Waste management in Estonian oil shale industry

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ABSTRACT
Oil shale industry of Estonia provides a significant contribution to the country’s economy, but causes a large number of different problems. In spite of high economical parameters of the current underground mining (room-and-pillar) technology it is not effective. Backfill technology will be applicable in condition of Estonian oil shale mines. Nowadays attention has been focused on the use of combustion and mining by-products as filling materials. Use of ash and limestone in mining industry is treated as a part of mining technology, not as a waste disposal. Underground utilization of wastes reduces the volume and area required for surface disposal, environmental taxes. It improves the quality of mining works. The use of backfill technology has great impact on mining practice in Estonian oil shale industry.

1. INTRODUCTION
The most important mineral resource in Estonia is a special kind of oil shale. Currently Estonia is independent energy producer thanks to existing of oil shale deposit and favourable mining and processing conditions. About 85% of oil shale is consumed by power plants which produce 98% of Estonian electricity and great part of thermal power. Oil shale industry provides a significant contribution to the country’s economy, but causes a large number of different problems. As a result every oil-shale producer and consumer should think today how to be successful in the future.

Underground oil shale production is obtained by room-and-pillar technology with blasting. This method is cheap, highly productive and easily mechanizing. Investigations showed that if the depth of excavation increases over 60 m (mine Estonia), the current underground mining technology is not effective. The loss in pillars increases up to 40% and the efficiency of mining works decreases. In these conditions the room-and-pillar technology is not applicable. New flexible and powerful mining technology will guarantee securing independence of Estonian energy sector. Backfill technology will be applicable in conditions of Estonian oil shale mines.

On the other hand, appears the problems of landfill of waste. Strong environmental impacts are caused by disposal sites of waste generated by oil shale combustion as Arro [1]. Use of combustion and mining by-products in mining industry is treated as a part of mining technology (Directive 2006/21/EC), not as a waste disposal.
Underground utilization of oil shale combustion and mining by-products reduces the volume and area required for surface disposal and consequently the environmental taxes.

In Estonia there are CO\textsubscript{2} emissions per capita one of the highest in Europe as Shogenova [7]. Reduction of the flue gases could be reached using different measures. Mineral sequestration of CO\textsubscript{2} and SO\textsubscript{2} is possible as Kuusik [2]. Unfortunately, it is still in the development stage and is not yet ready for implementation.

Complex approach is needed for solving above mentioned problems. It will have great impact on mining practice in Estonian oil shale industry.

2. GEOLOGY

The Estonia oil shale deposit is located in the north-eastern part of the country. The commercially important oil shale layer stretches for 200 km from west to east, and for 30 km from north to south. The oil shale bed has a form of a flat bed slightly inclined (2...3 ‰) southward. The depth at which oil shale bed occurs varies significantly: the bed lies straight under the Quaternary sediments at the northern border of the field and it reaches 100-150 m at its southern rim. The oil shale reserves in Estonia are estimated to be approximately four thousand million tons as Raukas [6].

The oil shale seams occur among the limestone seams in the Kukruse Regional Stage of the Middle Ordovician. The commercial oil shale bed and its immediate roof consists of oil shale and limestone seams. The main roof consists of carbonate rocks. Characteristics of the individual oil shale and limestone seams are rather different. Oil shale compressive strength is 20-40 MPa and that of limestone is 40-80 MPa. The strength of the rocks increases southward and their volume density are 1.5-1.8 and 2.2-2.6 Mg/m\textsuperscript{3}, respectively. Clear oil shale has a calorific value between 8 and 19 MJ/kg. Presence of limestone can decrease heating value of mineral from specific layer significantly.

3. MINING TECHNOLOGY

In Estonian oil shale mines the room-and-pillar technology with blasting is used. The field on the oil shale mine is divided into panels, subdivided into mining blocks approximately 300-350 m wide and 600-800 m long each. A mining block consists usually of two semi blocks. The oil shale bed is embedded at the depth of 40-70 m. The height of a block corresponds to the thickness of the commercial oil shale bed, approximately 2.8 or 3.8 m. The width of the room is determined by the stability of the immediate roof. Although the latter is very stable when it is 6-10 m wide, bolting must still supported the immediate roof. The pillars are arranged in a singular grid. Actual mining practice has shown that pillar with a square cross-section suit best.
The cross-sectional area of the pillars is 30-45 m$^2$, depending on the depth of the oil shale bed. Room-and-pillar technology gives an extraction factor of 70-80%. Loading and transportation of blasted mined rock is carried out by powerful load-haul-dump (LHD) machines. A work cycle lasts a week.

