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Comparison between uni-axial and isostatic compaction method for the production of bentonite components

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Contents

1 Background

1.1 LUCOEX

The overall objective of the LUCOEX project is to demonstrate the technical feasibility for a safe and reliable construction, manufacturing, disposal and sealing of repositories for long-lived high-level nuclear waste in situ. The demonstration activities in the project take place in four different underground research laboratories (URL) in Europe, which have been constructed for the specific purpose of developing repository technology under repository-like conditions.

This document concerns the manufacturing of buffer blocks, in particular, the blocks used in SKB and Posivas KBS-3 system. SKB participates in the project primarily through Work Package 4 - The Multi-Purpose Test (MPT) which is a full scale demonstration of KBS-3H technology which is further described in LUCOEX-report D4:03 available on the LUCOEX homepage. Posiva is primarily participating in LUCOEX through Work Package 5, described in LUCOEX deliverable D5:01, which includes development and demonstration of the buffer handling equipment's for KBS-3V.

SKB and Posiva have actively studied different buffer compaction methods during the last years where SKB has been focusing on uniaxial compaction while Posiva has been focusing on isostatic compaction. In parallel to their work Nagra in Switzerland has worked with uniaxial compression for the production of their Pedestal-blocks used in the Swiss repository concept.

1.2 Buffer manufacturing

In the reference design of the final repository in Sweden and Finland, the spent fuel is encapsulated in a copper canister before being deposited 500 m down in the bedrock surrounded by swelling clay with a specified density. The clay closest to the copper canister is called buffer. To be able to install this buffer with correct density the clay first needs to be compacted to blocks.

The blocks are rather large with a final diameter of 1.65 meters for KBS-3V and 1.74 meters for KBS-3H and therefore the main challenge has been to find equipment big enough to compact the blocks.

There are two ways the blocks can be produced, with uniaxial compaction and with isostatic compaction. In uniaxial compaction the material is compacted into a ridged mould with a piston compacting from one or two sides. In isostatic compaction the material is placed in a soft mould and is then submerged in a pressurized media. Both methods require machining to the final buffer dimensions.

The uniaxial blocks have been produced in full diameter in number in excess of 250 blocks. The reason for this is that an enough large press was available early at the development of the block production and many of the blocks for SKBs and Posivas full-scale demonstrations have been produced with this method.

Isostatic blocks have so far only been produced up to a diameter of 1200mm because no press has been available to produce full-scale blocks. Recently a large enough isostatic presses have become available and it is expected that full-scale blocks can be produced during the fall of 2015.

SKB and Posiva will require large amounts of blocks, for example, SKB plans for 6000 canisters which according to the current KBS-3V reference design each will require 12 blocks.

1.3 Purpose of this document

SKB and Posiva will jointly select one of the compaction methods in the coming years and thus the question is still open which technique should be used. The purpose of this document is to briefly present the two methods with their respective advantages and their potentials in relation to SKB and Posivas requirements.

2 Block requirements

2.1 KBS-3V, WP5

The requirements on Posivas KBS-3V blocks are presented in Table 1. (Juvankoski 2012)

Table 1. Posiva's current KBS-3V reference design of buffer

Design parameter	Design value	Allowed deviation
Disk blocks		
Water content of disk blocks	17 %	±1 %-unit
Bulk density of disk blocks	1990 kg/m^3	±20 kg/m^3
Disk block outer diameter	1650 mm	±2 mm
Disk block height (see Figure 3-3)	400, 500 800 mm	±1 mm
Parallelism block bottom / top		< 1 mm / 1750 mm
Ring blocks		
Water content of ring blocks	17 %	±1 %-unit
Bulk density of ring blocks	2050 kg/m^3	±20 kg/m^3
Ring block outer diameter	1650 mm	±2 mm
Hole diameter in ring blocks	1070 mm	±1 mm
Ring block height (see Figure 3-3)	OL3: 875 mm LO1,2: 900 mm OL1,2: 960 mm	+2 mm

SKB has basically the same requirements for vertical disposal as Posiva which are presented in details in Chapter 3 in SKB (2010).

2.2 KBS-3H, WP4

The KBS-3H buffer is placed inside a Supercontainer, which constitutes a canister surrounded by buffer with an outer metallic shell, Figure 1. Additionally KBS-3H has distance blocks which are placed in-between Supercontainers in deposition drifts.

The KBS-3H Supercontainer is presented in Figure 1 and the buffer block requirements are presented in Table 2. It should be noted that in the MPT the height of the blocks were limited to 500 mm due to limitations in the compaction equipment used. The KBS-3H blocks are slightly larger than in KBS-3V.

