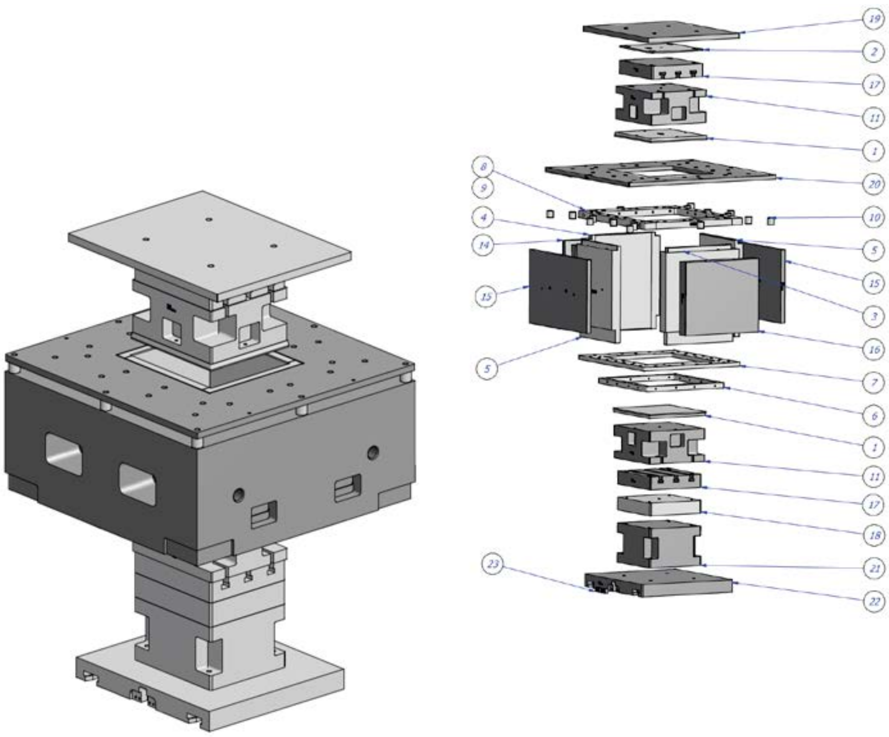

Figure 5-4. Compaction mould used during test production.

5.8 Pellet production

Pellets can be produced in two ways, either by extrusion or through roller compaction. It has been concluded that extruded pellets with a diameter of 6 mm works best in backfill (Andersson and Sandén 2012). The pellets produced with extrusion have an elongated form and a slightly lower bulk density than roller compacted ones but have better overall characteristics for usage in the backfill application.

Extruded pellets have been produced at Äspö HRL using equipment from Amandus Kahl. The pellet extruder is shown in Figure 5-5. The clay is in this process pushed through a metal matrix. The extruded pellets are then run through a cooler to reduce the temperature before being packed in containers. A suitable pellet press would be 37–850 from Amandus Kahl which has the capacity to produce approximately 3 tonnes per hour.

Figure 5-5. Pellet press for extruded pellets used for test production at Äspö.

6 Production capacity

There are several steps in the production, a time estimation for each production step has been made to analyse the total production capacity required. The assumptions for the required amounts can be found in Chapter 3.

A recommendation of a suitable mixer, based on the required mixing capacity of 240 tonnes of material in 16 hours, is the RV24 mixer from Eirich It has a capacity of 1.6 tonnes and the mixing takes approximately 5 minutes per batch. In one hour the mixer can mix 19 tonnes per hour, this means that the required amount, 240 tonnes per day, can be mixed in 12.5 hours. The mixer has a very high availability, defined as the operational time divided with the total time, approximately 96%.

The block compaction cycle in the current test production takes approximately 3.5 minutes. However in the test production no vacuum is used and instead several de-airing steps are used, which takes extra time. The second thing affecting the cycle time is the mould filling, which in the test production needs to be done in two steps. With a better dimensioned filling equipment, and use of vacuum during compaction, it is estimated that the cycle time can be reduced to less than 2 minutes. Press manufacturers believe that the cycle time could be as low as one minute. However in this work the assumption is that the cycle time for one block can be reduced to two minutes. In this case two presses would produce the needed amount of blocks in 17 hours. The required amount of blocks could also be produced with one press in three shifts, 24 hours, although this would require a cycle time less than one minute and 20 seconds. These figures assume an availability of 85% of the press.

