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ELECTRICAL ENGINEERING, MINING ENGINEERING D47

Best Available Technology for the Environmentally Friendly Mining with Surface Miner

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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ENERGEETIKA. ELEKTROTEHNIKA. MÄENDUS D47

Freeskombainil põhinev optimaalne keskkonnasäästlik avakaevandamise tehnoloogia

ERIK VÄLI

TTÜ KIRJASTUS

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1. INTRODUCTION

The future of oil shale mining is closely related to the past and current situation in Estonian deposits and international oil prices. Mining and processing technology has been continuously developed but further development of BAT (*Best Available Technology)* technological decisions are required for meeting environmental and economic requirements.

Estonia is currently an independent energy producer due to existing oil shale deposits and favourable mining and processing conditions. Estonia is presently the only Baltic State with an own oil shale deposit, which is used as fuel for independent local energy producers. Conditions in the Estonian energy market will change in the near future, however, especially following the deregulation of regional energy from 2013. Conditions in the energy market are changing daily, and there is great pressure to use “green” energy, which is subsidized by the Estonian government. Deregulation of the Estonian energy market will greatly affect the local energy market. As a result, oil shale producers need to think today about how to be successful in the future.

More and more conditions of mining are changing for the worse and more strict environmental requirements engender situation where mining companies have to apply new methods of mining. Methods in the result of which environment would be threatened as little as possible and high quality products could be got. One of such methods is high-selective mining of oil shale by surface milling cutter. Surface miner allows to mine oil shale environmentally sustainable, to reduce losses, to improve oil shale heating value as well as helps Power Stations to decrease the volumes of SO_2, NO_x, ash and CO_2 by environmental requirements. Strict environmental standards gave an impetus to Power Plants to research oil shale use of different heating value.

The most perspective advantage of SM is high-selective mining. Surface Miner can cut limestone and oil-shale seams separately and more exactly than rippers (2…7 cm) with deviations about one centimetre. It is estimated that precise cutting enables Surface Miner to increase the output of oil shale up to 1 ton per square meter. It means, that oil-shale looses in case of SM technology can be decreased from conventional 12 up to 5 percent. The oil yield increase by 30%, up to 1 barrel per tonne during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning at Power Plants because of less limestone content in oil shale. It results to higher efficiency of boilers, because up to 30% of energy is wasted for limestone decomposes during the burning process. Positive effect would result in lower carbon dioxide and ash emissions. High-selective mining allows to use extracted oil shale without preparation and to generate electric energy in new fluidized bed boilers. Because of that emissions of CO_2 are reduced by 20 % and ash amount is reduced up to 15 %.

Presented thesis is an overview of technological and environmental problems and a search for optimum decisions to reduce environmental impacts. A practical version of optimisation that is possible to use as a background for the BAT optimisation methodology is presented in this thesis on example of high-selective mining *in situ* tests. The thesis deals with risk management problems in Estonian oil shale mines also. Investigations are focused on application of the method to determination of the quality of geological data and with risk assessment of a high-selective oil-shale mining technology using surface miner.

The main targets are:

- Overview of the oil shale usage in Estonia.
- Analysis of oil shale quality, surface miner environmental impacts, CO_2 capture and storage technologies.
- Analysis of available mining parameters with surface miner by the quality, extraction and productivity factors.
- Elaboration of the optimization methods of cutting parameters and estimation of their potential applicability by analysis of actual statistical data.
- Analysis of risk management problems in Estonian oil shale mines.

The methods include theoretical and practical research of proposed modern mining technology with flexible operating system, analysis and comparison of different cutting schemes and parameters, collecting and interpretation of actual technological data, creating a database and elaboration of calculation methods for the BAT optimization, monitoring and calculation of main technological parameters.

The adequacy of the proposed methods is proved by the in-situ tests and laboratory investigations. Analysis has shown that the received results are very close to the data obtained in practice. For risk estimation, the empirical and judgmental approaches and the event tree were used. They allow determining the probability of the occurrence of geological features and its influence on the mining process.

The originality of the study consists in the areas of application. It enables to use elaborated methods and mining schemes for various mining conditions, especially when stratified structure of excavated seam is presented. Results which will be obtained by presented thesis can result in applications in different industrial sectors. The main applications will of course be found in the surface high-selective mining and road construction sectors. New applications could be seen in zones where rock soils could be transformed into zones with agricultural capacities. To avoid a potential problem of non-utilizable waste in stockpiles of mine areas, selective mining leaves the low-grade ore in mined-out surface areas. Analysis showed that the risk management method used is applicable to mining industries, which are of particular interest for practical purposes.

The main ways of increasing output material quality are high-selective mining or more effective processing after mining. The tests of mechanical mining have shown that selective mining with ripper-dozers have proved themselves, but in order to decrease losses, higher accuracy of cutting samples is needed. Selective mining, in particular highly selective mining, enhances the possibility of mining out minerals at the required quality. The cutting process enables the mineral resource to be utilized more effectively while lowering the environmental impact at the same time. The disturbing impact of drilling and blasting operations in quarries and opencast mines next to densely populated areas causes vibration, dust and noise emissions that are valid arguments to stop operations where blasting is used. The highly selective surface miner technology offers excellent perspectives due to reduced noise levels, non-existent vibration and reduced dust emission levels.

1.1. Geology of Oil Shale Deposit

Oil shale is an argillaceous and carbonaceous, fine grained sedimentary rock of which waxy organic matter known as kerogen forms a substantial part. It smells oily and, like coal, can be burnt without preliminary processing. Shale oil, along with gas and residual carbon, can be produced from it through heating in retorts at temperatures of around 500ºC. The first production of shale oil on an industrial scale took place in France in the 1830s. It has a lower energy capacity (heating value) than any form of coal. The Estonian oil shale, when compared to other world deposits, has a high kerogen content, low sulphur content and good separation of oil.

Estonian oil shale is called kukersite and is the most important mineral resource of the country. It is now generally agreed that marine algae deposited in shallow coastal waters are the source of the organic material in the shale and that the algal structures have remained largely unchanged or have undergone only minor changes. The exploitable seam of kukersite accumulated on a carbonate shelf along the southern margin of a lowland area that occupied southern Finland during early Upper Ordovician times, approximately 460 million years ago.
The content of kerogen in thin individual beds ranges from 15 – 55%, with oil yields from the kerogen of 65 – 67%. As such, it is the second highest yielding oil shale in the world, after those in Australia. Aside from its organic content, the rock contains detrital material in the form of clay with subsidiary quartz, feldspar and carbonate in the form of calcium carbonate (limestone) and less frequently dolomite.

The light brown to chocolate brown kukersite occurs in up to 50 very thin beds, but the only exploitable section is of early Upper Ordovician age (Kukruse Stage, Viivikonna Formation, Kiviõli Member) where several beds of oil shale occur within approximately 3 m of strata comprising interbedded layers of kukersite and limestone. Thinner kukersites are also found in slightly older strata (Uhaku Stage, Middle Ordovician). This exploitable seam is of economic interest within an area of some 400 km^2 (the Estonian deposit), approximately 50 km from west to east (from Kiviõli to the Narva River) and 20 km maximum from Jõhvi in the north to Väike-Pungerja in the south. It continues eastwards into Russia (the Leningrad deposit). The seam also continues further west and south in a thinner and poorer quality form. Much of the remaining area which has not yet been worked lies to the south and southeast of Estonia and Narva and between the two sites and is designated as “reserved areas” (areas of ecological importance).

Generally the oil shale thins and decreases in heating value from north to south across the deposit.

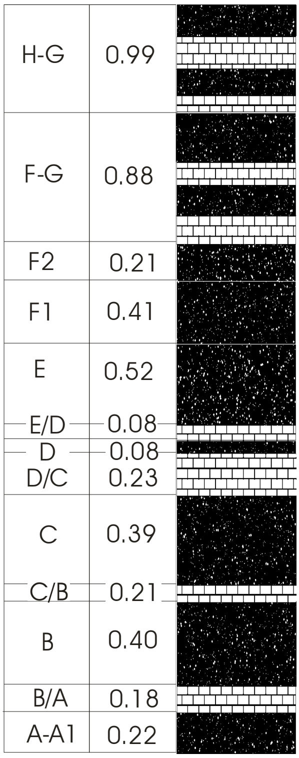


Figure 1. Generalised structural cross-section of the Estonian oil-shale bed for testing area.

The productive oil shale unit (Figure 1) being exploited throughout the Estonian deposit comprises a number of kukersite beds with intervals of limestone. In total, the workable unit is typically 2.5 to 3.0 m, comprising 1.8 to 2.6 m oil shales and 0.6 to 0.7 m limestone. Each bed has variable amounts of carbonate, organic matter and detrital matter. Beds are assigned letters from A (and sometimes A1, F2 etc) at the base up to J. Interbeds of limestone are assigned the letters of the underlying and overlying kukersite (thus A/B, C/D etc). Average bed thicknesses generally range from 0.10 m to 0.60 m.

Bed A comprises argillaceous oil shale up to 0.20 m in thickness and is separated by a discontinuous thin nodular limestone (A/A1) from Bed A1, another thin argillaceous oil shale. Above this lies a bluish-grey argillaceous limestone 0.15 to 0.18 m thick, then Bed B, the
thickest oil shale layer (0.4 up to 0.80 m in the south, but thinning towards the edge of the deposit) with a high kerogen content and a chocolate brown colour.

Limestone B/C is approximately 0.10-0.21 m thick and is beige and nodular in appearance. Bed C oil shale is some 0.30 m and has a lower kerogen content than Bed B and contains two or three layers of discontinuous limestone nodules. A relatively pure limestone (C/D) of about 0.25 m splits the middle of the productive unit.

Bed D, some 0.10 m of slightly argillaceous oil shale, is overlain by a hard, uneven, kerogen-rich limestone (D/E) of about 0.10 m, and then by Bed E, 0.40-0.5 m of reddish-brown kerogen rich oil shale. The overlying limestone (E/F1) and oil shales F1 and F2 have transitional boundaries with a gradual decrease in kerogen content upwards through Beds F1 and F2.

The disposition of the kukersite and interbeds, from a mining perspective, is such that beds A to F1 are usually extracted as a single unit (seam) in open pits and underground operations. In some open pits the unit is selectively dug with

Beds A-A1, B-C and D-F1 and the principal partings (A/B and C/D) being extracted separately. Sometimes the overlying Seam F2 is included in the working section, dependent upon its quality. Beds E/F1, F1 and F2 are often not easy to distinguish individually.

The compressive strength is 20 MPa to 40 MPa compared to 40 MPa to 80 MPa for limestone. The density of oil shale is between 1.4 t/m^3 and 1.8 t/m^3 and that of limestone is between 2.2 t/m^3 and 2.6 t/m^3. The heating value of oil shale deposit is fairly consistent across the deposit. There is a slight decrease in quality from the north to the south, and from the west to the east across the area. Additional information can be read in Paper I.

1.2. European Union Directives and "BAT" Definition

Best available techniques not entailing excessive costs (BATNEEC), sometimes referred to as *best available technology (BAT)*, was introduced with the 1984 Air Framework Directive (AFD) and applies to air pollution emissions from large industrial installations.

In 1996 the AFD was superseded by the Integrated pollution prevention and control directive (IPPC), 96/61/EC, which applies the framework concept of Best Available Techniques (BAT) to the integrated control of pollution to the three media air, water and soil. The concept is also part of the directive's recast in 2008 (2008/1/EC) and its successor directive (Industrial Emissions Directive) published in 2010.

In the European Union directive 96/61/EC emission limit values were to be based on the best available techniques, as described in item #17: "Whereas emission limit values, parameters or equivalent technical measures should be based on the best available techniques, without prescribing the use of one specific technique or technology and taking into consideration the technical characteristics of the installation concerned, its geographical location and local environmental conditions; whereas in all cases the authorization conditions will lay down provisions on minimizing long-distance or transfrontier pollution and ensure a high level of protection for the environment as a whole" [Council of the European Union, council directive 96/61/EC].

The above mentioned directive includes a definition of best available techniques:

"*best available techniques*" shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

a) "*techniques*" shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,
b) "*available*" techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator,
c) "*best*" shall mean most effective in achieving a high general level of protection of the environment as a whole.