**4. WASTE GENERATION IN ESTONIAN OIL SHALE INDUSTRY**

The whole processing of oil shale from mining up to energy and oil generates large amounts of different waste:

1. By underground mining the amount of limestone equals oil shale production. Separation of limestone from the raw oil shale generates large amounts of waste, which consists in 82...94% of limestone and 6...28% of oil shale residues. These are stockpiled in form of cones (55 m height) and total area of these piles is about 3.5 km$^2$. Limestone production is about 6.5 Mt per year.

2. Second part of waste comes from power stations and oil generation in a form of ash. 67% of oil shale composition is inorganic matter: calcite (CaCO$_3$ - 58%), dolomite (CaMg(CO$_3$)$_2$ - 13%) and quartz (SiO$_2$ - 12%). Analysis showed that 1 t of oil shale gives 0.43-0.44 t of hazardous ash (contains CaO). From the point of chemistry ash from oil shale combustion is very similar to cement and there is no significant difference between the potential environmental impacts from the side of oil shale ash - water slurries as from concrete mixtures of other materials containing cement. About 4 km$^2$ of the landfill are occupied with ash ponds. Oil shale combustion residues from power plants are being produced over 5 Mt per annum.

3. SO$_2$ and CO$_2$ are essential components of the flue gases formed at oil shale combustion. The first is of them is a precursor of acid rain, the other one causes greenhouse effect. In Estonian power plants two combustion methods are used:
   a) Circulating fluidized bed combustion (CFBC), temperature 720-800$^0$C. It gives 0.6-0.7 t CO$_2$ per 1 t of oil shale.
   b) Pulverized firing (PF), temperature 1200-1400$^0$C. The amount of CO$_2$ is 0.97 t per 1 t of oil shale.

Investigation showed that combustion (oil generation) of 1 t oil shale gives in average 0.84 -0.89 t of CO$_2$, 5-8 kg of SO$_2$. Annual emission of CO$_2$ is 10 Mt and SO$_2$ 0.07 Mt.
5. WASTE MANAGEMENT

Backfilling in mining operations is in wide use entire world (Poland, France Finland, Germany, Belgium, Ireland and etc.). Nowadays attention has been focused on the use of combustion and mining by-products as filling materials. Use of ash and limestone in Estonian mining industry is treated as a part of mining technology (Directive 2006/21/EC), not as a waste disposal. The investigation showed that the amount of backfill materials is enough for modernization of mining technology (‘see table 1’).

Nine great CO$_2$ sources were registered in Estonia, where CO$_2$ emissions per capita are one of the highest in Europe. This is explained by the structure of the energy sector, using mainly Estonian oil shale for power supply. Main CO$_2$ sources are located in the northeast of the country, close to the oil shale deposit. The largest CO$_2$ sources in the Baltic States are the Estonian and Baltic Electric Power Stations as Shogenova [7]. The second largest anomaly in Estonia is related to the enterprise Kunda Nordic Cement. Reduction of carbon dioxide could be reached using different measures including the improvement of energy efficiency and demand, use of renewable energy sources, and capture and geological storage of CO$_2$.

<table>
<thead>
<tr>
<th>1. Mines Estonia and Viru:</th>
<th></th>
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<tbody>
<tr>
<td>Oil shale production, Mt</td>
<td>6.45</td>
</tr>
<tr>
<td>Limestone production, Mt</td>
<td>6.45</td>
</tr>
<tr>
<td>Total, Mt</td>
<td>12.90</td>
</tr>
<tr>
<td>Volume of voids, Mm$^3$</td>
<td>6.45</td>
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</tbody>
</table>

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<tr>
<th>2. Joint Stock Company Narva Power Plants:</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Oil shale consumption, Mt</td>
<td>11.74</td>
</tr>
<tr>
<td>Ash (43-44 % of oil shale), Mt</td>
<td>5.17</td>
</tr>
</tbody>
</table>

