Perspectives for the Mining of Oil Shale and Limestone with Surface Miner in Estonia

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ABSTRACT: The paper introduces a mining of two most important mineral resources in Estonia. The goal is to present main factors which play an important role for perspectives of the mining of oil shale and limestone with a surface miner. Detailed overview of oil shale mining will be given because in Estonia is situated one of the world's largest oil shale mining area. Comparing with oil shale is limestone more common mineral resource and therefore will be limestone mining introduced briefly.

1 INTRODUCTION

Oil shale and limestone mining have a great influence on Estonia's economy: 98% of electricity is produced in oil shale power plants and limestone is used as main aggregate in civil engineering. Mining sector faces challenges to increase the output of mines and to minimize the environmental impact of mining at the same time. Technological improvements are necessary in this situation and surface miners have perspectives to offer solutions because there are some experiences of the continuous mining with surface miners in Estonia. Wirtgen surface miner was used for limestone mining from 1989 to 1991. Tests for oil shale mining were carried through in 2004 with Wirtgen and MAN TAKRAF surface miners.

2 PERSPECTIVES FOR THE MINING OF OIL SHALE WITH SURFACE MINER

2.1 *Importance of oil shale mining in Estonia (Kattel & Valgma 2005)*

Oil shale is primary mineral resource in Estonia which has been mined for 90 years. During that period approximately 1 billion tonnes of oil shale has been extracted from estimated 5 billion tonnes of resources. Mineable reserve is currently about 1.5 billion tonnes. Oil shale mining peaked in 1980 when more than 30 millions tonnes of oil shale were mined annually. Last few years the annual output has stayed between 11.5 and 14 millions tonnes per year. Estonian oil shale production makes 70% of world's oil shale production (excluding tar sands) and two thirds of Estonia's total mineral production.

Oil shale consumers are primary power plants and shale oil plants what consume approximately 85% and 15% of oil shale respectively. In addition, oil shale is supplied for cement industry. Oil shale covers over half of Estonia's primary power resources (Fig. 1). About 98% of electric power and a large share of thermal power are produced from oil shale. Therefore main goal of the oil shale industry is to preserve its competitive ability in the market of power resources.

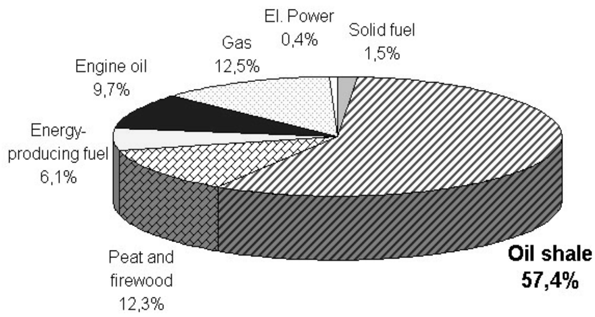

Figure 1. Balance of Estonia's primary power resources

All oil shale mining enterprises have belonged to the Eesti Põlevkivi (Estonian Oil Shale Company) group which has three subsidiaries. In addition to surface and underground mines, Põlevkivi Raudtee Ltd (a railway enterprise) and Mäetehnika Ltd (Mining Machinery Enterprise) also belong to the group. However, during past few years in addition to Eesti Põlevkivi, few other enterprises have started to mine oil shale. In 2003 Kiviõli Keemiatööstus OÜ, the owner of shale oil plant, opened a new surface mine with annual output 800,000 tonnes. In 2005 Kunda Nordic Cement, owned by HeidelbergCement Group, opened a new surface mine as well.
Like any kind of mining activity, oil shale mining has great influence to regions environment as well. The area affected by oil shale surface and underground mining is over 400 km^2 (almost 1% of Estonia’s territory). About 220 km^2 of this mining area lies underground. On that area a number of ground subsidences have occurred. The scale of subsidences depends on mining depth and used technologies. Mining influences region’s hydrology but as experienced, the influence is temporary. Besides to the mining activity, more serious impact to the environment is caused by waste deposits from oil shale processing and energy production residues as ash and semi coke.