The requirement for using a more effective extraction method is related to the worsening of mining conditions for oil shale and the increase in environmental taxes. Higher quality (heating value, moisture, grain size) and courser material is required for more effective usage of boilers and generator units in power stations and oil plants [Valgma, 2008]

1.3. Environmental Impact, CO_2 Capture and Storage Technologies

Oil-shale resources of Estonia are state-owned and lie in the Estonian deposit which is of national importance. State has issued mining licenses to the mines and pitches allowing them to perform mining works. About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Power stations can burn oil shale with net heating values of around 2.050 kcal/kg or heating value 8.4 MJ/kg. Net heating values of oil shale used for retorting and chemical processing must be approximately 2.700 kcal/kg or heating value 11.4 MJ/kg.

Stratified structure of oil shale seam specifies that content and properties of the fuel supplied to the Power Plants largely depend upon the conditions of oil shale mining and enrichment. Limestone interbeds attending to saleable oil shale are the decisive factor. Estonian Power Plants are trying to upgrade heating value of oil shale used as well as to reduce content of ash and CO_2 [Paper II].

More and more strict environmental requirements produce new challenges to Power Plants to reduce emissions discharged into the environment. The main requirements for Power Plants are as follows:

- overall limit amount of SO2 emitted by the oil shale burning plants should be about 25 000 t/per year since the 1st of January, 2012.
- ash disposal should be carried out according to Landfill Directive by January,1st, 2013.
- all boilers should meet the requirements of LCP Directive by January,1st, 2016.

This gave an impetus to Power Plants to research oil shale use of different heating values.

One of the possible alternative solutions for Power Plants is to research usage of oil shale of 10.5 MJ/kg or 11.5 MJ/kg heating value [Ots. A, 2007]. Alternative capacity in electric power generation of a new complex is 2x300 MW or 2x400 MW and heating value of oil shale used at EEJ (block of fluidized bed) and at shale oil plant (TSK-140) is 8.5, 10.5 or 11.5 MJ/kg.

When using oil shale of the above mentioned heating value in the blocks of fluidized bed sulphur dioxide (SO_2) emissions into atmosphere are very small. They make up some percent from 25 000 ton. In the mode of pulverized burning emissions of SO_2 of four blocks make up maximum 13 000 ton. In addition to this it is necessary to install NO_x equipment by 2016.

During burning carbon dioxide (CO_2) is emitted into atmosphere too. During oil shale burning in addition to CO_2 emerging from carbon burning there is surplus amount of CO_2 arising from limestone decomposition. Under conditions where prices for CO_2 quotas are high it is necessary to actuate all possibilities for CO_2 reduction. Emitted CO_2 has to be caught and stored.

In the world roughly 60% of the CO_2 emissions takes place at large stationary source, such as electric power plants, refineries, gas processing plants and industrial plants. In the majority of these processes, the exhaust flue gas contains diluted CO_2 (5% to 15%) One options is to separate the CO_2 from other gases. Another option is to remove the carbon before combustion, as in the case where hydrogen and CO_2 are produced from natural gas (CH_4).

Captured CO_2 can be either stored or reused (e.g. resource for producing soft drinks or in greenhouses to help plant growth). Because the market for CO_2 reuse in currently limited, the majority of CO_2 extractedneeds to be stored. CO_2 can be stored in geologic formations (including depleted gas reservoirs, deep saline aquifers and unminable coal seams). CO_2 can
also be fixed in the form of minerals.

In Estonian there are two ways of storage CO_2. One is open-cast, ash field storage and another is open-cast storage or underground back filling.

I version: CO_2 open-cast, ash field storage. Ash and minimal quantity of water is bumped into tank, which is next to pot. Ash and water are mixed and then CO_2 is carried into the mixture. Unnecessary CO_2 is lead to chimney. Dry pulp form mixture is transported to open-cast or ash fields.

II version: CO_2 open-cast storage or underground back filling. Ash and water is bumped into tank, which is next to pot. Ash and water are mixed and then CO_2

is carried into the mixture. Unnecessary CO_2 is lead to chimney. As appropriate pulp and CO_2 mixture is transported to open pit, ash field or underground mine. When pulp and CO_2 mixture is transported to mine, then tails are added and the mixture becomes petrify fill. In such case it is possible to make new pillars in the mine and to extract more oil shale from pillars.

The main reason for developing oil shale mining technology is to decrease CO_2 emissions from furnaces and to offset the continuing decline of mining conditions and increase of oil price as side product for Estonian electricity production. BAT analyses showed that one of the solutions for increasing oil shale quality (heating value as well as grain distribution) is selective mining. Tests have shown that mechanical cutting is possible, and the size distribution and increasing oil shale quality are possible. In addition to better quality of the product that is related to the higher yield and less dilution, the opposition of society to the mining industry decreases due to its lower impact on the surroundings. The results of the test can be used for redistricting of mining regions and for creating criteria for resource usage and mining impact evaluation [Valgma, 2008].

Mining conditions are degreasing continuously, therefore new technologies must take in use to increase output materials quality, to protect environment and to make mining more effective. One effective way is to use high selective mining method, such as mining with Surface Miner.

2. METHODOLOGY OF "BAT" ACHIEVEMENT

In context of Surface Miners technology the BAT is taking into account limitations to optimum achievements in: technical, technological, economical, environmental and social sphere.

The technical optimum characterized by lowest specific energy consumption (optimized fuel consumption) during mechanical rock cutting. It is in dependence from other parameters like direction of cutting (up-down or down-up), right cutting tools, thickness of cutting, advance rate per cutting and etc.

The technological optimum is availability of highest production rates achievement thru the operating regulations and cost effective changes in technological steps. It is in dependence from so-called *direct effects* like loading method (sidecasting or direct truck loading), optimized fuel consumption (shift time distribution, operating time on cutting) when high-selective mining technology with surface miner is applied.

Environmental optimum is in decreasing losses of minerals and lowering the impact on the environment from surface mining, is optimized usage of mineral resources in the economy, and to establish sustainable development of mining, land usage, resource and surface usage. It is in dependence from couple of *indirect effects* which reducing cost price due to less mineral (oil shale) loss and as a result lesser: reclamation cost, royalty taxes, overburden operating cost and available additional income from oil shale looses decreasing.

Methodology of BAT allows for decreasing expenses both in mining and planning. The experiences, gained in this field, can be used for other similar deposits elsewhere. It is possible to extract minerals in populated areas with suitable technology and at an acceptable cost. The criteria for solving the problems include minimum influence and cost, minimum influence to the environment and social sphere, minimum waste and residue production and maximum benefit for society, economy, education and country.

Thesis offers the determination of BAT to consider in particular the following, giving regard to the likely costs and advantages of measures and to the principles of precaution and prevention:

- the use of low-waste technology;
- the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
- comparable processes, facilities or methods of operation, which have been tried with success on an industrial scale;
- technological advances and changes in scientific knowledge and understanding;
- the nature, effects and volume of the emissions concerned;
- the need to prevent or reduce to a minimum the overall impact on the environment (mineral extraction or recovery) and the technological risks to it.

3. AVAILABLE SURFACE MINERS

Surface miners find their natural applications in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Besides they offer further advantages as for example:

- Less loss and dilution.
- Improved recovery especially in areas sensitive to blasting.
- Less stress and strain on trucks due to minimum impact of the excavated material.
- Primary crushing and fragmentation.
- Reduced capacity requirements for preparation plants.

The most important parameter is the cutting tool. The selection of right cutting tool is essential for good cutting performance & high life, since, it constitute a major portion of operation cost of the machine. The cutting depth can be regulated by automatic leveling system mounted on the machine, the pre-selected cutting depth is maintained either automatically or manually. Based on the cutting direction and position of the drum, the surface miner is classified in three types.

Basically three types of surface miners are available on the market today:

- with middle drum configuration (Wirtgen);
- with front boom cutting drum (Vermeer; Man Takraf; Rock Hawg; Trencor, etc.)
- with front cutting wheel (KSM).

Of these three types of machines the machines with middle drum configuration (the SM type machines from Wirtgen) find the widest range of applications especially in small scale operations below 1000 t/h required output (Figure 2).

Figure 2. Wirtgen SM 2500 at Estonia in 2007 (Narva open-cast)

Today, there are more than 280 Wirtgen Surface Miners work in all kind of material from soft lignite to hard rock (granite) and realize a performance range from 100 to 3000 tonnes per hour.

The Large Surface Miner with Front Cutting wheel – KSM type machine from Krupp Fördertechnik is three times bigger than the largest SM type machine and specially designed for large scale operations in overburden and coal.

The Surface Miner shown in the figure 3 has been operated since 1996 in the Russian Open Pit Mine Taldinskij to mine overburden. Designed for an output of 3500 - 4000 t/h in materials ranging from 30 to 40 MPa in hardness, the KSM has already proved it's ability to dig material with a uniaxial compressive strength of 100 MPa, of course at a reduced production level.

The surface miner as presented offers the possibility to mine the different materials selectively, as it is offered for all other surface miners available in the market, which operate, however, *normally at much lower capacities*.

Figure 3. KSM 2000 at Russian Open Pit Mine Taldinskij since 1996

In view of the applied mining technology, the KSM is not suitable for the mining of soils with plastic consistency such as clay or loam, whose natural water content exceeds the plastic limit. Machine is capable mining of changing rock layers with thickness *exceeding 0.5 m*. The maximum dimensions of the cut are 0.6-times the bucket-wheel diameter by the width of the four bucket-wheels.
The most favorable operating conditions for the KSM are a relatively long and even bench. At the end of the bench, sufficient space should be available for turning and ramping in and out of the cut.

The front boom cutting drums machines or modified trenchers traditionally equipped with front boom. Most of manufactures offering down-cutting method, but for example Astec Industies Company (Trencor Road Miner) offers both a down-cutting method for softer rock and an up-cutting method for harder materials.

Figure 4. Vermeer T1255 tests at Estonia (left) and Belgium (right) in 2007

In terms of the difference between the Vermeer T1255 concept and other surface miners, such as those from Wirtgen and Takraf, a major distinction is "Vermeer's philosophy" of decoupling mining and loading; i.e. not loading directly from miner to truck. When coupling mining and loading, the availability of the miner drops, logistics [are] more complicated and mining efficiency is less. Vermeer's top-down cut ensures the shortest contact possible between the cutting edge and the mined ore [Mining Magazine; November 2008].

But in conditions when high selectivity required the front or rear crawler concept with the downward rotating drum does not allow precise cutting depth control. Especially when harder sections come up the danger of climbing up (cutting depth reduction) will occur. The system is unstable and required continuous control.

4. CUTTING DIRECTION IMPORTANCE

Evaluation of breakability and cutting direction importance for Estonian Oil Shale deposit was performed by a method developed by A. A. Skotchinsky Institute of Mining Engineering (St Petersburg, Russia) in 1970-1980-s. For this purpose over a hundred samples produced by cutting of oil shale and limestone, as well as taken in mines by mechanical cutting of oil shale were analyzed. In researches evaluations were made for using coal-mining equipment for mining oil shale [Adamson, A., 1998]. There are two possible cutting directions of rock cutting: *up-down* (top-down) and *down-up* (Figure 5).

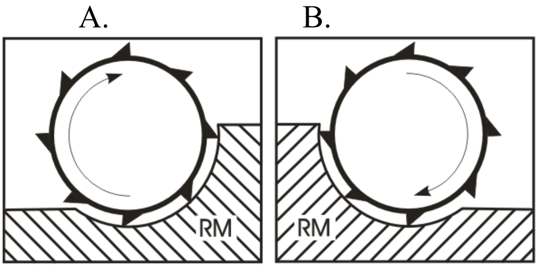


Figure 5. Direction of rock cutting up-down (*A.*) and down-up (*B.*); RM is rock massive (Nikitin O., 2003)

Comparative evaluations were made by the experimental cutting of oil shale in both directions *–up-down* (on closed surface) and *down-up* (on open surface) the bedding, including also mining scale experiments with long-wall shearers at "Tammiku" and "Estonia (902 lava)" underground mine (see table 1).

Table 1. Mining scale experiments results for different direction of cutting at "Estonia" mine

Layer to cut	Cutting thickness, m	Specific energy consumption, kWh/bm^3		-25 mm output, %		Cutting tools consumption, 1/1000 t	
		up-down	down-up	up-down	down-up	up-down	down-up
A-C	1.3	1.3	0.72	47	37	98	25
difference, times		1.8		1.3		3.9	
B-C	0.9	1.12	0.7	43	36	46	25
difference, times		1.6		1.2		1.8	
D-F	1.1	0.94	0.66	50	41	60	20
difference, times		1.4		1.2		3.0	
Average differences		1.6		1.2		2.9	

In both cases the efficiency was estimated by power requirement for cutting. The feasibility was shown of breaking oil shale by direction of cutting down-up the bedding.