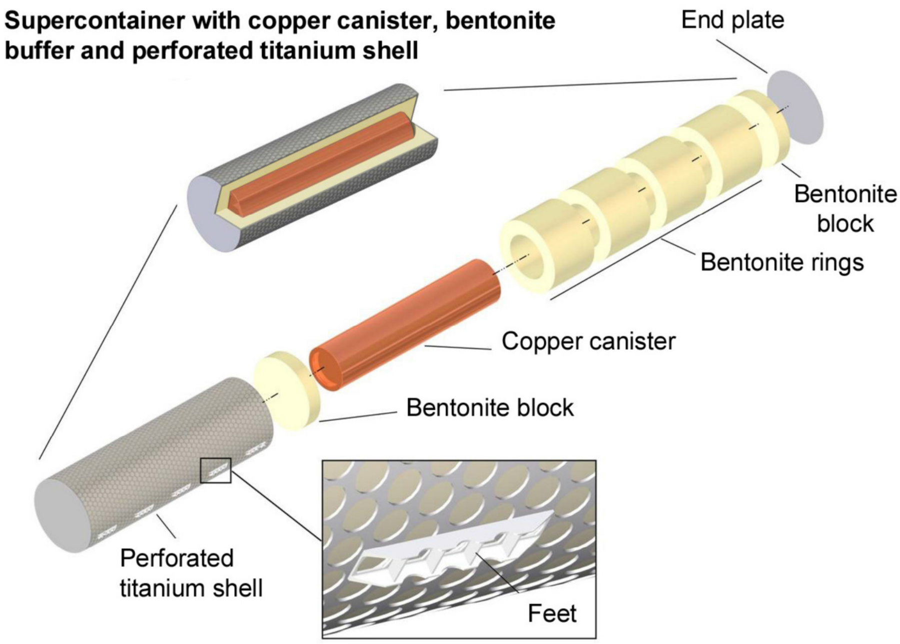


Figure 1. *The buffer and canister are embedded in a perforated shell (with solid end plates) forming a Supercontainer in the KBS-3H design.*

Table 2. Current KBS-3H reference design of buffer, including the distance blocks which are placed between the Supercontainers.

Design parameter	Nominal design	Accepted variation
Solid bocks inside the Supercontainer		
Dry density (kg/m^3)	1,753	±20
Water content (%)	10–17	±1
Dimensions (mm)	Height: 350	±1
	Outer diameter: 1,740	+1/–2
Ring shaped blocks inside the Supercontainer		
Dry density (kg/m^3)	1,885	±20
Water content (%)	10–12	±1
Dimensions (mm)	Height: 1,211 (500 in MPT)	±1
	Outer diameter: 1,740	+1/–2
	Inner diameter: 1,058	±1
Solid blocks outside the Supercontainer (distance blocks)		
Dry density (kg/m^3)	1,712	±20
Water content (%)	21	±1
Dimensions (mm)	Height: 500	±1
	Outer diameter: 1,765	

3 Manufacturing techniques

3.1 Uniaxial compaction

3.1.1 About the technique

For the uniaxial compaction technique, the material is placed in a ridged mould and a pressure is applied with a piston. This pressure can be applied from one side or from two opposite sides, see Figure 2. To simplify the mould design and because of the construction and dimensions of the presses available the compaction of the produced buffer blocks has been done by compressing from one side. Due to the movement of material relative to the mould there will be friction between the mould and the bentonite which limits the maximum height of the block in order to avoid variation in density within the block.

Figure 2. *uni-axial compaction, the red arrow marks the mould filled with clay and ready for compaction.*

This friction is very much affected by the diameter to height ratio of the block. This means that a block with larger diameter can be produced with larger height without getting unfavorable variation in density within the block. This also means that if the diameter to height ratio is high then lubricants are needed. However, it is not completely clear at what height lubricants are needed.

3.1.2 Results from test manufacture

Up to date more then 250 block with full diameter (1650 and 1740 mm) and a height of 500 mm has been produced with the uniaxial method. This production has shown that the method works and produces blocks with good quality at a wide range of water content of the bentonite. The most recent manufacturing is presented in Johannesson (2014) where the manufacturing of distance blocks and blocks for the Super-container is reported.

For all produced blocks; a lubricant has been used on the mould. The lubricant is a problem because it needs to be removed before installation and the material machined away after compaction cannot be reused in the production. Small scale test has however shown that a lubricant may not be needed. However, this has not been demonstrated in full scale.

It is estimated that approximately 1.5-2% of the material needs to be machined away with current usage of lubricants and the existing mould technology.

There has also been some development work regarding the mould and small scale block that are very close to the intended dimensions have been produced. If this would be possible to do in full-scale then the machining of the blocks after the compaction could be minimized.

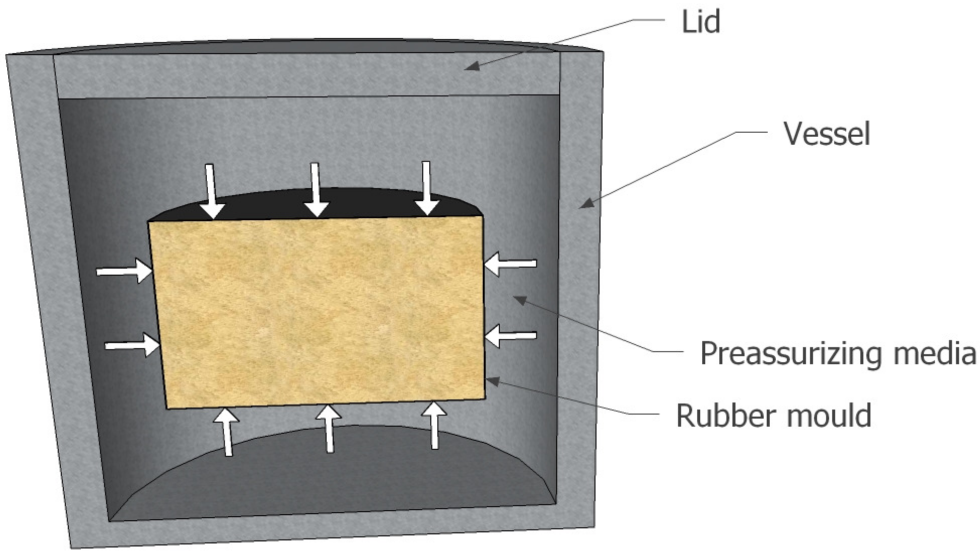
3.2 Isostatic compaction

3.2.1 About the technique

At isostatic compaction the material is placed in a soft elastic mould and then submerged into a fluid, normally water. The pressure of the fluid is increased and the bentonite block is compacted. The fact that the block is compacted from all directions makes it possible to make blocks that have a large height to diameter ratio without any variation of the density within the blocks. This method also eliminates the friction against the mould and thus results in a block with a very homogeneous density.

The non-rigid mould causes the block to have rather big variations in dimensions and, therefore the block need to be machined to the correct dimensions after compaction. Since the compaction is done in radial direction as well as in axial direction a larger press than for the case with uniaxial compaction is needed. This is because of the diameter of the vessel needs to be much larger than the diameter of the finished block. Therefore, at the same compaction pressure the force on the press is much larger than using uniaxial compaction.

The size of the press could be reduced if the initial bulk density in the mould is increased. This could be done by vibrating the mould or choose a granule size distribution of the material that is optimum to get a high initial density of the material inside the mould. It is also most likely that the final dimensions of the block are more accurate if the initial bulk density is higher.



3.2.2 Results from test manufacture

Both small and middle scale blocks have been produced (Ritola and Pyy 2012). The water content for the small scale blocks has been varied between 11 to 23% while the middle scale blocks (70% of full-scale) has been produced with the water contents between 12 to 21%. The tests have shown that it is possible to produce blocks that fulfill the requirements. Based on the finding it is expected that full-scale blocks can be produced as well, but this still needs to be demonstrated.

It has also been shown that vibrating the material in the mould before compaction increases the initial bulk density with approximately 20%. An increased initial density would reduce the size of the press needed to produce the full scale blocks.

Approximately 10-15% of the material is today machined away from the middle scale blocks produced in order to get a cylindrical block. This is expected to be lowered to 5-10% thanks to the advances in mold design. How much that will be machined away from the full-scale block needs to be investigated. By optimized filling of the mould and updated mould designs we expect to be able to reduce the machining of the blocks even further.

4 Comparison of blocks

A comparison between one isostatic and one uniaxial block has been carried out (Bohner et al. 2015) to be able to compare the two technologies. A uniaxial block with a height of 500 mm and a diameter of 1650 mm was compared with an isostatic block with a height of 1200 mm and a diameter of 1200 mm. To avoid possible differences depending on material the blocks were produced from the same batch of material.

Cores were taken from both blocks in both horizontal and vertical direction and different properties were tested on the samples. Both types of blocks fulfilled the requirements and most of the differences can be explained with variations in water content and density.

The uniaxial blocks tend to be slightly more anisotropic.

5 Advantages and potential of the respective methods

5.1 General

Both methods fulfill the technical requirements and can be used to produce the buffer blocks. Both methods have their advantages and disadvantages. In the next subchapters the advantages considered for each method are described.

5.2 Uniaxial compaction

5.2.1 Main advantages

The main advantages of the uniaxial method are:

- Smaller and thereby a cheaper press is needed
- Higher capacity
- Good dimensional control
- Wide range of water content of the buffer material can be used

5.2.2 Smaller press needed

A smaller press is needed when using uniaxial compression because the force is applied only to the block. The force used during uniaxial compression is roughly 26 000 ton while isostatic compression will require roughly 32 000 ton due to the fact that the force is being applied to the full pressure chamber volume. If KBS-3H blocks is compacted the difference will be even larger since they have a slightly larger diameter than the KBS-3V blocks (1.765 m compared to 1.65 m).

5.2.3 Higher capacity

The process when using uniaxial compaction is a quite fast compared to the isostatic process. The slower isostatic process could however be compensated by having more blocks compacted at the same time in a larger press chamber.

5.2.4 Good dimensional control

The uniaxial blocks get a specified geometry directly after pressing which makes it easier to control the density after compaction. The better control of the dimensions also means less machining of the block than for the isostatic blocks, 0-2 % compared to 5-10 %.

5.2.5 Wide range of water content can be used

Full-scale blocks have been produced with water contents between 11% and 26% (Cuss et al. 2010) and (Johannesson 2014). High water content has also been used in small scale test with the isostatic method but has not yet been tested in larger scale.

5.3 Isostatic compaction

5.3.1 Main advantages

The main advantages of the isostatic method are:

- Lower maintenance cost
- Low mould costs
- Wider range of block sizes can be produced
- more common technologies
- mechanically simpler
- no lubricants

5.3.2 Lower maintenance cost

An isostatic press is mechanically simpler than a uniaxial press for which the pressing table needs to be controlled and monitored. Also, a uniaxial press will use more advanced moulds that needs maintenance. The uniaxial press also has a carousel or similar which handles the moulds. This carousel also needs maintenance.

5.3.3 Wider range of block sizes can be produced

In the isostatic method there is no real limitation on height of the blocks. It is only limited by the height of the press chamber. It is believed the 800 mm high block can be produced with uniaxial in full-scale (Eriksson 2014) however, this has not been proved. Therefore isostatic compaction is probably needed if blocks higher than 800 mm need to be produced.

5.3.4 More common technologies

Big isostatic presses are more common on the market today. Big uniaxial presses are mainly used in sheet metal pressing and the stroke is usually much smaller than required for our application which means that a uniaxial press will be more of a specially designed product.

In regards to upgrades of the machinery we also expect that it will be easier to get upgrade the control system and supporting systems and electronics for an isostatic press as they are more of a standard product.

5.3.5 Commercial applications

A large isostatic press is expensive, but it could potentially be used in other commercial applications when not used to compact buffer blocks. Such incomes could reduce the cost for the buffer manufacturing. A uniaxial press is currently not seen as having the same potential.

5.3.6 No lubricates needed

No lubricants are needed for the isostatic blocks. This means that the material machined away can probably be reused. It is also expected that the uniaxial process could be run without lubricants but this has so far only been done in smaller scale – full scale tests remain.

6 Discussion

The main objective of a press and mould is to manufacture the clay components in accordance with the requirements and at a pace that satisfies the deposition speed, i.e. ensuring the quality and production rate of the clay components.

Quality and fulfilment of technical requirement will always be the primary deciding factor in regards to which technique that will be used for the production of the clay components. Based on our tests we have shown that both methods can be expected to fulfil the all requirements.

To make a final choice of which technology to use it is therefore necessary to evaluate secondary criteria's including but not limited to:

- Local availability and support
- Investment and life time costs
- Cost of secondary process equipment
- Availability and Maintenance costs
- Required machining for producing specially shaped blocks
- Potential for other commercial incomes should also be evaluate if there is capacity left in the press after the needed amount of clay components have been produced.

Evaluation of these secondary criteria needs to be done by each individual organisation as these are intimately linked to the chosen repository design and the local conditions in regards to what support and know-how that is available locally, local business opportunities etc.

As a final note we encourage readers to visit www.lucex.eu for further information regarding the manufacturing of clay components which are presented in project deliverable:

- D2:03 Requirements, manufacturing and QC of the buffer components
- D4:01 Working Report on manufacturing of distance blocks and blocks for the Supercontainer

7 References

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