2.2 *Overwiev of Estonian oil shale deposit (Kattel & Valgma 2005)*

Baltic oil shale area covers about 50,000 km^2 and includes the Estonia and Leningrad deposits and Tapa occurrences, of which the first two are commercially exploited. Estonia deposit is one of the largest commercially exploited oil shale deposits in the world with its total resources exceeding 5 billion tonnes of oil shale. The oil shale bed lies in the form of a flat bed having a small inclination (2-3 m per km) in southern direction. The commercially important part of oil shale is deposited in a single mineable layer with thickness of 2.5 to 3.8 m in depth of 3 to 100 m in area of 2700 km^2.
The oil shale layers occur among the limestone interlayers in Kukruse Regional Stage of the Middle Ordovician (O2kk). It is a stratified sedimentary rock, rich in organic matter. The commercial oil shale bed and immediate roof consists of oil shale and limestone layers (Fig. 2). The main roof consists of carbonate rocks of various thicknesses.

Index of layers	Average thickness, m	Heating value, MJ/kg	View of oil shale bed
F	0.90	9.0	
E	0.39	5.2	
E/D	0.13	2.6	
D	0.13	13.5	
D/C	0.24	0.5	
C	0.37	10.7	
C/B	0.10	2.6	
B	0.55	15.0	
B/A	0.13	2.6	
A	0.15	15.0	

Figure 2. Structural cross-section of oil shale bed

The characteristics of the individual oil shale and limestone seams are quite different. The compressive strength of oil shale is 15-40 MPa and that of limestone is 40-80 MPa. The strength of the rock increases in the southward direction. The volume density is 1.5-1.8 Mg/m^3 and 2.2-2.6 Mg/m^3 respectively. The calorific value of dry oil shale is 7.5-18.8 MJ/kg depending of the seam and the area in the deposit.

2.3 *Overview of Oil shale mining (Kattel & Valgma 2005)*

Oil shale mining in Estonia started in 1916; it was extracted in surface mines using the opencast method. Underground mining started in 1922. Room-and-pillar mining, which is the only underground oil shale mining method today, was started in 1960. During years 1971-2001 in some mines longwall mining with shearers was used. In total ten oil shale surface mines and thirteen underground mines have been in operation. Today two surface mines (Aidu and Narva with Sirgala) and two underground mines (Viru and Estonia) are in operation.

Surface mining is carried out in open casts with maximum overburden thickness of 30 m. Draglines with 90 m boom length and 15 m^3 bucket size are used for the overburden removal. Hard overburden consists of limestone layers and is blasted before excavation. Oil shale layers are blasted as well or broken by ripping. Excavated rock is transported with 40 and 60 tonnes trucks to the processing or crushing plant depending on opencast. Distance vary from 3 to 8 km. Open casts drainage system is based on drainage drifts which are drifted before the open cast is opened, about 3-5 m deeper from the bottom of oil shale seam.

Underground oil shale mines operate in the depth from 40 to 70 m. Mining field are opened with vertical shafts and ramps. For the main hoisting ramps with belt conveyors are used. In auxiliary shaft cage hoisting is used. In Viru underground mine only rail transportation is used. In Estonia underground mine rail transportation is for staff and equipment, excavated rock is transported by conveyors. In 2004 an inclined shaft was built to replace in the nearest future inefficient rail transportation in Estonia mine.

The field of an underground oil shale mine is divided into panels by the panel drifts. Panels are subdivided into mining blocks, approximately 300-350 m in width and from 600 to 800 m in length each. Mining blocks usually consist of two semi blocks with 6 m width collecting drift. Rooms and drifts height corresponds to the thickness of the commercial oil shale bed, approximately 2.8 m. The width of the room is determined by the stability of the immediate roof. The latter is very stable when the room is 6-10 m wide. In this case, bolting must still support the immediate roof. The pillars are arranged in a singular grid. Actual mining practice has shown that pillars with a square cross-section suit best. The cross sectional area of the pillars is 30-40 m^2, depending on the mining depth. Room-and-pillar mining system gives an extraction factor of 70–80%.

The main operations carried out in rooms include undercutting, drilling of blast holes, blasting, loading of excavated rock on the conveyor and roof bolting. Loading and transportation of excavated rock in face is carried out by LHD machines like TORO and WAGNER. The average productivity of such technology is 1500 m^3 of rock mass per day. The main problems are the high number of blasting operations, low mobility and concentration of loading works due to the small entry advance rates, about 1.5-1.7 m per blasting.