Specific energy for cutting down-up is 1.4–1.8 times lower which practically corresponds to the change of the -25 mm particle sizing output and as result cutting tools consumption 1.8-3.9 times lower than up-down direction.

Therefore for Estonian oil-shale deposit conditions are reasonable to choose machines with down-up cutting method, method with precise cutting depth control and practically proved much lower specific energy consumption than up-down method.

5. TESTED SURFACE MINERS

The Wirtgen 2500SM surface miner was delivered to AS Eesti Energia Kaevandused (former AS Eesti Põlevkivi) at the end of 2006. The testing of SM was beginning at "Narva" oil-shale open pit. The test place "Narva" is located approx. 200 km north-east of Tallinn near the city of Sillamäe in the north-eastern part of Estonia (N59 15; E27 44).

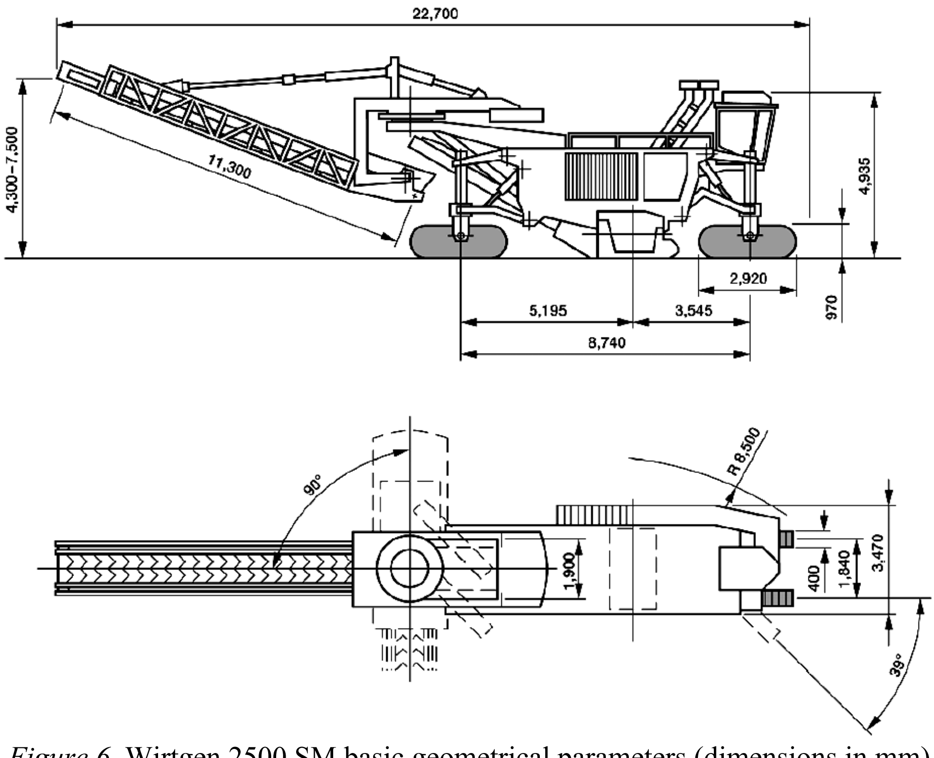


Figure 6. Wirtgen 2500 SM basic geometrical parameters (dimensions in mm)

Estonian mining industry have also tested Wirtgen surface miners 2100 SM (Kurevere dolomite open pit), 2600 SM (Väo limestone open pit) for two years, 2200 SM and 2500 SM (Põhja-Kiviõli, oil-shale open cast) and Vermeer Terrain Leveler (Väo limestone open pit) since 1989-2007, and currently testing Wirtgen surface miner 2500 SM for high selective mining in an open cast mine. The result of testing machines with operating weights less than 80 tones shows unsuitability for hard rock cutting with UCS > 80MPa.

The main requirement for Estonian oil-shale deposit is to cut hard limestone (UCS > 80MPa) and soft oil shale (UCS < 40MPa) with the same machine.

Imbedded between oil-shale layers there is a hard and massive two-layer limestone layer (layer C/D).This layer is approx. 30 to 50 cm thick. The UCS is from 60-80 at Narva Open Cast mine and up to 160 MPa at Põhja-Kiviõli Open Cast mine. Experience shows that this seam (UCS > 80MPa) is cuttable by means of the 2500 SM Wirtgen Surface Miner. However, the production is low and operating cost, especially tool wear, are high.

Figure 7. Wirtgen SM 2500 at Põhja-Kiviõli Open Cast mine (2006) with hydraulic rock breaker

The cut material is small particle size material. Since this limestone layer is waste it would not be necessary to cut it in such small particle size. Therefore it is recommended to loosen this layer more economically than with the Wirtgen Surface Miner, especial for rock with UCS > 80 MPa. Worldwide practice shows that a hydraulically operated rock breaker, mounted to a hydraulic excavator or ripper-dozers (with machine weight 100 tones), would be the most effective method to loosen this rock layer. The so build slabs can be loaded to trucks by means of a hydraulic excavator and transported to the dump or to mobile crushing plant for aggregate production.

5.1. Cutting Tools Analysis

One of the most important parameter is the cutting tool. The selection of right cutting tool is essential for good cutting performance & high life, since, it constitute a major portion of operation cost of the machine. The in-situ testing of different drums for longwall mining shearers was held at “Tammiku” mine from August 30 to September 30, 1982 [Adamson A., 1982]. One of the main results of tests was in conclusion: the number of cutting bits increasing from 1 to 2 picks per cutting line gives decreasing of specific energy consumption by 44%.

To check on practise in 1982 received data on a case of modern surface miner from 2007 to 2009 two milling drums were tested, with one and two cutting bits per cutting line. During the year 2007, 4961 engine operating hours (mh) with first drum and during year 2008 about 3442 mh with second drum has been operated. Different types of cutting tools with cooperation with Wirtgen Eesti AS and BETEK manufacturers were tested. On the table 2 below you can see results of milling drums and cutting tools testing.

Table 2 . Results of milling drums and cutting tools testing

Parameter & Year (calendar)	2007 (first drum)	2008 (second drum)
Engine mh, per year	4 961	3 442
Diesel, l/bm3	0.70	0.67
Cutting tools, 1/1000bm3	3.1	1.3
Holders, 1/1000bm3	0.06	0.005
Cutting performance, bm3/mh	142	153

For the first milling drum equipped with WSM-19, the cutting tools average consumption was 3.1 picks per 1000 bulk cubic metres (bm^3) of rock mass. For the second drum equipped with WSM-22 CP (Plasma coated) this number is 2.4 times lesser and equal 1.3 picks per 1000 bm^3. In oil shale cost price (SM technology without transportation cost) the cutting tools modified about 3.5 % for first and 1.9% for the second drum. *But the decreasing in energy consumption (fuel) varies from 3% up to 45% and was not stable for both drums.*

To understand the influence of others available factors, analysis of size distribution of oil-shale particles for different cutting layers and parameters was held at Narva Open Cast and analysis of engine working time on cutting was done also. Testing results described in the next parts of given thesis.

6. SPECIFIC ENERGY CONSUMPTION VERSUS THICKNESS TO SPEED RATIO

The fractional analysis of crushed oil shale was held from 16.04.2008 to 20.06.2008 for drum with two cutting bits per cutting line. During testing period mined rock from different layers was analyzed (Paper III, table 1). On the same time monitoring of parameters of cutting like (advance) speed per cutting (V, m/min) and thickness of cutting (h, m) was made.

The SM testing shown that size distribution and heating value of oil shale is in dependence on cutting thickness and cutting (advance) speed [Paper II]. It is possible to achieve required average size of mined oil-shale particles with minimal energy consumption, which was completed with the present investigation data.

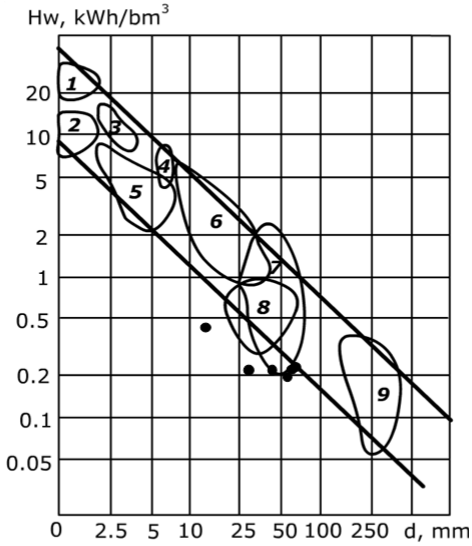


Figure 8. Effect of method of breakage on specific energy consumption (Hw) and the resulting average oil shale sizing (d): *1* – drilling in limestone; *2* – drilling in oil shale; *3* – cutting machine in limestone; *4* – cutting machine in oil shale; *5* – cutting of layer B with shearer loader UKR-1; *6* – cutting with shearer; *7* – cutting with DKS (a mean for measured cuttability) in limestone; *8* – cutting with DKS in oil shale; *9* – breaking with ripper (surface mining); ● – Wirtgen surface miner data points on oil shale cutting.

6.1. Theoretical Background

In 1968 E. Reinsalu had proposed an approximate relationship between energy consumption by different methods of breaking and average size of mined oil-shale particles, which was completed with the present investigation data (Figure 8).

From the surface miner testing results presented on figure 8 it’s showed that there are similar data for specific energy consumption but on same time an average particle sizing varies greatly. The conventional method (Specific energy consumption vs Average particle sizing output) gives the logical result but not correct answer for reasons of that (see figures 9 below). Unfortunately there is influence on particle size output of such parameters like cutting thickness and advance per cutting (cutting speed). The influence of physical-mechanical properties of cutted rock have influence also but on this stage the study concentrated on oil shale cutting with UCS 30-40 MPa.

According “theory of cutting”: with average particle sizing (mm) increasing decrease required specific energy for cutting (Table 3).

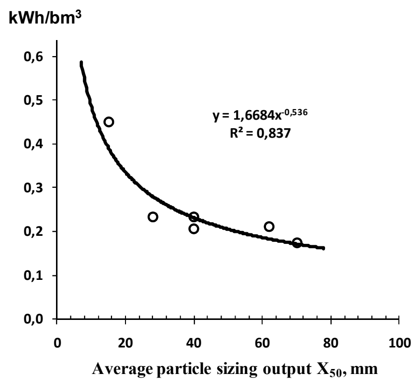
Table 3. Testing results for different oil shale layers cutting

Layer to cut	Thickness to cut,	Advance speed,	Thickness to speed ratio,	50 mm particle output,	Average particle sizing output,	Specific energy consumption*,
	h, m	V, m/min	h/V, %	X_{50}mm, %	$X_{50\%}$,mm	H_w, kWh/bm3
EF-1	0.55	8	6.9	41	62	0.21
EF-2	0.40	10	4.5	51	40	0.21
EF-3	0.40	10	4.0	59	28	0.23
CB-1	0.55	10	5.5	40	70	0.17
CB-2	0.45	10	4.0	51	40	0.23
AA	0.25	8	3.1	79	15	0.45

**-on cutting only*

Or in our case for testing data: greater thickness to speed ratio (%) gives greater available size of pieces (see graphs below).

A.



B.

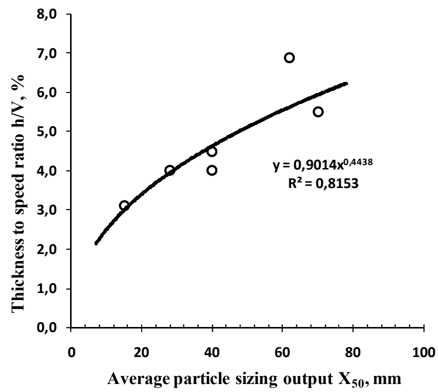


Figure 9. Specific energy consumption (A) and thickness to speed ratio (B) dependence on average particle sizing

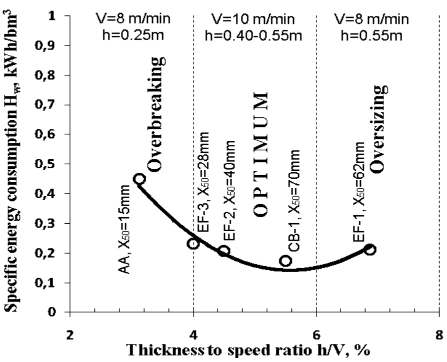
6.2. Understanding of Thickness to Speed Ratio Method

Results presented on graph “B” (Figure 9) shows that there is no contradictions between theory of cutting and h/V ratio method. With this method it is possible to understand the great variations of our SM tests data points presented on Figure 8. By the way of such deviations (Figure 8; Table 3) understanding it is possible to analyze the same dependences for the case of constant particle size, in our case choosed class 0-50mm (X_{50mm}, %), for example. If we have 0-50mm output between 40-60% from ROM. specific energy is between 0.17-0.23

kWh/bm^3 that is minimal, or we can say optimal case for such particle size (Table 3; Figure 10, B). With increasing of output up to 80% required energy increased twice, up to 0.45 kWh/bm^3. To prevent such effect we must keep the h/V ratio inside of 4-6%.

On a graph A (Figure 10) presented dependence of specific energy consumption on thickness to speed ratio for the three basic cases that available during the rock cutting: *oversizing* and *overbreaking* zones that can be characterized by greater energy consumption and *optimum* area which typically lying between first two zones.

A.



B.

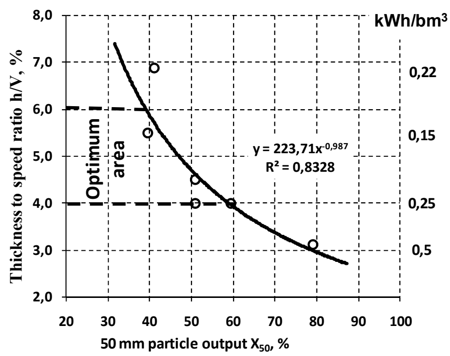


Figure 10. Dependence of specific energy consumption on thickness to speed ratio (A) and Specific energy consumption (right axis) and thickness to speed ratio (left axis) dependence on 0-50mm particle output (B).

In general case (norm) the sensitivity of main parameters from advance speed per cutting (V) and thickness of cutting (h) can be presented on table 4. Arrows means parameter increasing or decreasing.

Table 4. Sensitivity of main technological parameters

<table>
<tr><th>Parameter</th><th colspan="2">Parameter variations</th><td rowspan="7">Where,
h is thickness to cut; V is advance speed per cutting; X_{50} is average particle sizing (50% output); H_w is specific energy consumption per one bank cubic meter cutting; h/V is thickness to speed ratio;
Data from layers taken from table 3.</td></tr>
<tr><td>h, m</td><td>constant</td><td>↓ ↑</td></tr>
<tr><td>V, m/min</td><td>↑ ↓</td><td>constant</td></tr>
<tr><td>X_{50}, mm</td><td>↑ ↓</td><td>↓ ↑</td></tr>
<tr><td>H_w, kWh/bm^3</td><td>↓ ↑</td><td>↑ ↓</td></tr>
<tr><td>h/V, %</td><td>↓ ↑</td><td>↓ ↑</td></tr>
<tr><td>Data from layers</td><td>CB-1 & EF-1</td><td>AA & EF-1</td></tr>
</table>

Such method of analysis can help in optimal cutting rates finding for minimal specific energy and as a result – effective fuel consumption on cutting.

6.2.1. Example of Oversizing Situation

The practical example of oversizing situation presented on figure 11 below. From the right photo it is shown large particle sized rock between the crawlers as a result of small thickness to speed ratio. On this case depth of cutting was h = 0.55 m and advance rate V = 8 m/min. then h/V = 0.55/8*100%=6.9%. Practically proved when h/V> 6 % effect of oversizing of cutted rock can be achieved.

In such cases we need much more energy to crush big lumps and as a result – non-effective fuel consumption.

To control optimum cutting regimes and parameters it is possible stabilizing fuel consumption inside the optimum area. In-situ testing shows that energy consumption during the rock cutting can be decreasing up to 45% not only by the means of right cutting tools usage but by the way of thickness to speed ratio (h/V) regulation also.

Figure 11. Effect of cutted rock oversizing. when h/V ratio > 6%

6.2.2. Definition of Optimal Cutting

During the analysis of graphs on figure 10 the optimal parameter for specific energy was inside the numbers H_w=0.17÷0.23 kWh/bm^3. Optimal cutting can be characterized also by fuel or specific energy consumption, cutting performance and cutting effectiveness. The average fuel consumption during the testing period was about 97 litres per engine hour. In oil shale cost price (SM technology without transportation cost) the fuel modified more than 30%. It is significant to optimize fuel consumption to minimize SM technological oil shale cost price.

The *cutting effectiveness* is percent of SM working on cutting from total number of engine hours. To estimate cutting effectiveness influence to specific energy consumption (fuel consumption on cutting only) analysis of total engine hours on cutting was done (Fig 12).

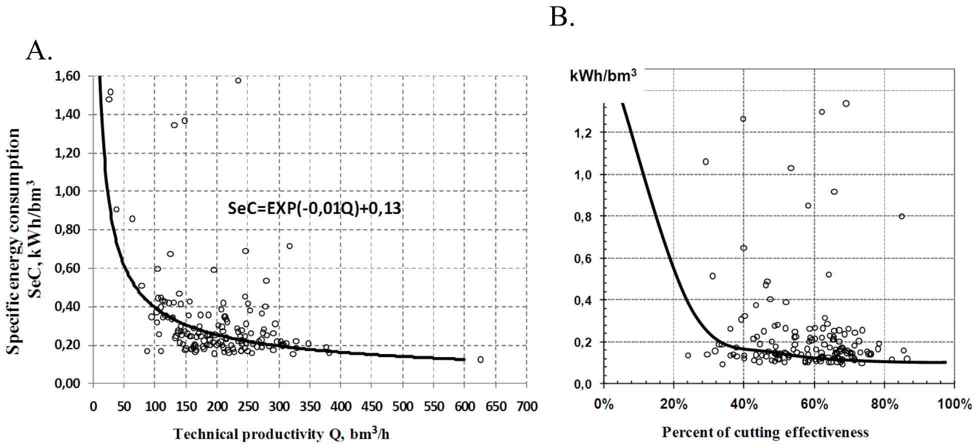


Figure 12. Specific energy (on cutting) influence on cutting effectiveness (B) and technical productivity for oil shale and limestone cutting (A).

To have such statistical data was elaborated special data basis which covered all testing period. At the end of each working shift SM operator fixed all required data (fuel consumption, cutting performance, working hours on cutting, total number of engine hours, etc.) for the future analysis.

On the graph (Figure 12) the optimal number 0.2 kWh/bm^3 achieved inside of cutting effectiveness range 60÷80%. Each point is a one working shift average data. The great deviation of points for both graphs presented above can be explained. One reason of this is non-optimal regime of cutting, that means not right h/V ratio and the second one is differences in rock properties: limestone and oil shale.

If we analyzing data presented on graph A., Figure 12 there are quite a lot of various technical productivity data points inside the optimal number 0.2 kWh/bm^3. For example, we have the same specific energy consumption but with different technical productivities. It's mean that h/V ratio was optimal, but percent of cutting effectiveness varies greatly.

7. DIRECT AND INDIRECT EFFECTS INFLUENCE ON OIL SHALE COST PRICE

As was mentioned before, most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2-7 cm) with deviations about one centimeter (see Fig. 13). It is estimated and proved on practical data that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. Its mean, that oil-shale looses on the case of SM technology can be decreased from conventional 12 up to 5 percent (Paper IV).

Figure 13. The Ripper-dozer at ripping and oil-shale losses on contact with limestone layer (C/D).

During two technologies comparison it is very important to take into account available direct (SM operating costs, loading method incl.) and indirect affects (oil shale recovery) influence on rock (oil shale) cost price.

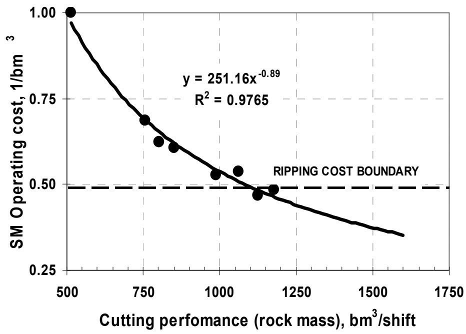


Figure 14. The SM operating cost direct dependence on cutting performance per shift

From the graph on Figure 14 it is seen that in SM cutting performance range 1100-1200 bm^3 per shift of rock mass (available if containing not more than 20% of limestone with 2.4 t/m^3) the SM high-selective technology on same level with Ripping low-selective technology, when direct effects taken into account.

7.1. The SM Technology Direct Effects

The analysis of *loading method influence* has shown that by direct truck loading method, truck-waiting downtime decrease real cutting time by 1.0-1.5 hour per shift and average cutting speed by 20-25%. On a Figure 15 dependence of SM cutting performance on windrowing percentage is presented.

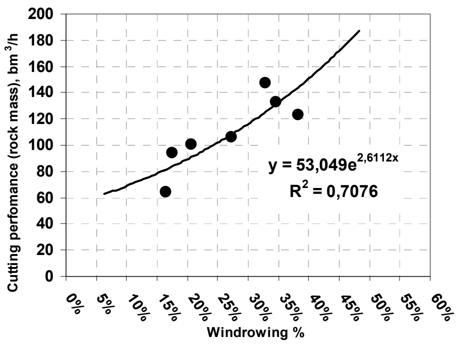


Figure 15. Dependence of SM cutting performance (per shift) on windrowing percentage

As you can see from the graph (Figure 15), there is a great SM productivity potential when windrowing percent is growing. The additional LHD-machine operating and SM depreciation costs greater oil-shale excavation rate is coating. As a result the oil shale operating cost can be reduced up to 10-15%.

7.1.1. Fuel Consumption Influence

The SM average fuel total consumption (for cutting, advance, loading, maneuvers) during the testing period was about 0.63 l/bm^3 or 97 liters per engine hour. In oil shale cost price (SM technology without transportation cost) the fuel modified about 30%.

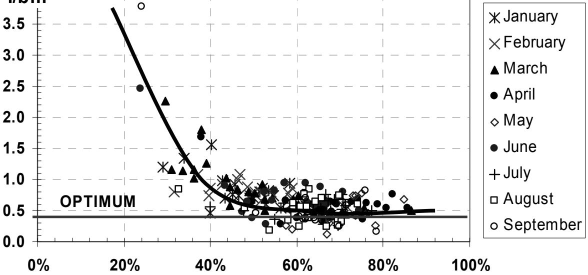


Figure 16. SM Total fuel consumption influence on a percent of cutting effectiveness

It is significant to optimize fuel consumption to minimize SM technological oil shale cost price up to 15%. On the graph (Figure 16) the optimal number (less than 0.45 l/bm^3 line) achieved inside of cutting effectiveness range 60÷80%. The cutting effectiveness is percent of SM working on cutting from total number of engine hours.

7.2. The SM Technology Indirect Effects

Due to the less mineral loss (effect 7%) there are indirect effects like:

a) Lesser reclamation cost per square meter
b) Lesser royalty taxes
c) Lesser overburden operating cost per bm^3 of oil shale
d) Additional income from oil shale looses decreasing

It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. Then additional income can reduce oil shale cost price up to 16-20% and effect will growing with oil shale sale price. The lifetime of "Narva" open pit will increase up to one year.

With oil shale output increasing the overburden removing operating cost decreasing and minimizing oil shale cost price by 25%.

From year to year the royalty taxes increase up to 4% per year in Estonia. On such situation the effect from lesser royalty taxes per excavated oil shale can be from 7% up to 15%. The reclamation cost effect on oil shale cost price decreasing is about 1-2%.

So, the total indirect effect is about 50%. As a result the SM high-selective technology on same level with ripping low-selective technology when 750 bm^3 per shift is achieved (Figure 14).

8. ASPECTS OF RISK MANAGEMENT IN OIL SHALE MINING

This part of thesis deals with risk management problems in Estonian oil shale mines. The result of investigations was supported by the Estonian Science Foundation (Grant ETF 6558) and presented in papers: Paper V and VI. Author of given thesis was actively participated in research of Risk Assessment Methods elaboration and investigations. By this topic was defended one dissertation in Tallinn University of Technology Department of Mining (ISBN 978-9985-59-794-1). "Risk Assessment Methods in Estonian Oil Shale Mining Industry" dissertation was defended by Sergei Sabanov in Power Engineering and Geotechnology on 21 April, 2008.