For the pellet production an estimation has been done together with pellet press manufactures and there is equipment that can produce the required amounts in less than 16 hours.

The conclusion is that the required amount of backfill components can be produced in two shifts if two block presses are used.

7 Large scale production test of blocks

7.1 Introduction

In order to get a large quantity of backfill blocks for an installation test performed in Äspö HRL approximately 400 tonnes of backfill blocks were produced. Blocks had only been produced in smaller series before and handled manually with the help of a forklift, see Figure 7-1. The production site used earlier did not have adequate equipment to handle the large and heavy backfill blocks. Therefore modification of the site used for production of the blocks was done. The modification included rebuilding of a mould and modification of the press, to enable manufacturing of 400 mm high blocks as specified for the test. Also a new industrial robot and some handling equipment were installed, Figure 7-5.

7.2 Equipment and material

The material that was used for this test was a bentonite clay, ASHA NW BFL-L, bought during 2012, specifically for this test. This material was a granulated material that had been run between rollers and then broken into smaller pieces. Due to this the larger granules had the shape of flakes, see Figure 7-2. A characterization of the material has been done (Sandén et al. 2014a) and the material fulfilled the specification set on the material.

Figure 7-1. *Manual handling of backfill blocks.*

Figure 7-2. *Material used for the large scale production test.*

7.3 Production

7.3.1 Mixing

The mixing was done in an Eirich mixer, Figure 7-4, placed in the factory where the block compaction was done. The purpose of the mixing is to adjust the water content to a value suitable for compaction. Compaction with different water contents had been tested earlier (Sandén et al. 2014b) and since material with 20% water content resulted in blocks with good quality it was decided that 20% was to be used for this production run. To keep the mixing at the same rate as the block production some simplifications needed to be done. Normally the water content is measured before mixing to know how much water needs to be added. However the water content measurement takes some time and therefore it was decided that the average water content for the whole delivery would be used. This resulted in a larger variation in water content than according to specification after mixing. The water content was measured after mixing in each bag and the result is shown in Figure 7-3.

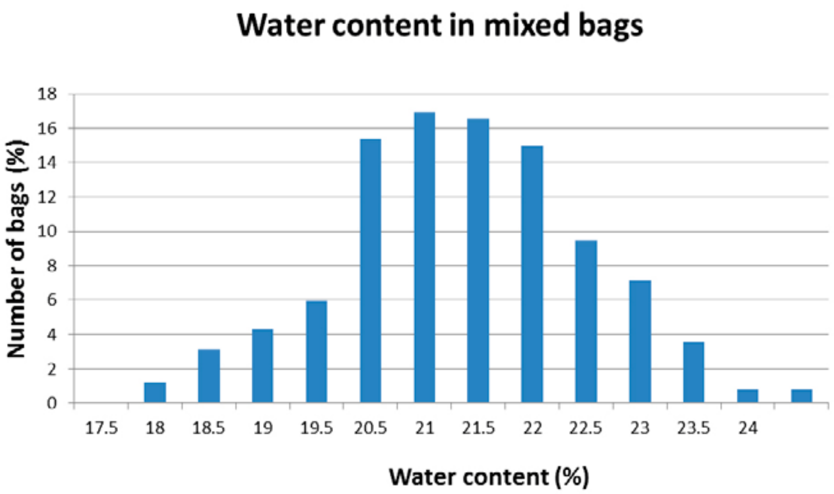

Figure 7-3. *Variation in water content between the mixed bags.*

Figure 7-4. *Eirich mixer used to mix the material.*

7.3.2 Compaction

The compaction of blocks was done in a press from SACMI. The press had a maximum pressing force of 1,600 kN. The press is similar to what could be expected to be used in a future production facility. For this production a compaction pressure of 20–25 MPa was applied. There was a need to keep the dimension of the blocks in a rather small interval. This was a requirement in order to be able to stack the blocks properly in the installation test. Therefore the height of the blocks where prioritized before achieving high density. This trade-off between density and height is not expected to be so big when a better control of the material can be implemented.

The compaction and handling of the blocks worked well and the cycle time for one block was approximately 3.5 minutes. This cycle time is longer than expected in a production building. The two main reasons why this test production took longer than expected in a production building was that no vacuum was applied and that the mould filling took long time. If vacuum will be applied the compaction stroke can have a higher velocity and the de-airing steps can be removed. The mould filling which in this case is not designed for blocks as large as these are expected to be faster in a press designed for the right purpose. The filling needs to be done in several steps with the filling equipment moving back and forward. During the production the height of all of the blocks was registered in the press and blocks outside the height specified for this test, 400 ± 2.5 mm, was discarded. A few blocks were taken out for density and dimension measurements. The result can be seen in Figure 7-6 and Figure 7-7. It can be seen that the height of all the measured blocks are within the ± 2 mm originally specified, but the density is lower than specified. Due to the big variation in granule size distribution between the bags, and the fact that the mould is filled to a specified height instead of a weight, some blocks were approximately 20 mm below the nominal height. This shows that a good control of material quality is needed to achieve a high yield.

7.4 Experiences from large scale production

The block production worked well and the blocks had the quality required for the test. Although the density of the blocks were quite low, it can be increased with fine tuning of the process. The compaction press and handling equipment used in this production test are similar to the one that are planned to be used in a backfill block production facility. This indicates that the method is suitable which in turn implies that blocks can be produced with a high productivity.

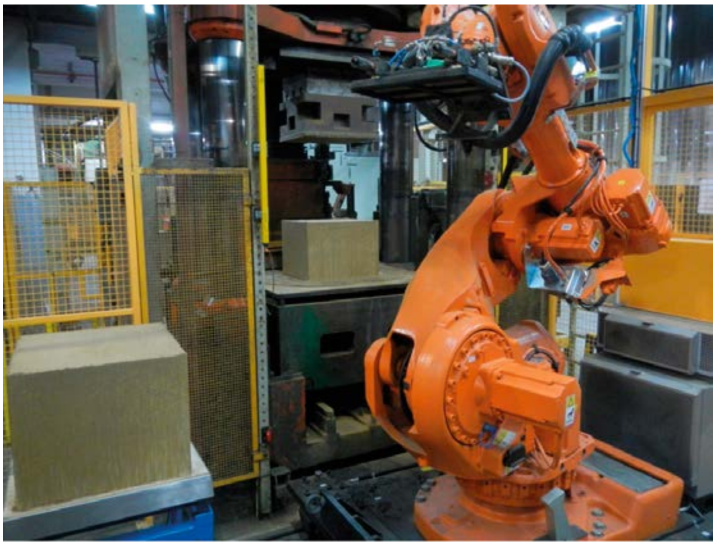

Figure 7-5. *Press and industrial robot used to produce the blocks.*

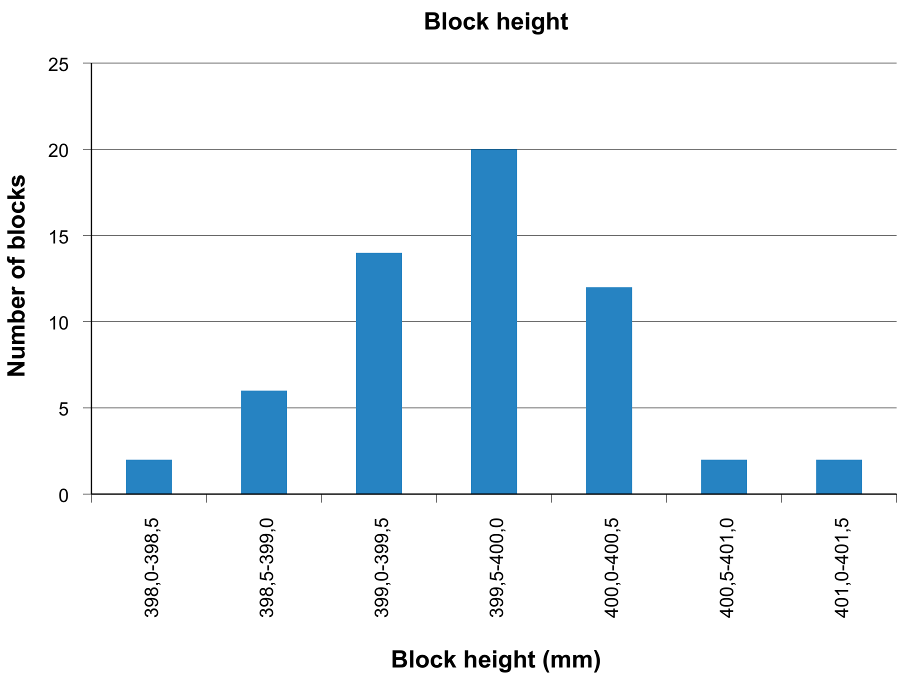

Figure 7-6. *Height of the blocks taken out for measurements.*

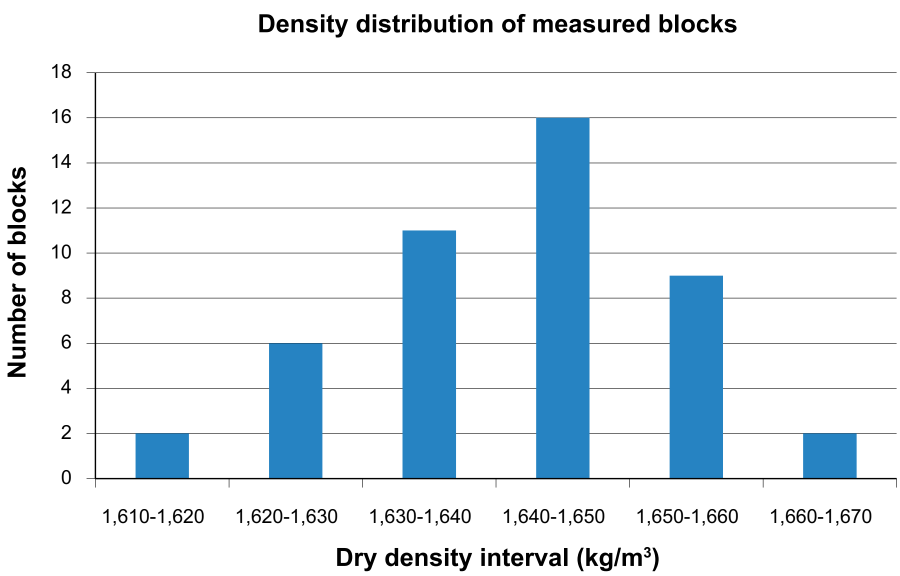

Figure 7-7. *Density distribution in the measured blocks.*

Table 7-1. Data from the production of backfill blocks.

	Water content	Height (mm)	Dry density(kg/m^3)
Average value	21.1	399.8	1,641.7
Standard deviation	1.17	0.67	10.86

The major problems that arose during the production were mainly connected to the material. One problem was that the granule size distribution varied between the bags, maybe even within the bag. This is due to the fact that the material has a tendency to segregate when handled and the finer material falls to the bottom of the bag. Different granule size distributions would give the material different bulk densities. Since the mould filling was controlled by filling height and not by mass this made it impossible to get an even density and height measurement.

The second problem that was experienced was that the material contained stones. These stones, see Figure 7-8, got stuck in the mould filling equipment and caused the built in mill to overheat. The production had to be shut down in order to remove the stones and let the machinery cool down. This extended the production time and shows that it is important to have good control of the material. The material should be processed in a way that ensures that no foreign materials are present and that the material does not separate during handling of the material between the different process steps.

Also some minor problems with build-up of material on the upper tool were seen in the production. In this case it was solved by cleaning the tool at regular intervals. In real production this will probably be done automatically, for example by the industrial robot handling the blocks.

Figure 7-8. *Stones found in the material used.*

8 Conclusions

A basic engineering of a backfill production system has been done. A production test has been conducted where 1,820 approved blocks was produced. The following conclusions can be made:

- A production system for backfill components can be built based on standard equipment. No special equipment was needed.
- The production time per block has been estimated to 1–2 minutes assuming that vacuum can be applied during compaction and that a larger filling box is added to the press.
- With two presses it is likely that required capacity can be achieved in two working shifts, 16 hours.
- Good control of the ingoing material regarding foreign materials and granule size distribution is essential to produce blocks with good quality and repeatability. The material must be handled in a way that prevents separation through all the production steps.

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Appendix 1

Flow sheet