Currently is applied improved underground mining technology. The new mining technology is based on improved drilling-and-blasting method to move from packaged to underground bulk emulsion explosives (Nobelit 2000), from 2.0 to 4.0 m borehole length with large boreholes to gain free space instead of undercutting and to automatization of roof drilling-bolting process with roof bolting machine. The old undercutting technology based on bottom cutting with the help of the cutter (Ural-33) which gives horizontal cut into the bottom layer A, 15 cm high and 1.7 to 1.8 m deep. The new technology is based on six large holes drilling with SMAG machine into the central oil shale layer C, up to 4.7 m deep with 3 x 280 mm diameter. Roof bolter and face drilling machines are operating with remote controls that provide higher safety conditions on a working place.

2.4 *Perspectives*

After focusing on improvements in underground mines, the new direction is to evolve surface mining and one priority is to apply surface miners.

First tests with surface miners were made in 2004 when Wirtgen 2200SM and MAN TAKRAF's TM25 were tested. As a result of tests the first machine, Wirtgen 2500SM, started to operate in May 2006. Next machine will be delivered in the end of 2006.

Main difficulty to be stressed is that, due to the property of the oil shale bed, two different rocks must be cut at the same time. Oil shale is relatively soft rock (compressive strength 15-40 MPa) and limestone on the other hand is relatively hard rock (compressive strength 40-80 MPa, occasionally 100 MPa). Therefore in the process of cutting high average loads are present at significant variations which lead increased loading of the cutting drum. A lot of experiences and research on this field has been made during thirty-year period when in underground mines longwall shearers were used (Adamson, 1988).

The most perspective advantage of surface miner is selective mining. That reduces the need to process oil shale and enables to enhance the quality of oil shale. Oil shale bed contains about 40% limestone in form of single layers or concretions, as seen on the Figure 2. Today the whole oil shale bed is blasted and hauled to the processing plant where it processed in heavy suspension. After processing waste limestone is deposited in heaps near the plant or hauled back to a surface mine or used as aggregate to a certain extent. Also another mining method is used: semi-selective mining which is extracting of thicker limestone layers with rippers. Oil shale with thinner limestone layers and concretions are hauled directly to consumers. Disadvantage of ripping is excessive crushing of oil shale by bulldozer crawlers.

Surface miner can extract also thinner limestone and oil shale layers separately. It is estimated that due to the precise cutting enables surface miner to increase the output of oil shale up to 1 tonne per m^2. Extracted oil shale layers with limestone concretions don't need complicated processing. Screening and crushing are sufficient because, as experiences have shown, most of concretions remain unbroken and can be easily separated from oil shale. Separated concretions and separately extracted limestone can be left directly in mine which reduces haul costs. The thickest limestone layer (D/C) has sufficient quality to produce aggregate of it.

Selective mining enhances the quality of oil shale. Through the quality is the utilization of the mineral resource more efficient and environmental impact is lower. For instance oil retorting with oil shale which is extracted by ripping. Because of lower quality of oil shale, the oil yield is 0.7 barrel per tonne of oil shale instead of 1.0 barrel with processed oil shale. In addition, the amount of retorting waste (semi coke) is higher. Almost same principle is valid with oil shale burning in power plants: less limestone in oil shale results higher efficiency of boilers (up to 1/3 of energy of oil shale is needed to decompose limestone during the burning process) and less ash from boilers. Limestone is in the burning process necessary to capture the sulphur dioxide from flue gas. Sulphur content in oil shale is 0.5-0.7%. Optimum Ca / S molar ratio, to capture the sulphur dioxide in fluidized bed combustion process, is 2.5-3.5. Today is hauled to power plants oil shale with much higher Ca / S molar ratio (8-10) (Ots, 2004). From that can be concluded that separating more limestone from oil shale doesn't affect the capture of sulphur dioxide from flue gas seriously and positive effect would result in lower carbon dioxide and ash emissions.

Another perspective of surface miner would apparent in mines with relative small overburden thickness (less than 10 m) where the removal of hard overburden with surface miner should be considered as well. Hard overburden consists of fractured limestone, mergel and low quality oil shale layers. Currently are used for stripping in these mines excavators with assistance of bulldozers and LHD-s. Surface miner would cut considerably operating costs of stripping.

Concerning the total output of oil shale surface mines today (8 million tonnes), four surface miners like Wirtgen 2500SM or similar would be essential to improve surface mining technology at the first step. After applying the new technology, the number of machines should be considered to increase.

