Mine pool water and energy production
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Abstract
Mine pool water and energy production issues intersect in numerous ways. However, water and energy are often not in the proper balance. For example, even if water is available in sufficient quantities, it may not have the physical and chemical characteristics suitable for energy or other uses. Pre-mining time groundwater goes through geochemical processes when formed natural with low sulphate content groundwater. The oil shale mines dewatering lowered groundwater level in Keil-Kukruse layer, and the sulphate content increasing about 50 times by intensive oxidation of pyrite.

The use of mine pool water is technically feasible and can be approved under existing regulatory authorities. Nevertheless, mine pool water is not widely used today.

Keywords
Closed mining sites, mine pool water, energy, dewatering, sulphate content, oil shale.

Introduction
Nearly every European country has closed mining sites [1, 2, 3, and 4]. Closed underground mines may induce risks for the environment. Some of these risks are linked to the shut down of the mine water pumping operations leading to a water level rising and the pollution of groundwater by sulphates and others chemical elements. After the mine closing these risks may exist during a short, long and very long period of time depending on the quantity and flow of water involved and the volume of the mine workings concerned [5]. Generally, the water of closed mines in oil shale area meets the requirements of the Drinking Water Standard of Estonia (RTL 2001/100/1369). Environmental benefits can result in connection with the use of mine pool water at some locations. Throughout the oil shale region of Ida-Virumaa, numerous mines are currently discharging to streams and rivers. Water from flooded underground mines represents a large untapped resource for power plant cooling. These mines water “reservoirs” could serve as a source of water to replace surface water sources.

Description of Study Area
The closed oil shale mines are located in central part of oil shale deposit (Fig. 1) and the area is about 176 km² (Table 2). From a hydrogeologic standpoint, the oil shale deposit is divided into three principal hydrostratigraphic units associated with a northeast and east topographically driven flow with recharge zones at the highest outcrops and discharge zones in the rivers. Oil shale mining affected the groundwater regime and chemistry of Quaternary and Ordovician aquifer. Hydraulic properties of the aquifers are summarised in Table 1.

Fig. 1. Closed oil shale mines within the Estonian oil shale deposit. UM – underground mine, SM – surface mine
Table 1. The hydraulic properties of aquifers in the Estonian oil shale deposit [6].

<table>
<thead>
<tr>
<th>Age</th>
<th>Aquifer system</th>
<th>Rock type</th>
<th>Depth, m</th>
<th>Thick ness, m</th>
<th>Water table (piezometric), m below surface</th>
<th>Specific capacity, l/sec/m drawdown</th>
<th>Hydraulic conductivity, m/day</th>
<th>Transmissivity, m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Q</td>
<td>Sand, till, peat</td>
<td>0</td>
<td>0-77</td>
<td>+0.3-16</td>
<td>0.001-54</td>
<td>0.02-175</td>
<td>0.1-1980</td>
</tr>
<tr>
<td>Ordovician</td>
<td>Nabala-Rakvere</td>
<td>Limestone, marl, dolostone</td>
<td>2-20</td>
<td>0-50</td>
<td>+0.1-13.2</td>
<td>0.025-11.0</td>
<td>0.40-185</td>
<td>4-2546</td>
</tr>
<tr>
<td></td>
<td>Kunda</td>
<td>Limestone, marl, dolostone</td>
<td>0.5-50</td>
<td>0-44</td>
<td>0.2-28.2</td>
<td>0.007-8.3</td>
<td>0.04-170</td>
<td>0.03-2308</td>
</tr>
<tr>
<td></td>
<td>Lasnamäe-Kunda</td>
<td>Limestone, marl, dolostone</td>
<td>0.5-100</td>
<td>17-24</td>
<td>0.6-15.6</td>
<td>0.001-2.1</td>
<td>0.48</td>
<td>0.01-187</td>
</tr>
</tbody>
</table>

Quaternary deposits comprise a thin layer of peat, sand and till and unconsolidated glacial sediments that constitute porous aquifers with mainly unconfined groundwater [6], influenced directly by the meteorological conditions. The surface water percolates directly into the Quaternary cover, and most of the groundwater flows through the cover as the groundwater discharges into springs, streams, rivers and wetlands.

Ordovician aquifer system consisting of lime- and dolostones with clayey interlayer lenses are found below the shallow cover of the Quaternary deposits in oil shale deposit. The limestone may be divided into a near-surface karst aquifer, cutting across the stratigraphic units, and several deep fracture aquifers, corresponding to the stratigraphic units [6, 7, 8]. The lateral near surface hydraulic conductivity of the Ordovician limestone is in the range of 5–300 m/d, whereas it is only 0.1 m/d [9] at a depth of 80–100 m. The vertical conductivity of the clayey layers separating the water-bearing zones is $10^5 – 10^6$ m²/d [9]. Therefore, these clayey layers serve as aquitards, dividing the limestone in many local aquifers of different vertical and horizontal extent. Long-term observation results [9] show that the inflow to the mines varies with the seasons. Of the total water amount 20% falls to the winter months, 29% to the spring months, 27% to the summer months and 24% to the autumn months. Rainfall is characterized by an inter-annual irregularity. The weather impact on the mine decreases with the depth of the mine and the coefficient of inflow irregularity decrease by 2.3% while mine become deeper 1%.