Investigations are focused on application of the method to determination of the quality of geological data and with risk assessment of a high-selective oil-shale mining technology using surface miner.

In Estonia, oil shales of different quality are used in the power plants to generate electricity and in shale oil processing; however, the different excavation methods and accompanying development processes have various emissions. Oil shale mining can significantly disturb the environment as a result of water and air pollution derived from the different extraction methods. However, waste generation as well as land-use impacts will be of greater concern than emissions to the water and atmosphere. Life Cycle Assessment (LCA) has proved to be one of the most attractive approaches for sustainability of the mining industry, which has used several environmental and economic indicators to assess its performance. The methodology comprises finding the best available way according to environmentally friendly technology [Amman 1999; Callow 1998; DETR 2000; Durucan 2006; Jaber 1999].

The method of technological and environmental assessment of a combination of impacts arising from different mining processes gives an opportunity to find better ways for planning new mines in accordance with environmental performances for oil shale deposit conditions [Sabanov, 2008].

Various factors relevant to mining technology in Estonian oil shale deposit have been determined. For risk estimation, the empirical and judgmental approaches and the event tree were used. They allow determining the probability of the occurrence of geological features and its influence on the mining process. Analysis of obtained results showed that it is necessary to elaborate special methods for determination of the geological conditions in the mining area. The obtained information affords specialists to improve the quality of geological information and consequently the mine work efficiency. The analysis shows that the used method is applicable in conditions of Estonian oil shale industry. The results of the investigation are of particular interest for practical purposes.

8.1. Theoretical Background

In the world, risk management methods are used in different branches of industry and for many different technical systems. In Estonia, including Eesti Energia Mining AS, risk management methods are focused on health safety problems. There is less information about the application of risk management methods to geological conditions and technological processes. In spite of the varied terminology, there is general agreement on the basic requirements [in Paper V: 1, 3, 5, 6]. Terminology and risk management/assessment methodology used in the frame of this project are presented below. Risk can be defined as the likelihood or expected frequency of a specified adverse consequences [in Paper V: 1. 4]. Risk management is the systematic application of management policies, procedures and practices to the task of identifying. Analyzing, assessing, treating and monitoring risk [in Paper V: 1. 3. 4]. Having obtained the risk information, a decision-maker must come to a decision.

8.2. Risk Estimation of Surface Miner Testing Results

Main aspects influencing the efficiency of the SM work concern the duration of the processes and presented in Paper VI. Cutting different layers, track dumper loading (waiting), manoeuvres and maintenance processes are the most important factors. Investigations have shown that duration of the processes influence on productivity. The main quantitative approach used in risk estimation is the event tree method (Calow, P. 1998). This method was selected as the most appropriate one for the risk estimation of the SM. In the first stage of the project time factor was taken into consideration. For probability determination the empirical approach was used (Williams at al. 2004). The event tree indicating the probabilities of the SM processes and spent time. It is possible to select different variants and to determine the probability of one. The event tree allows determining time deviations from average value (in Paper VI: Figure 5). Four different testing phases of the SM were observed. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Application of the fault tree is presented in Table 1, Paper VI. Selected variant of the tests give different value of the probabilities and deviations from the average value. For determination the higher productivity is necessary to give attention on processes with positive value and improve it quality (in Paper VI: Figure 5).

Event tree allow determining suitable variant of different processes for continuous surface miner. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Surface miner higher productivity in testing phase (IV) was achieved on account of 100 % windrowing method. The high cutting performance can be explainable absence of waiting time. This information allows finding adequate decision to improve quality of the processes and avoid negative influence.

9. CONCLUSION

- The requirement for using a more effective extraction method is related to the worsening of mining conditions for oil shale and the increase in environmental taxes. Higher quality (heating value, moisture, grain size) and courser material is required for more effective usage of boilers and generator units in power stations and oil plants.

- For Estonian oil-shale deposit conditions are reasonable to choose machines with down-up cutting method, method with precise cutting depth control and practically proved much lower specific energy consumption than up-down method.

- It is estimated and proved on practical data that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. Its mean, that oil-shale looses on the case of SM technology can be decreased from conventional 12 up to 5 percent that decrease the environmental impact.

- To control optimum cutting regimes and parameters it is possible stabilizing fuel consumption inside the optimum area. In-situ testing shows that energy consumption during the rock cutting can be decreasing up to 45% not only by the means of right cutting tools usage but by the way of thickness to speed ratio (h/V) regulation also.

- Results which will be obtained by presented thesis can result in applications in different industrial sectors. The main applications will of course be found in the surface high-selective mining and road construction sectors. New applications could be seen in zones where rock soils could be transformed into zones with agricultural capacities. To avoid a potential problem of non-utilizable waste in stockpiles of mine areas, selective mining leaves the low-grade ore in mined-out surface areas.

- BAT analyses showed that one of the solutions for increasing oil shale quality (heating value as well as grain distribution) is selective mining. Tests have shown that mechanical cutting is possible, and the size distribution and increasing oil shale quality are possible. In addition to better quality of the product that is related to the higher yield and less dilution, the opposition of society to the mining industry decreases due to its lower impact on the surroundings. The results of the test can be used for redistricting of mining regions and for creating criteria for resource usage and mining impact evaluation.

- For selective mining of commercial oil shale the method of risk analysis was elaborated. Elaborated modified methods using fault tree gives information about the deviation of the processes and possibility determination of suitable variant. Basing on the excellent results of this investigation, it is recommended to use the applied methods for the whole network of transportation from mines and open casts to consumers and in selective mining processes.

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IN MEMORY OF
MATI JOSTOV
WHO GREATLY SUPPORTED SURFACE MINER TESTING IN ESTONIA

KOKKUVÕTE

Eesti põlevkivi tootmise tulevik on tihedalt seotud olemasolevate varudega ning ka rahvusvahelise nafta hinnaga. Põlevkivi tootmise, selle ümbertöötlemise ning kasutamise tehnoloogiad arenevad pidevalt. Et järgida kaasaja keskkonna ja majanduslike nõuete täitmist on vajalik arendada erinevaid BAT tehnoloogilisi lahendusi.
Üha raskemaks muutuvad põlevkivi tootmise tingimused ja karmimaks muutuvad keskkonna nõuded sunnivad tootmisettevõtteid üha rohkem juurutama uusi tootmisalaseid lahendusi. Fookuses on uute kaevise väljamise meetodite väljaarendamine, tänu millele saavutatakse väikseim keskkonna mõju ning saavutatakse toote kõrge kvaliteet. Üheks lahenduseks on kõrgselektiivne väljamine Wirtgen 2500 SM tüüpi freeskombainiga. Freesimine avatud kaevanduse ehk karjäärikombainiga (edaspidi Surface Miner või selle lühend SM) võimaldab väljata põlevkivi ratsionaalsemalt – keskkonnahoiu seisukohalt vähenevad põlevkivi kaod, selektiivne freesimine võimaldab tõsta kaevise kütteväärtust ning see omakorda aitab elektrijaamades tootmisega eralduvate heitmete (SO_2, NO_x, tuhk ja CO_2) mahu viimist vajalike keskkonna normideni. Üha karmistuvad keskkonnanõuded on ka üheks põhjuseks uutele uuringutele, mis keskenduvad erineva kütteväärtusega põlevkivi põletamisele elektrijaamades.

SM kõige olulisemaks eeliseks on kaevise kõrgselektiivse väljamise võimalus. Kõrgselektiivne kaevandamine võimaldab väljata paekivi ja põlevkivi kihindeid eraldi ja täpsemalt. Kui buldooser-kobestiga kaevandamisel läheb lubjakivi-põlevkivi kontaktide näol kadudesse 2…7 cm paksune põlevkivi kiht, siis freesimise korral ligikaudu 1 cm paksune kiht. Praktikas on tõestatud, et täpsem kihindi lõikamine võimaldab tõsta põlevkivi kihindi tootlikkust kuni ühe(1) tonnini ruutmeetrilt. See aga tähendab, et tehnoloogilised kaod võivad väheneda 12-st protsendilt 5 protsendini. Kõrgema kvaliteediga lähtematerjali kasutades, võib saavutada kaevise ümbertöötlemisel põlevkiviõli saagise suurenemist kuni 30% ehk genereeritakse põlevkiviõli kuni ühe(1) barrelini ühest(1)põlevkivi tonnist. Tänu täpsemale kihtide lõikamisele on saavutatav nii majanduslik kui keskkonnahoiualane efekt ka elektrijaamades, sest põlevkivikateldes saab põletada väiksema paekivi sisaldusega põlevkivi. See tõstab omakorda katelde kasutustegurit, kuna hoitakse kokku kuni 30% paekivi lagundamisele kuluvat soojusenergiast. Kõrgselektiivne väljamine võimaldab põletada elektrijaamade uut tüüpi keevkihtkateldes (CFB) rikastamata põlevkivi. Kaasnev positiivne efekt on süsihappegaasi ja tuha koguste vähenemises. Kusjuures õhkupaisatav CO_2 kogus väheneb 20% võrra ja nii ladustatav kui õhkupaisatav tuha kogus kuni 15%.

Käesolevas töös esitas autor avakaevandamiseks sobiva tehnoloogia optimeerimise praktilise versiooni. Majanduslikult kasulik ja keskkonda säästev kaevandamisviis, mis põhineb kõrgselektiivsel väljamisel Wirtgen 2500 SM tüüpi freeskombainiga. Freesimine avatud kaevanduse tingimustes võimaldab väljata põlevkivi ratsionaalsemalt. Autori poolt välja pakutud põlevkivi kaevandamise BAT(parimad võimalikud tehnoloogiad) on praktikas tõestatud karjääris kõrgselektiivse väljamise tehnoloogia näitel. Dissertatsioonis leiab kajastust riskide juhtimine olemasolevate geoloogiliste andmete kvaliteedi hindamiseks.

<u>Dissertatsiooni peamisteks eesmärkideks on:</u>

- Ülevaade põlevkivi kasutamise valdkondadest Eestis
- Riskide juhtimise probleemide analüüs
- Põlevkivi kvaliteedi analüüs, freesimise tehnoloogia mõju keskkonnale, CO_2 püüdmise ja selle talletamise tehnoloogiate ülevaade
- Võimalike freeskombaini tehnoloogiliste väljamise parameetrite analüüs lähtudes kvaliteedist, väljamise faktoritest ja tootlikkusest
- Lõikamise režiimide optimeerimise meetodite väljatöötamine ja nende praktilise kasutamise hindamine faktiliste statistiliste andmete alusel
- Pakkuda tehnoloogilisi ja tehnilisi BAT-teid enam säästva keskkonna kasutusele, millised aitaks teostada määratud eesmärkide saavutamist.

JÄRELDUSED

1. Mitmeaastane nn mehhaniseeritud väljamise kasutamise kogemus näitas buldooser-kobestite kasutamise otstarbekust, kuid kõrgselektiivseks väljamiseks on vajalik suurem lõikamise täpsus.
2. Selektiivse väljamise, kaasaarvatud kõrgselektiivse, lõikesuuna valimine alt-üles võimaldab väljata maavarasid (meie juhul põlevkivi) vajaliku kvaliteedi tagamisega.
3. Pakutud kõrgselektiivne lõikamise protsess võimaldab efektiivsemalt väljata maardlaid, vähendades sellega mõjus keskkonnale.
4. Freeskombaini kõrgselektiivne tehnoloogia pakub suurepäraseid perspektiive seoses müra taseme vähenemisega, vibratsiooni puudumisega ning tolmu heitmete vähenemisega võrreldes traditsiooniliste lõhketöödega.
5. Kontrollides optimaalse lõikamise režiime, võib stabiliseerida kütuse kulu optimaalse tsooni piirides. Katsetused tõestasid lõikamisel kulutatava energia vähenemise võimalust kuni 45 % võrra. Seda saavutatakse mitte ainult õige lõikeinstrumendi kasutamisega, vaid ka kasutades õiget suhet väljatava paksuse ja etteande kiiruse vahel (h/V).
6. BAT-analüüs näitas võimalikke lahendeid kaubapõlevkivi kvaliteedi tõstmise suunas (kütteväärtus ja väljatavate tükisuuruste klassid), peamiseks millistest on kõrgselektiivne väljamine. Lisaks kõrgemale kauba kvaliteedile suureneb õli väljatulek ja väheneb aherdumine, mis

soodustab ühiskonna opositsiooni vähenemist mäetööstuse suunas, tänu negatiivse mõju vähenemisele ümbritsevale keskkonnale.