3 PERSPECTIVES FOR THE MINING OF LIMESTONE WITH SURFACE MINER

3.1 *Overview of limestone mining*

Limestone has been quarried and used in Estonia very long time, mainly in northern, central and western parts of the country. It has been used as construction material and raw material for lime burning. Also decorative details and sculptures have been made. More than one thousand quarries situated near buildings and lime burning ovens. Today operates 24 quarries with total output of 2.4 million m^3 per year. Nearly 70% of limestone is used as aggregate in civil engineering (concrete, road ballast etc.). Cement industry uses 15% of the total output. The rest is used for lime burning or exported for metallurgic, sugar, paper and glass industries. Small extent is used as traditional building and decoration material.

Mineable limestone deposits occur at many stages in Estonia and the country is well endowed with limestone resources. However, because of the thickness of the overburden, quality and consistency of the material and the convenient location of the outcrops, more than 75% of mining activity has concentrated on Ordovician limestone and dolomites. Less are exploited Silurian limestone and dolomites. Most intensely quarried Ordovician limestone crops out with 7 to 10 m thick complex (Lasnamägi Stage) in an area, what is up to 10 km wide and runs through most densely populated and urbanized northern part of Estonia.

Limestone quarries are up to 15 m deep. Overburden thickness varies from 0.3 to 7 m. Mineable complex is usually 7-15 m thick consisting of different layers with thickness 2.5-20 cm (Fig. 3) and with compressive strength 80-120 MPa (sometimes up to 160 MPa). The rock is excavated with drilling-blasting operations and afterwards crushed and screened. Also mining technology based on hydraulic hammers is applied.

Figure 4. Working face of Kunda Nordic Cement’s limestone quarry

3.2 *Perspectives*

First experiences to extract limestone with surface miner were gained between 1989 and 1991. Then Wirtgen 2600SM with modified cutting tools was used. Despite of satisfactory performance of the machine, forced decreasing demand for aggregates to give it up. Few years later Wirtgen 2100SM was tested to mine dolomite but the machine wasn’t heavy enough to extract the rock effectively. As experiences have shown, the operating weight of a machine to break limestone mechanically must be at least 100 tonnes.

Crushed limestone, as main source of aggregates, must have certain shape of particles. Preferred is cubic-shape. The portion of thin particles is high in the rock mass extracted by surface miner. The solution is in the appropriate crushing technology

Situation in the aggregate production in Estonia is complicated because of rapid changes in Estonia’s economy during last years. Every year volumes of construction works are increasing considerably and demand for aggregates has multiplied. More than 2/3 of aggregates are produced in Tallinn area where several problems have occurred. Quarries increase output to produce more aggregates because of the intensive construction activity. At the same time, due to the intensive construction activity, city is expanding and sets limitations for further exploitation of reserves.

The disturbing impact of drilling-blasting operations in limestone quarries next to densely populated areas causes vibration, dust and noise emissions which are arguments to stop operations of limestone quarries where blasting is used. This is the issue where surface miner has perspectives due to reduced dust and noise development, also due to nearly non-existent vibration level.

Dust is the problem what surface miner unfortunately can’t solve alone. Most of limestone quarries have insufficiently arranged dust-control which needs to be improved. Noise emissions should reduce signifacally because main noise sources are hydraulical hammers and the loading process of extracted rock which contain boulders.

Surface miner’s ability to cut precise slopes and surface profiles is an advantage in point of view of reclamation. This makes reclamation easier because slopes or the bottom of a quarry can be formed according to the purpose of reclamation.

Some mining companies have planned to extract unmined limestone resources with surface miner near densely populated areas and had succeed to start discussion with local authorities. Few years earlier, when they attended to extract these reserves with blasting, no hope was given by local authorities.

Concerning annual output of three bigger limestone quarries (all together 2 million tonnes), three surface miners would be essential. Suitable surface miner for limestone mining should have at least

100 tonnes of operating weight and over 700 KW / 1000 HP engine.

4 CONCLUSIONS

Main perspective for the mining of oil shale with surface miner is selective mining what enhance the quality of the extracted oil shale. That results in reduced processing of oil shale after mining, more efficient exploitation of reserves, reduced haulage and stripping costs. Higher quality of oil shale also increases the efficiency of the power generation and oil retorting and at the same time ash, semi coke and carbon dioxide emissions decreases.

Mining process of the surface miner has a lower disturbing impact, which is topical in limestone quarries next to densely populated areas. The low level of dust and noise emissions and also very low vibration are arguments to mine limestone with surface miner instead of drilling-blasting operations.

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