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<tr>
<th>3. Filling materials:</th>
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<tbody>
<tr>
<td>Ash and limestone, Mt</td>
<td>11.62</td>
</tr>
<tr>
<td>Volume, Mm$^3$</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Table 1: Amount of backfilling materials

After capture and transport CO$_2$ could be stored in various underground formations, such as depleted oil and gas reservoirs, deep saline aquifers and structural traps. The shallow sedimentary basin (100-500 m), small depth of the closed oil shale mines (60-65 m) and use of all aquifers for drinking water supply makes geological conditions in Estonia unfavorable for CO$_2$ geological sequestration as Shogenova [7].
Mineral sequestration of CO₂ is a technology which is still in the development stage and is not yet ready for implementation. However, mineral sequestration is a potential future option for CO₂ sequestration for those Member States which do not have sufficient geological storage capacity.

It was found that about 13% of the CO₂ formed at oil shale combustion can be bound and that SO₂ and SO₃ can be completely bound by the end of the gas tract as Kuusik [2].

6. BACKFILL TECHNOLOGY

Backfilling in mining operations is in wide use all the world. There are two main aspects of backfilling voids, which are of great importance in mining operations as Palarski [3]:

1. Minimization of overburden deformation and subsidence effects on the ground surface, including improvement of stability and support conditions in underground workings.

2. Underground disposal of waste, mainly from processing of extracted minerals, mainly after exhausting if other utilization possibilities or as a result of high environmental costs, which make cost of backfill operation justified.

In modern backfill technologies past fill are preferred as Palarski [4]. It requires carefully selection grain-size distribution of solid particles and is able to flow without sedimentation in pipes by low water content (10...30%). In this case backfill slurry has several benefits:

1. Mixtures are able to set with lower or without presence of additional binders.

2. Shorter binding times and better mechanical properties.

3. Drainage and processing of bleed water eliminated.

Continuous, gradual filling of voids behind the front of mining is preferred in conditions of Estonian oil shale mines. In this case extraction and backfilling are fully correlated. Advance of mining is limited by efficiency of filling process. Necessary backfilling works can interfere with mining operations, decreased output and economic factors of extraction.

In Estonian oil shale industry a wide assortment of fill materials is available. They are waste rock (limestone) and oil shale combustion ash. Ash contains binding agents and other additives. The choice of a proper backfill material and other mixtures parameters is essential in the control of fill costs and backfill properties after placement. The requirements for the backfill components are site-specific, for example subsidence and stress distribution control, maximization of extraction and underground waste disposal. Some of backfill mixtures were tested. They gave excellent results (‘see table 2’).

<table>
<thead>
<tr>
<th>Ash, %</th>
<th>Limestone, %</th>
<th>Water/ash ratio</th>
<th>Compressive strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>28 days</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>0.50</td>
<td>7.9</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>0.64</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Table 2. Fill mixture parameters
Investigation showed that the compressive strength of backfill material does not exceed 7 MPa, depending on the mining technology as Pastarus [5].

Scheme of backfill technology in condition of Estonian oil shale industry is presented in Figure 1.

![Scheme of backfill technology](image)

**Figure 1. Scheme of backfill technology**

OSH - oil shale; FM - fill material (limestone); T - transport of materials

A number of options were elaborated for different mining methods and different ways of backfilling as Valgma [8] and Pastarus [5].

### 7. CONCLUSIONS

Oil shale industry of Estonia causes a large number of waste management, mining and environmental problems. Underground utilization of oil shale combustion and mining by-products reduces the volume and area required for surface disposal. Mineral sequestration of CO₂ and SO₂ is possible, but it is still in the development stage and is not yet ready for implementation.

Current room-and-pillar mining technology is not effective, if the excavation depth is over 60 m (mine Estonia). Backfill technology will be applicable in conditions of Estonian oil shale mines. Limestone and ash are the most fill materials. Backfill technology will have great impact on mining practice in Estonian oil shale industry.

The process of backfilling in oil shale mines should be preceded with an analysis of some important questions connected with different technological aspects, environmental protection and cost estimation.

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References