Mine Pool Development

Extensive pumping was needed to keep the mines free from water. When the mines became inactive, groundwater flooded the mines. Water levels in the mine would continue to rise until hydraulic equilibrium with the regional water table was achieved or the water followed paths to topographically low areas. Fractures caused by roof cave-ins, removed or breached pillar barriers as well as tunnels and shafts, allowed water to freely flow within one mine or a series of mines (commonly referred to as mine complexes).

After pumping of water stops the old shafts and tunnels fill up with water. In underground oil shale mines, there may be a number of disconnected pools at the early stage of flooding. Before flooding water sub-pools may exist at various locations and elevations within the mine. The abundance of sub-pools is greatest at the back of the mine where recharge and leakage collect. These sub-pools tend to coalesce and form a main pool, which will rise from the back of the mine in an up-dip direction. As flooding progresses, the sub-pools join into a single main pool with big water volume (Table 2). The flooding situation is a transient scenario, while the flooded case is a steady state one. In transient groundwater flow systems, hydraulic head is continuously changing with time, with minor seasonal or annual fluctuations. In 2004, the volume of water in the pools of the closed underground mines was about 165 million m³; in 2004 it amounted to 138 million m³ (Table 2).

The elevation of the water table in 1990 was about 42–53 m above sea level (Fig. 2 A) in Käva and Kukruse mines, Mine no 2 and Mine no 4. In some cases, water levels in two or more adjacent mines will fluctuate in conformity with the seasonal or man-induced stresses. Hydrologic investigations indicate that the elevation of the water table has fluctuated over time, especially in Mine no 2. The maximum elevation was about 51 m a.s.l., but seasonally it fluctuated between 50–56 m a.s.l., primarily as a result of variation in climate and increased precipitation. If the inflow rate is all the time greater than the outflow rate, the water storage and hydraulic head in the saturated portion of the mine will increase. If outflows are greater than inflows, then the hydraulic head will decline.
During the rainy August of 2003, the water table rose 4 m in Sompa underground mine, 2 m in Kohtla, 2.1 m in Kukruse, 1.8 m in Mine no 4 and 0.5 m in Ahtme mine. Closed mines water filling and restoration of Keila-Kukruse underground water level in 2003 is presented in figure 2 B.

The dissolution of pyrite leads to high concentrations of sulphates. The water displayed neutral pH and positive Eh in the spring-summer than in other times. These results reflect the increasing of the sulphide oxidation rate during the warm months, other time the sulphide oxidation rate was low, but depend on precipitation. In recent years, in the area of oil shale mines, the chemical composition of groundwater has been stable. The content of SO\(_4\) in groundwater was 2 times higher in spring than during the remaining seasons of the year. The sulphate content in the water filling up mine is high; in the closed mines it is low (Fig. 3).

However, mines may not generate sufficient water. Discharge from underground oil shale mine individually to sustain a consumptive use as large as a power plant.

In fact, large power plants can evaporate thousands of cubic meters per minute in order to maintain their operations. Therefore, a number of mines may have to be linked hydraulically, either by direct connection or through the use of mine to mine transfer pumps to obtain an adequate cooling water supply.

Table 2. Approximate water volume in closed underground oil shale mines

<table>
<thead>
<tr>
<th>Underground mine</th>
<th>Work started</th>
<th>Closed (pumping stopped)</th>
<th>Water table in 2003, [14]</th>
<th>Mined out area, km(^2) [14]</th>
<th>Water volume (approximately), (10^6) m(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Obs. well no. m, a.s.l.</td>
<td></td>
<td>2004</td>
<td>2006</td>
</tr>
<tr>
<td>Kukruse 1916</td>
<td>1967</td>
<td>8214A 52</td>
<td>13</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Käva 1924</td>
<td>1973</td>
<td>2</td>
<td>51.5</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Kohtla 1937 28.06.2001</td>
<td>W-15 41</td>
<td>17</td>
<td>13</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Ahtme 1948 1.04.2002</td>
<td>16122 25</td>
<td>35</td>
<td>63</td>
<td>50</td>
<td>27</td>
</tr>
<tr>
<td>Mine 2 1949 1974</td>
<td>3a 51.41</td>
<td>13</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Tammiku 1951 28.12.1999</td>
<td>714 50.04</td>
<td>47.95</td>
<td>40</td>
<td>42</td>
<td>38</td>
</tr>
<tr>
<td>Mine 4 1953 1975</td>
<td>302 1b 40.26</td>
<td>13</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Fig. 2. Water level in the Keila–Kukruse groundwater aquifer in 1990 (A) and in 2003 (B)

Fig. 3. The sulphate content in the Ordovician Keila–Kukruse aquifer of underground oil shale mine area
Conclusion

Mine pool water may be used at some small facilities. Because other, more traditional fresh water sources have been available historically, there has been little incentive to explore new water supplies. Before the resource can be more fully utilized, many questions will need to be answered, and industrial users, regulators, and the public must gain a better understanding of the value and potential impacts of using mine pool water.

Some of the areas that require further investigation include:

1. better characterization of the locations and volumes of mine pools;
2. better characterization of the variation in water quality parameters at various mine pools;
3. hydrological information relating to recharge rates;
4. the potential for ground surface subsidence as water is removed from mine pools.

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References: