Feasibility of Oil Shale Ash Storage in the Underground and Open-Cast Mines

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Introduction

In Estonia oil shale mining has been carried out for 90 years. About 80% of the extracted oil shale is used for power and heat generation, 20% for shale oil production. Power and heat energy produced from domestic oil shale ensure energy independence of Estonia.

Large content of mineral substances is a feature of oil shale. In the result of oil shale combustion is 45…50% ash. At present ash from Narva and Estonian Power Plants is disposed by means of hydraulic transport into the ash dumps situated next to the Power Plants. There is a large tableland formed for a long period here. Approximately 250 million ton of oil shale ash are disposed at the ash dumps. Total area of the ash dumps is 18.7 km²; the volume of alkaline water is 19 million m³ and rainwater amounts up to 11 million m³. The main reason of ash dumps environmental danger is high-alkaline water used for ash transportation in the system of ash removal. Circulation water composition was formed during repeated contacts with ash; high pH (12…13) of the water is just the one thing that defines danger for environment. Danger is conditioned by the case when in an emergency circulation water can get into the environment in spite of all aids and in large amounts can cause environmental damage [1].

According to EU legislation it is necessary to change existing system of ash removal. It is planned not later mid 2009 to transfer ash removal system to a new semi-dry technology named a technology of thick mixture as well as to take away present ash dumps. These changes will fairly reduce amounts of circulation water and new water bodies emerging in rainfalls. The whole system becomes safer.

Oil shale output

Two underground mines, Estonia and Viru, and two open-casts, Narva and Aidu, are working at Estonian oil shale deposit at present. They provide Narva Power Plants with oil shale (Fig.1). Estonia underground mine and Narva open-cast are the most suitable places for using oil shale ash and waste for backfilling and it allows to wave dangerous storage method what exists at the moment.
Figure 1. Underground mines and open-casts at Estonian oil shale deposit

The data of oil shale production in underground and surface mines is given in table 1 AS Narva Power Plants used 11 740 thousand tons of oil shale last 2006/2007 economical year. The volume of the extracted oil shale is the basis for estimation of the space in the workings to be backfilled.

Table 1. Oil shale output – mines and open-casts [6]

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<tbody>
<tr>
<td></td>
<td>Output</td>
<td>Share</td>
</tr>
<tr>
<td>Estonia mine</td>
<td>4 651</td>
<td>36%</td>
</tr>
<tr>
<td>Viru mine</td>
<td>1 794</td>
<td>14%</td>
</tr>
<tr>
<td>Total mines</td>
<td>6 445</td>
<td>50%</td>
</tr>
<tr>
<td>Narva open-cast</td>
<td>4 582</td>
<td>36%</td>
</tr>
<tr>
<td>Aidu open-cast</td>
<td>1 868</td>
<td>14%</td>
</tr>
<tr>
<td>Total open-casts</td>
<td>6 450</td>
<td>50%</td>
</tr>
<tr>
<td>Total all</td>
<td>12 895</td>
<td>100%</td>
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</tbody>
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Table 1 shows that last economic year oil shale output was 12 895 million ton at mines and open-pits. Underground mines and open-pits produced in 50% of oil shale correspondingly.

**Application of the filling mixture in the mines and open-casts**

**Underground mining**

To extract oil shale chamber-and pillar system is used at underground mine. The main roof (carbonate rocks) is supported by pillars, immediate roof is supported by anchor bolts. Pillar sizes are 6...6.5 x 6...6.5m when mining oil shale layer 2.8m thick. If the roof is unstable, oil shale layer 3.8m thick is extracted. In this case the length of anchor bolts...
decreases considerably, but the sizes of pillars increase (7...8 x 7...8m). Chamber width is 6.5...7.5m. Optimally calculated and being in use sizes of pillars and chambers ensure stability of overburden rocks and land surface. Block sizes are 300...400 x 700...900m. Oil shale losses are up to 30%, they originate from pillars in the main. Drilling – and – blasting operations are applied when extracting useful mineral. Chamber – and – pillar method used in underground mine is presented in Fig.2

![Figure 2. Chamber-and-pillar method of mining](image)

Broken ground consists of 60% of oil shale and 40% of limestone ($\rho=1.8\text{ to }2.0 \text{ t/m}^3$). Volume mass of the filling material (ash, limestone, water) is $1.8\text{ to }2.0 \text{ t/m}^3$. On the basis of the data it turns out that 11.62 million ton of the filling material is available per year, 50% of it is used for recultivation of open-casts. 30% of waste is used for making breakstone. Because of this it is possible to fill up 2.79 million m$^3$ of workings in Estonia underground mine. 12.90 million ton of the broken ground have been extracted, in the result 6.45 million m$^3$ of the workings have been arranged underground. Because of this it is possible to fill 43% of them can be backfilled.

Table 2.

Volumes of filling materials

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<tbody>
<tr>
<td></td>
<td>Estonia and Viru mines</td>
</tr>
<tr>
<td>Oil shale output, million ton</td>
<td>6.45</td>
</tr>
<tr>
<td>Limestone output, million ton</td>
<td>6.45</td>
</tr>
<tr>
<td>Extracted broken ground, million ton</td>
<td>12.90</td>
</tr>
<tr>
<td>Volume of the extracted workings, million m$^3$</td>
<td>6.45</td>
</tr>
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<td>Narva Power Plants</td>
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<tr>
<td>Oil shale consumption, million ton</td>
<td>11.74</td>
</tr>
<tr>
<td>Ash (45…50% of oil shale consumed), million ton</td>
<td>5.28</td>
</tr>
<tr>
<td></td>
<td>Filling materials</td>
</tr>
<tr>
<td>Ash and limestone, million ton</td>
<td>5.57</td>
</tr>
<tr>
<td>Volume, million m$^3$</td>
<td>2.79</td>
</tr>
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</table>

The main parameter of the filling material in mine backfilling system is its strength. It has to ensure overburden stability and minimum deformation of the land surface. In full filling the roof effects on the filling space.
This relationship is expressed by the following formula (1):

\[ \sigma = \gamma H \]  

(1)

where \( \sigma \) – load on the filling space, Mpa; \( \gamma \) – volume weight of overburden, MN/m\(^3\); \( H \) – overburden thickness, m.

Under conditions of Estonia mine they are \( H = 60 \text{m} \) and \( \gamma = 2.5 \times 10^{-2} \text{ MN/m}^3 \). Load on the filling space is 1.5 Mpa and in partial filling (when 50% of the workings are filled) the load on the filling space is 2 times higher, i.e. 3Mpa. If natural pillars (25…30% losses of oil shale in pillars) are replaced by artificial pillars, then their minimum strength must be 4.5 MPa. In such a way, use of artificial pillars reduces oil shale losses up to 30%. Researches conducted under Estonian conditions earlier showed that maximum strength of the filling space was 9 MPa depending on the content of the filling mixture. Therefore, used materials can provide filling space with necessary strength.

**Opencast mining**

At present surface mining method is used at open-casts. It ensures efficiency of the works (Fig. 3).

![Figure 3. Surface mining method used at Estonian open-casts](image)

Mining operations at open-casts are carried out in two stages:
1. Removal of the overburden.
   Overburden is removed by draglines and is disposed into inside dumps which are located on the extracted area. During reclamation of spoil heaps they are levelled, covered with ground and soil.
2. Oil shale seam extraction
   To extract oil shale seam bulldozer-rippers (selective mining) or drilling-and-blasting (complete mining) are used. Bucket loaders, shovels or hydraulic excavators are used for oil shale loading into dump trucks. Oil shale is transported by dump trucks to the preparation plant, crushing-and-sorting plant or loading point. Application of combined cutter loader allowing oil shale seam selective mining is a perspective solution. Overburden recasting does not depend on the oil shale mining method. Rehandling overburden contains marls and bulk materials which become unstable in recasting and complicate mining. To increase stability of the rocks of inside dumps it is feasible to use ash of Power Plant. During recultivation disposed ash remains under rehandled overburden. This method makes it possible to improve efficiency of mining and to employ the ash unused before.
Oil shale ash impact on the environment

Ash contains limestone. The result of limestone hydrolysis is calcium hydroxide which alkalizes water (pH > 11). The last represents danger for environment. In addition, the ash contains organic compounds chemically poisonous enough [8] and partially adsorbed by soil contaminants such as Mo, Pb, Ni, Co, Hg, etc [9] which are dangerous for the human health even in low concentrations.

Recent research [10] shows that ash after fluidization has 2 times lower concentration of polycyclic compounds (PAH) in comparison with ash after pulverized burning (47 µg/kg and 108µg/kg). Besides, relative concentration of heavy PAH-s is higher in ash after pulverized burning process than in ash after fluidization.

Figure 4. Hydrogeological section of the Ordovician Aquifer System

When mining oil shale the water level of mineable seam substratum is lowered. The main forming source of mine water is Ordovician water complex in the boundaries of which vast conical depression in the water table has been formed under the influence of mining operations.

Body of ground water of oil shale basin consists of three aquifers:

- **O₃nb-rk** – Nabala-Rakvere aquifer,
- **O₃kl-kk** – Upper Ordovician Keila-Kukruse aquifer,
- **O₂ls-kn** – Middle Ordovician Lasnamäe-Kunda aquifer (Fig.4).

Ground water of Quaternary sediments (Q) and the highest from the surface aquifer in Ida-Virumaa are free ground waters, the rest ground waters are confined aquifers. Due to lower aquifers are confined ones it is impossible to pollute them by above mentioned compounds and contaminants partially absorbed by the ground.

Large volumes of the water pumped from open-casts and underground mines (439 000m per day in 2002 and 556 000m³ per day in 2003) exercise a positive impact dissolving leaching substances and concentrations of all hazardous impurities are considerably lower than permissible limits.

Ash transportation is the main environmental problem. Ash or mixture transportation from Power Plants to the mine and then to the filling space causes transport risk. When using hydrotransport the ash mixed with water or with filling material and water can always cause troubles in the pipeline. In the result of such failure some amount of the transported material can flow onto the land surface. For such situation special measures have to be developed to
eliminate breakdown and to liquidate contamination of the land surface quickly. It is necessary to find possibility for mixture storing for the time of failure elimination. Similar problems occur in conveying of dry ash. Risks caused by filling space behaviour remain as well.

To develop ash loading procedure regardless of all suitable and hydrological preferences it is necessary to carry out constant monitoring of ground waters to keep pollutants in prescribed limits. Because of possible hazards it is necessary to work out technical solutions and measures to eliminate contamination.

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The major problem in backfilling is calcium hydroxide, which alkalizes water (pH > 11). In addition, the ash contains organic compounds chemically poisonous enough and partially adsorbed by soil contaminants, which are dangerous for the human health even in low concentrations. Due to lower aquifers are confined ones it is impossible to pollute them by above mentioned compounds and contaminants partially absorbed by the ground. To develop ash loading procedure regardless of all suitable and hydrological preferences it is necessary to carry out constant monitoring of ground waters to keep pollutants in prescribed limits. Because of possible hazards it is necessary to work out technical solutions and measures to eliminate contamination.