Läbivaadatud meetodid käsitlevad endas praktilisi soovitusi kaasaegse tootmistehnoloogia paindlikumale juhtimissüsteemile, erinevate lõikamise skeemide ja parameetrite analüüsi ja võrdlust, praktiliste katsetamiste andmete kogumist ja analüüsi, nn BAT optimiseerimisandmete loomist ja arvutusmetoodikat, peamiste tehnoloogiliste parameetrite monitooringut ja arvutust.

Pakutud meetodite adekvaatsus on tõestatud praktiliste katsetustega ja laboratoorsete uurimustega. Analüüs näitas, et pakutud meetoditega saadud andmed on ligilähedased praktikast tulenevatega. Riski hindamiseks kasutati empiirilisi ja subjektiivseid lähenemisi, ning nn sündmuste puud. Niisugune lähenemine võimaldab määrata eriliste geoloogiliste tingimuste ilmnemise tõenäosust ja nende mõju mäetööde teostamisele.

Uurimuse unikaalsus seisneb selle laiendatud kasutuse alas, mis annab võimaluse kasutada väljatöötatud tootmise meetodeid ja skeeme erinevate tootmistingimuste jaoks, eriti kihtmaardlate tingimustes. Töös saadud tulemused võivad huvitada erinevaid tööstusharusid. Peamised kasutusalad oleks kõrgselektiivne tootmine ja tee-ehitus. Uut kasutusala võib leida piirkondades, kus väljatöötatud alasid saaks kujundada ümber põlumajandusaladeks. Et vältida kõrgselektiivse väljamise tehnoloogiliste jäätmete ladustamist, on pakutud madalakvaliteediliste jäätmete ladustamise variandid väljatöötatud alasse. Analüüs näitas, et pakutud riskide juhtimise meetodid on kasutatavad kaasaegses mäetööstuses ja pakuvad ettevõtetele praktilist huvi.

ЗАКЛЮЧЕНИЕ

Будущее Эстонской сланцедобывающей промышленности тесно связано с прошлой и нынешней ситуацией по запасам, а также с международными ценами на нефть. Технологии добычи и переработки непрерывно развиваются, но необходимо дальнейшее развитие BAT технологических решений для соблюдения современных экологических и экономических требований.

Все чаще и чаще условия добычи меняются к худшему и более строгие экологические требования порождают ситуации, когда добывающие компании должны применять новые методы добычи. Необходимо разработать методы отработки, в результаты которых окружающей среде наносится наименьший урон и достигается высокое качество исходного продукта. Одним из таких методов является высокоселективная добыча сланца фрезерным комбайном типа Wirtgen 2500 SM. Surface Miner позволяет добывать сланца рациональнее с экологической точки зрения путем уменьшения потерь, улучшения качества по теплотворной способности, а также помогает электростанциям снизить объемы выбросов и отходов в виде SO_2, NO_x, золы и CO_2 до необходимых экологических норм. Строгие экологические стандарты дали толчок для исследований по использованию сланца с различной теплотой сгорания на электростанциях.

Наиболее перспективным преимуществом SM является высокоселективная добыча. Surface Miner может отрабатывать известняковые и сланцевые слои отдельно и более точно, чем рыхлители (2 ... 7 см), с отклонениями около 1 сантиметра. Практически доказано, что более точная послойная резка позволяет увеличить производительность пласта сланца до 1 тонны на квадратный метр. Это означает, что технологические потери могут быть уменьшены с обычных 12 до 5 процентов. Увеличение выхода сланцевого масла на 30%, до 1 барреля за тонну в процессе перегонки, может быть достигнуто за счет более высокого качества исходного продукта. Тот же принцип действует при сжигании сланца на электростанциях из-за меньшего содержания известняка. Это приводит к более высокому КПД котлов, так как до 30% тепловой энергии экономится на разложение известняка в процессе горения. Положительный эффект, достигается за счет снижения выбросов углекислого газа и отходов золы. Высокоселективная добыча позволяет использовать сланец без дополнительного обогащения для получения электроэнергии на электростанциях в котлах нового типа (CFB), где сжигание происходит в кипящем слое. В связи с этим выбросы CO_2 снижаются на 20% и суммарный выход золы сокращается до 15%.

В данной работе представлена практическая версия оптимизации, как основа для поиска BAT, применение которой практически доказано на примере высокоселективной технологии добычи сланцев карьерным фрезерным комбайном. Диссертация также посвящена проблемам управления рисками и в условиях подземной добычи. Исследования нацелены на применение метода для оценки качества имеющейся геологической информации.

<u>Основными целями диссертации являются:</u>

- Обзор областей использования сланца в Эстонии.
- Анализ проблем управления рисками.
- Анализ качества сланца, влияние технологии фрезерования на окружающую среду, обзор технологий улавливания CO_2 и его хранения.
- Анализ возможных технологических параметров разработки с фрезерным комбайном по качеству, факторам извлечения и производительности.
- Разработка методов оптимизации режимов резания и оценка их практического применения на основе анализа фактических статистических данных.
- Предложить BAT- пути улучшения: технологический, технический и направленный на более бережное природопользование, которые помогли бы справиться с выполнением поставленных целей.

ВЫВОДЫ

1. Опыт многолетнего использования так называемой механизированной выемки, показал целесообразность применения бульдозеров-рыхлителей, однако для высокоселективной выемки требуется высокая точность резания.
2. Селективная выемка, в частности, высокоселективная выемка при выборе направления резания снизу-вверх позволяет отрабатывать полезные ископаемые (в нашем случае сланец), достигая требуемого качества.
3. Предложенный высокоселективный процесс резания, позволяет более эффективно отрабатывать месторождения, уменьшая тем самым влияние на окружающую среду.
4. Высокоселективная технология с фрезерным комбайном предлагает отличные перспективы в связи с сокращением уровня шума, отсутствие вибрации и снижения уровня выбросов пыли *по сравнению с традиционными взрывными работами.*
5. Контролируя выбор оптимальных режимов резания, возможно стабилизировать расход топлива в пределах оптимальной зоны.

Испытания доказали возможность уменьшить потребляемую энергию при резании до 45 процентов. Это достигается не только за счет применения правильного режущего инструмента, но и применяя метод соотношения вынимаемой мощности к скорости подачи при резании.

6. BAT- анализ показал возможные решения на пути увеличения качества товарного сланца (калорийность и выход классов кусковатости), главным из которых является высокоселективная выемка. В дополнение к более высокому качеству товара повышается выход масла и уменьшается разубоживание, что благотворно сказывается на уменьшении оппозиции общества к горной промышленности благодаря меньшему влиянию на окружающую среду.

Рассмотренные методы включают практические рекомендации к современной технологии добычи с гибкой системой управления, анализ и сравнение различных схем и параметров резания, сбор и анализ практических данных испытаний, создание базы данных и разработка метода расчета т.н. BAT оптимизации, мониторинг и расчет основных технологических параметров.

Адекватность предлагаемых методов доказана практическими испытаниями и лабораторными исследованиями. Анализ показал, что полученные методы близки к данным, полученным на практике. Для оценки риска были использованы эмпирические и субъективные подходы, а также т.н. древо событий. Такие подходы позволяют определить вероятность возникновения особенностей геологических условий и их влияние на ведение горных работ.

Уникальность исследования состоит в области применения, что дает возможность использовать разработанные методы и схемы добычи для различных условий добычи, особенно в условиях слоистых месторождений. Результаты, которые получены в диссертации могут представлять интерес в различных отраслях промышленности. Основные области применения, относятся к высокоселективной добыче и строительству дорог. Новое применение можно видеть в районах, где отработанные площади могут быть преобразованы в сельскохозяйственные зоны. Анализ показал, что предложенные методы управления рисками применимы к современной горнодобывающей промышленности, и представляют практический интерес для предприятий.

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USAGE OF ESTONIAN OIL SHALE

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Estonian oil shale has been used for 90 years mainly for electricity and oil generation with the ash being used for cement and light brick production. The oil shale usage has always been related to available mining and processing technology, and vice versa, with external influences of worldwide petroleum prices. The same situation is true today, when new technology is being applied in power generation units, in oil generators and in oil shale extracting processes.

Introduction

There are two oil shale types in Estonia – Dictyonema argillite (claystone) and kukersite. The organic content of Dictyonema argillite is low, varying from 10 to 20%, and it contains up to 9% pyrite.

The argillite in north-eastern Estonia contains heavy metals on a small scale: uranium up to 300 g/t, molybdenum up to 600 g/t and vanadium up to 1200 g/t. From 1949 to 1952, 60 tonnes of uranium were produced in Sillamäe [1, 2]. However, metal content of ore is an order of magnitude less than the content of corresponding ores.

The argillite of north-western Estonia contains less metals and up to 17% organic matter. Attempts to put this kind of Dictyonema argillite to use ended with no success because of its low organic matter and high sulphur content.

The main Estonian oil shale type is kukersite, which is the sedimentary rock of Kukruse stage. It belongs to the lowest Upper Ordovician formation. Kukersite deposits form the Baltic basin of Estonia where Estonian deposits and Tapa occurrences belong (Fig. 1). In Russia there are Leningrad deposits as well as Veimarn and Chudovo-Babino occurrences [3].

The useful component of oil shale is kerogen, the main harmful admixture is pyrite and the useless, or noncombustible, matter (i.e. ballast) consists of lime and clay minerals. There are a total of fifty oil shale layers

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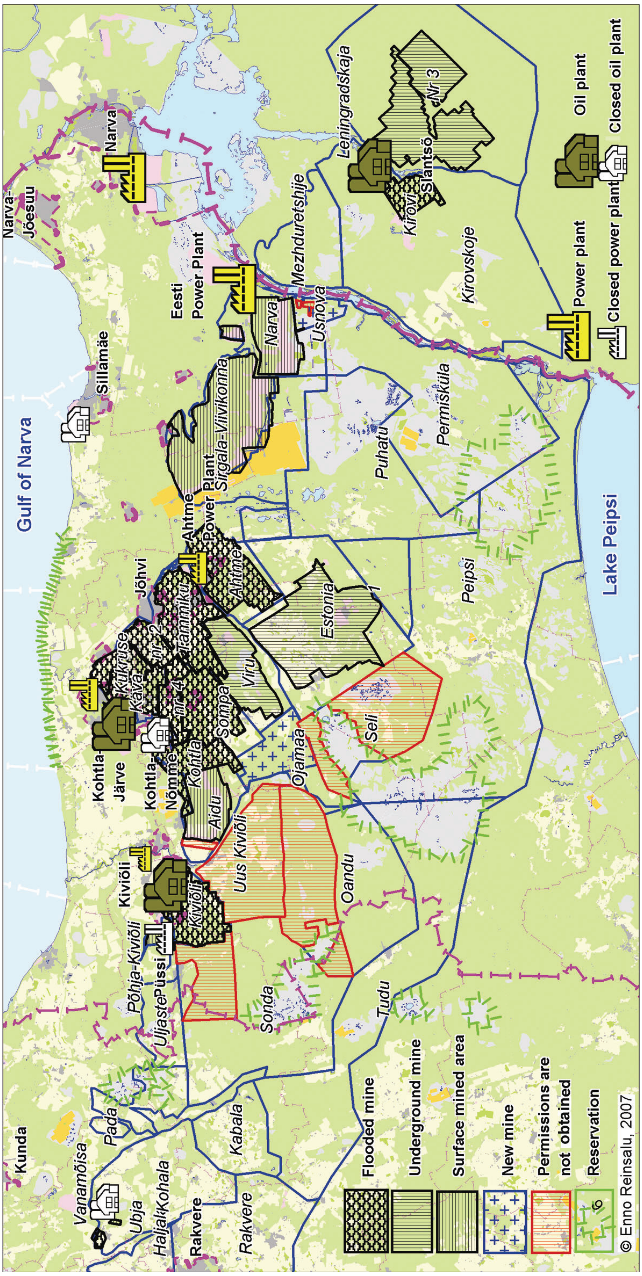

Fig. 1. Estonian and Leningrad oil shale deposits.

in northern Estonia. The lowest layers of Kukruse stage are the most interesting from the mining standpoint. The complex of layers A-F, the thickest in north-eastern Estonia, is called the mineable bed. The mineable bed forms the primary part of the Estonia oil shale deposit. The northern part of the deposit was broken and swept off in ice ages. That is why the layers are thickest on the outcrop. The thickness of the mineable bed in the deposit ranges from 2.5 to 3 m. Run-of-mine (ROM) general production varies from 4.2 to 5.5 t/m^2. At the present moment the cut-off grade is energy productivity, which should be not less than 35 GJ/m^2 [4].

The lowest layers of Kukruse stage are the most interesting from a mining perspective. They are designated with capital letters A-H in Estonia (see Fig. 2). Layers A-F are situated in proximity to each other, being separated by thin limestone interlayers (the latter ones are marked E/F-A/B or have names: D/E – "Roosa paas" (Pink flagstone), C/D – "Valge paas" (White flagstone), A/B – "Sinine paas" (Blue limestone). Some oil shale layers are divided into sublayers (Fig. 2). The lower part of layer F is indicated as F_1, while the upper one is marked F_2. The upper part of layer A in the central and western part of the Estonia deposit is differentiated by A/A'.

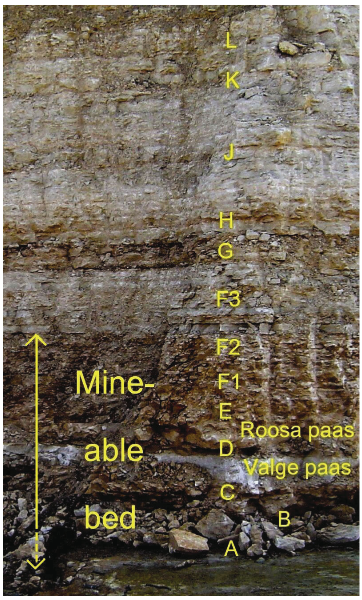

Fig. 2. Upper part of mineable bed and overlying rock in Põhja-Kiviõli opencast.

The upper bed, which is about half a meter thick and consists of two oil shale layers G and H and a limestone interlayer G/H, rests on the mineable bed. General production from the upper bed is approximately 1 t/m^2 and its energy content is 6.5 GJ/m^2. According to present economic considerations, the upper bed is not mineable, because of an intercomplex layer that is about 1 meter thick and which is between the upper bed and the mineable bed. Extraction of the intercomplex would lower ROM calorific value. That is why the upper bed is not extracted in underground mining [4, 5]. It would be possible in surface mining, when using high-selection extraction. Since layers G and H are not considered mineable, they have not been investigated much geologically. These layers contain little concretions, that is why their calorific value in the deposit is homogeneous, and the mineability of the upper bed depends on the thickness of oil shale layers H and G [6–9]. The mineable and upper beds are the thickest in the central part of the Estonia deposit, to the south of the towns of Jõhvi and Kohtla-Järve. The greater part of this reserve is already extracted.

The higher oil shale layers (marked I – P) are thin, with low (less than 20%) or sometimes average (20–30%) organic matter content. These oil shale layers are separated from each other with thick limestone layers. The upper layers are thickest in the western part of the Estonia deposit, to the south of the town of Rakvere (Fig. 1). The layers situated even higher than layer P are marked with Roman numerals I–VII. Layer III, with average organic matter content, is rich in concretions and has a thickness of 1.6 m. It forms the Tapa oil shale occurrence. This oil shale bedding is at a depth of 60 to 170 m under Pandivere uplands. Pursuant to mining conditions existing in the former Soviet Union, the oil shale was mineable in this area, but now it is not.

Layers A, B and E of the mineable bed are the richest in organic matter, while A' and F are the poorest. As for organic matter content, layer H in the upper bed can be compared to layer B, and layer G – to layer D. Limestone interlayers B/C and C/D are kerogenic limestone, while A/B and D/E are clay-like limestone. Kerogen content of oil shale can be up to 60%. Such oil shale can be found as pure seams in the best oil shale layers A, B and E (Table 1).

Oil shale reserve calculations are done according to layers, though only layers A, D and evidently H consist of pure oil shale. Other layers contain, on a bigger or smaller scale, limestone concretions with kerogen content averaging 8%. The quality of oil shale layers varies indirectly depending on the abundance of concretions – the more concretions, the lower is the energy content of the layer.

The quality of oil shale is evaluated according to several characteristics. The main index in Estonia and Russia is calorific value (Q, MJ/kg) which shows the thermal energy obtained from burning a mass unit. This correlates with kerogen content. However, oil (tar) yield (T, %) is more widely known in the world. It is defined in a lab using a Fischer retort, and the oil amount obtained from a mass unit in the process of low temperature carbonization of oil shale is correlated to it. All quality characteristics are defined for dry oil shale – that is why moisture content is another important index for the quality of the product. The moisture content of commercial oil shale can vary from 8 to 14%. Working calorific value is used for calculations in sales deals, which unites the calorific value of dry oil shale and the moisture content of commercial oil shale into one parameter. The third quality index is grain size, which classifies oil shale in millimeters.

Table 1. **Main parameters of oil shale mineable bed**

Matter	Index of layers	Calorific value, *Q*		Kerogen content, *K*		Volume weight of non-combustible matter, d_m	Constant c according to units *Q* or *K*:			Volume weight, *d*
		kcal/kg	GJ/t	t / t	%	t/m^3	kg/kcal	t/GJ	t/1	t/m^3
Oil shale, pure, without concretions	F_2	1600	6.7	0.19	19	2.55	0.000304	0.07262	2.56	1.72
	F_1	2750	11.5	0.33	33	2.43	0.0002	0.0533	1.88	1.51
	E	4200	17.5	0.50	50	2.41	0.0002	0.0499	1.76	1.28
	D	2264	9.4	0.27	27	2.16	0.0002	0.0389	1.37	1.59
	C	3400	14.2	0.40	40	2.42	0.0002	0.0523	1.84	1.38
	B	4600	19.2	0.54	54	2.40	0.0002	0.0492	1.73	1.22
	A'	1792	7.5	0.21	21	1.70	0.0001	0.0251	0.88	1.42
	A	3628	15.1	0.43	43	2.16	0.0002	0.0389	1.37	1.37
Limestone concretion in layers	F, E, C, B	700	2.9	0.08	8	2.38	0.0002	0.0456	1.61	2.10
Interlayers, kerogenic limestone	E/F, D/E, B/C, A/A'									
Interlayer - flagstone "Valge paas"	C/D	150	0.6	0.02	2	2.53	0.0002	0.0504	1.77	2.45
Interlayer - flagstone "Sinine paas"	A/B	300	1.3	0.04	4	2.38	0.0002	0.0456	1.61	2.25

Composition of oil shale

Oil shale consists of three components:

- Organic matter or kerogen
- Calcareous material (lime minerals) manifested as calcite and, on a lesser scale, dolomite
- Terragenous matter, or clay minerals, which consists of quartz, hydromica, feldspars et al.

The higher is the content of kerogen, the lower is the content of carbon dioxide and ash (Fig. 3) [10]. The calorific value and oil yield of oil shale are proportional to kerogen content. As kerogen's calorific value is 35±3 MJ/kg, so oil shale calorific value formula is

$$Q = 35\ K,\ \text{MJ/kg}$$

where K is kerogen fraction (100% = 1), and its oil yield formula is

$$T = 65.5\ K = 1.86\ Q\ \%.$$

When doing energy productivity calculations, one has to be aware that the calcareous components of fuel and oil raw material absorb heat in the process of decomposition, thus the actual calorific value of oil shale as ROM is lower than calculated. Dry volume weight of oil shale depends on the ratio of kerogen, lime and clay minerals and can be calculated as follows [10]:

$$d = d_m / (c\ Q + 1)\ \text{t/m}^3$$

where Q – calorific value of oil shale with concretions or ROM, d_m – volume weight of noncombustible part, i.e. clay and lime minerals in oil shale.

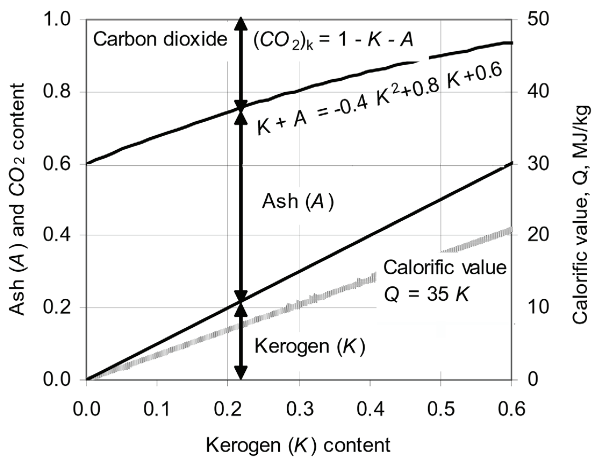

Fig. 3. Dependence between oil shale components and organic matter (kerogen) content.

Table 2. **Ojamaa mining field ROM quality sheet**

Block: Ojamaa 1
Layers: A…F_{lower}

Geological data						Run-off-mine, dry									Run-off-mine, natural					
Layer, seam		Extrac-tion rate	Thickness natural, m	extraxt., m	heigth, m	Calorific value, kcal/kg	MJ/kg GJ/t	Fischer oli, %	Org. matter, %	Volum weight, t/m^3	Mass product., t/m^2	Oil product., t/m^2	Org. product., t/m^2	Energy product., GJ/m^2	Moisture content, %	Calorific value, kcal/kg	MJ/kg GJ/t	Volum weight, t/m^3	Mass product., t/m^2	Energy product., GJ/m^2
Topsoil		0	0	0.00			0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.000	1.3	0	0.00	2.39	0.00	0.000
Morain		0	2	0.00			0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.000	1.3	0	0.00	2.39	0.00	0.000
Rock		0	25.00	0.00			0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.000	1.3	0	0.00	2.39	0.00	0.000
Upper	H	0	*0.20*	0.00		*2000*	8.4	15.0	22.5	1.74	0.00	0.00	0.00	0.00	10.2	*1589*	6.65	1.94	0.00	0.00
bed (not	H/G	0	*0.20*	0.00		*0*	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
mineable)	G	0	*0.15*	0.00		*4500*	18.8	33.8	50.6	1.34	0.00	0.00	0.00	0.00	9.9	*3716*	15.56	1.49	0.00	0.00
	G/F_3	0	*0.10*	0.00		*0*	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
	F_3	0	*0.3*	0.00		*1100*	4.6	8.3	12.4	1.97	0.00	0.00	0.00	0.00	7.2	*876*	3.67	2.13	0.00	0.00
Inter-	$F_3/F_{1\text{-}2}$	0	0.13	0.00		*600*	2.5	4.5	6.7	2.14	0.00	0.00	0.00	0.00	4.8	*600*	2.51	2.24	0.00	0.00
bed	$F_{1\text{-}2}$	0	0.18	0.00		*1100*	4.6	8.3	12.4	1.97	0.00	0.00	0.00	0.00	7.2	*876*	3.67	2.13	0.00	0.00
	Draw roof	0	0.17	0.00		*600*	2.5	4.5	6.7	2.14	0.00	0.00	0.00	0.00	4.8	*600*	2.51	2.24	0.00	0.00
	F_{upper}	0	0.23	0.00		1197	5.0	9.0	13.4	1.95	0.00	0.00	0.00	0.00	7.6	954	4.00	2.11	0.00	0.00
	F_{lower}	1	0.38	0.38	2.6	2340	9.8	17.6	26.3	1.67	0.63	0.11	0.17	6.20	10.9	1857	7.78	1.87	0.71	5.52
	F/E	1	0.00	0.00	2.2	0	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
	E	1	0.44	0.44	2.2	2896	12.1	21.7	32.5	1.56	0.69	0.15	0.22	8.32	11.6	2302	9.64	1.76	0.78	7.48
	E/D	1	0.00	0.00	1.8	0	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
Mine-	D	1	0.00	0.00	1.8	0	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
able	D/C	1	0.20	0.20	1.8	596	2.5	4.5	6.7	2.14	0.43	0.02	0.03	1.07	4.8	596	2.49	2.24	0.45	1.12
bed	C	1	0.57	0.57	1.6	2926	12.2	22.0	32.9	1.56	0.89	0.19	0.29	10.86	11.6	2327	9.74	1.76	1.00	9.76
	C/B	1	0.11	0.11	1.0	778	3.3	5.8	8.7	2.08	0.23	0.01	0.02	0.74	5.7	778	3.26	2.20	0.24	0.79
	B	1	0.54	0.54	0.9	4340	18.2	32.6	48.8	1.36	0.73	0.24	0.36	13.31	10.3	3562	14.91	1.51	0.82	12.18
	B/A	1	0.14	0.14	0.4	365	1.5	2.7	4.1	2.22	0.31	0.01	0.01	0.47	3.5	365	1.53	2.30	0.32	0.49
	A'	1	0.09	0.09	0.2	1927	8.1	14.5	21.7	1.76	0.16	0.02	0.03	1.27	10.0	1532	6.41	1.95	0.18	1.13
	A'/A	1	0.02	0.02	0.2	602	2.5	4.5	6.8	2.13	0.04	0.00	0.00	0.11	4.8	602	2.52	2.24	0.04	0.11
	A	1	0.13	0.13	0.1	3610	15.1	27.1	40.6	1.45	0.19	0.05	0.08	2.85	11.5	2900	12.14	1.64	0.21	2.58
Bottom		0	1.00	0.00	0.0	0	0.0	0.0	0.0	2.36	0.00	0.00	0.00	0.00	1.3	0	0.00	2.39	0.00	0.00
Sum/ average			5.28	2.62	2.62	2515	10.5	18.9	28.3	1.64	4.29	0.81	1.21	45.20	9.6	2070	8.66	1.81	4.75	41.17
				m	m	kcal/kg	MJ/kg	%	%	t/m^3	t/m^2	t/m^2	t/m^2	GJ/m^2	%	kcal/kg	MJ/kg	t/m^3	t/m^2	GJ/m^2

italic - extrapolated geological data

The density of oil shale varies from 1.22 to 1.72 t/m^3, and interlayer densities, accompanying oil shale, vary from 2.1 to 2.45 t/m^3. Moisture adds weight to commercial oil shale because it fills the pores both in the rock and in the dust on the rock surface and even between them. That is why the density of natural oil shale increases with the occurrence of moisture.

Calculations of reserves for the Ojamaa mining field blocks are presented in Table 2, based on these rules and quality data of all layers and interlayers.

Oil shale mining

Industrial use of Estonian oil shale began after World War I. Two mining areas – Kohtla-Järve and Ubja-Vanamõisa – were developed in three years in Virumaa County. The oil shale in Kohtla area was better and a bigger oil shale industry center formed there. There are over twenty mining areas in Estonia, including opencasts and underground mines, where oil shale was, or has been, extracted. Currently six mines and opencasts are in operation (Table 3).

Mining technology

Surface mining technology used in the Aidu and Narva opencast mines, operated by *AS Eesti Põlevkivi*, developed after World War II when stripping with relatively big bucket (10–35 m^3) excavators, mainly draglines, started to be used. Both the overburden and the bed are at first broken up by blasting. Stripping is done with smaller excavators in opencasts with thin overburden using front end loaders and hydraulic excavators. The overburden is transported with front end loaders and trucks.

Bulk extraction of all beds (layers A-F) is performed only in the Aidu opencast where a separation plant is in operation. The Narva opencast uses selective extraction in three layers of seams. The upper (layers E-F) and the lower (layers B-C) seams are extracted as ROM, the middle seam (interlayers C/D-E/F) is shoved or dozed into the mined-out area. If the bed is broken mechanically, with ripper dozers, the oil shale can be extracted selectively and more completely taking layers A and D into ROM, which were lost in partial selective extraction. Highly selective extraction was started in 2006 in Põhja-Kiviõli opencast of *Kiviõli keemiatööstus*, using milling cutter surface miner from the German Company *Wirtgen*. And in 2007, the Narva opencast mine of *Eesti Põlevkivi* started highly selective extraction as well [9].

ROM was loaded into vehicles with front shovel excavators till the end of the 90s. In the 90s front end loaders were put into use. ROM is transported with trucks of up to 40 tonne payload capacity. It is delivered to consumers by railway, highway trucks and dump trucks. The surface mining is finished by reclamation of the mined out area.

Table 3. **Oil shale mines in Estonia in year 2007**

Enterprise, Mine	Approximate annual output, Mt	Started
AS Eesti Põlevkivi (state owned mining company):		
Viru mine with separating plant	2	1964
Narva opencast	5	1970
Estonia mine with separating plant	5	1972
Aidu opencast with separating plant	2	1974
OÜ VKG Aidu Oil Ojamaa mine	Preparation phase	2006
AS Kiviõli Keemiatööstus Põhja-Kiviõli open cast	1	2003
AS Kunda Nordic Tsement Ubja open cast	0.3	2005
Total	15–16	

Underground mining technology evolved in the 60's when room and pillar mining was put to use. The main characteristics are as follows:

- Blocks of rooms, formed by a number of small (up to 10 m long) working faces
- The roof and the mined out land are supported with pillars of unextracted oil shale (averaging 25% of the reserve)
- The ground does not subside
- The direct immediate roof of the rooms is anchored to the upper rock layers.

Longwall mining has also been used, where the bed was mined with a coal cutting shearer-loader [11]. The roof was temporarily supported by hydraulic support. When mining with the shearer, layers A-C were extracted, so in reality it was selective extraction. This mining method was more productive but much more capital-intensive and the changes in land surface were noticeable. These were the reasons for abandoning longwall mining in the 90's.

Separating oil shale

Oil shale ROM dressing was put into use and it has been used up to now mainly for the benefit of the shale oil processing industry. The present day technology of oil processing (vertical retort) can use only oil shale lumps of size 25–125 mm, because the processed raw material must have sufficient gas permeability to ensure the separation process in the retort. Oil shale is separated in dressing plants out of big ROM (>25 mm) pieces. This takes place in heavy medium where pieces of limestone interlayer lumps and concretions of ROM sink, and oil shale floats on the surface (Fig. 4.). The fine oil shale, sifted out of ROM before dressing separation, goes to power plants. The limestone separated from ROM, i.e. waste, which is approximately 40% of ROM ore, is suitable for production of low-quality crushed aggregate used in building construction, but most of it goes into waste dumps as this market is too small.

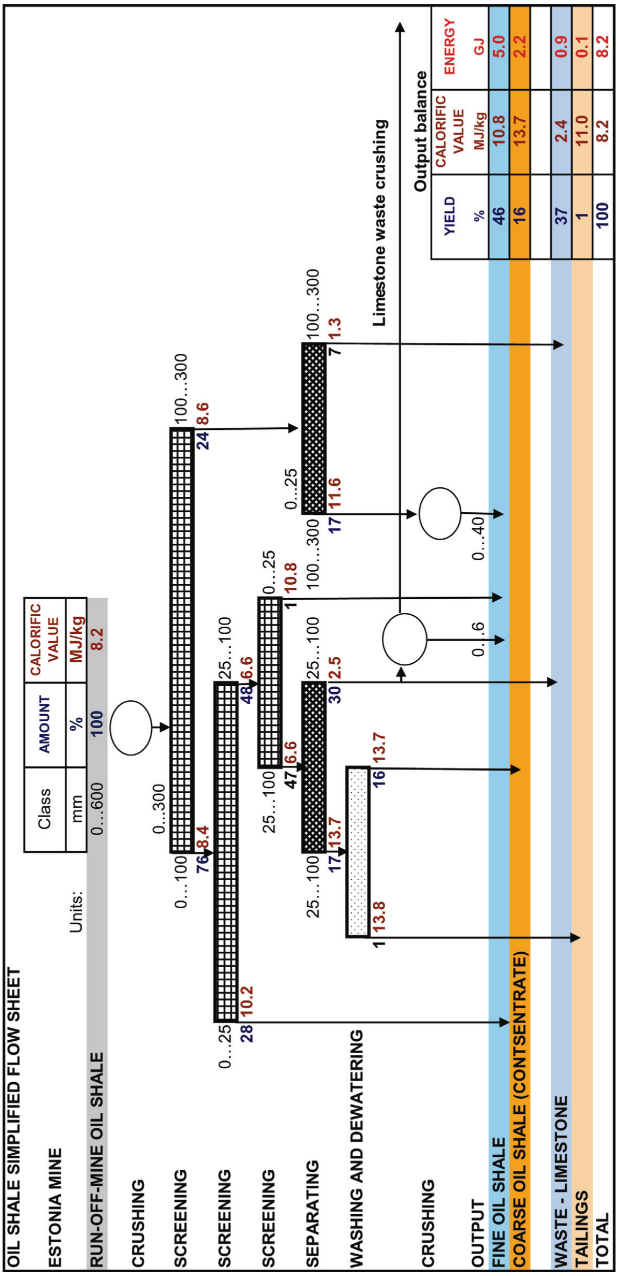

Fig. 4. Oil shale separation sheet, Estonia mine.

Oil shale processing

Oil production

In the early years oil shale was used as a solid fuel for steam locomotives and heat plants. The development of the oil shale industry started due to changes in the conventional petroleum industry. Until World War II the main uses of oil shale were for the oil and chemical industries, processing 60% of mined oil shale. Oil gave 8% of Estonia's export income [12, 13]. After WW II the conventional petroleum industry developed. At the end of the last century the importance of oil production decreased since oil prices were low and oil production in Russia increased. In the seventies the interest for oil had increased for a while in connection with the Arab oil embargo. The same reason has developed today for oil shale processing interest in Estonia [14–16], due to the recent rise in international oil prices.

Several oil and gas production technologies have been developed, tested and used (Table 4).

The main product of the chamber retort was gas. The produced oil was a by-product. Although it was a valuable chemical product, the yield of oil was low. The low yield of oil from fusion-retort was caused by the low organic content of oil shale in the mining area of Vanamõisa. The simplest and most proven units are vertical generators where processing is carried out with an internal energy source of blowing hot gas from the generation chamber. At the same time, vertical generators have the lowest yield of oil.

Table 4. **Oil production technologies in Estonia**

Process, name versions	User	Years	Processed mill tonnes	Average oil yield, %
Pintsch's generator or Vertical retort or Kiviter process	First Estonian oil shale Industry, *Eesti Esimene põlevkivitööstus* (in Estonian) ⇒ *VKG – Viru Keemia Grup*p	1921…	80.3	16
	A/Ü Kiviõli ⇒ Kiviõli Keemiatööstuse OÜ	1953…	14.0	
Horizontal retort or Fusion retort	Vanamõisa Oil Plant	1923–1931	0.004	16
Davidson's retort	Kohtla Oil Plant	1931–1961	1.4	19
Tunnel oven	Kohtla-Järve Oil Shale Processing Plant	1955–1968	2.7	21
	A/Ü Kiviõli	1929–1975	14.4	
	Sillamäe Oil Plant	1928–1941	0.8	
Chamber retort	Kohtla-Järve Oil Shale Processing Plant	1947–1987	55.9	5
Solid heat carrier (SHC) or Galoter process	*Kiviõli Keemiatööstuse OÜ*	1953–1981 2006…	2.2	13
	Eesti Power Plant	1980…	7.7	
Amount		since 2002	179.3	13

The Davidson and Fusion-retort and tunnel oven and chamber retorts that used external heating produced higher yield, but required more repair, handling and workload. In SHC generators, oil shale is heated by the ash/mineral residue from heating. At first SHC units required too much service and repair and had short equipment lifetimes. The reason was mainly low construction quality, low quality of fabrication materials and low levels of automation. Today most of these disadvantages have been corrected. Units that were more commonly used – vertical retorts and tunnel and chamber retorts – required material that is called lump oil shale. This material provided enough permeability for gas movement. Pelletized fine oil shale was tested in generators in Sillamäe but these tests were not successful.

Oil shale separation is costly. For that reason lump oil shale has been sold to oil production plants at a cost that is below its actual production cost. The oil industry has been subsidized by the power industry [17, 18]. This guaranteed that the oil production industry did not vanish already 40 years ago. Already at that time it was a goal to find technology that would be capable of using unprocessed oil shale. The most successful approach has been the SHC unit. Due to the fact that this technology is complicated, the development has not been totally successful enough in the beginning of the free market economy period. An important obstacle for SHC development has been the attitude of academic society in Estonia.

Tests of underground oil extraction were performed in the Kiviõli mine in a block measuring 25×75 m. The better-quality oil shale was brought to the surface but low-quality oil shale was set into piles and ignited. Air was pumped into and gas out of the mine. The oil shale bed was only 12 m deep, and most of the gas came out from cracks in the ground. Water flowed into the mine from side pillars and from the surface; this absorbed heat. This method did not prove itself because of the work load, low yield and environmental impact. The last test block was prepared but not ignited and was abandoned in the sixties.

Power production

Estonian heating and power stations started to use oil shale in the 1920's. The first oil shale power plant with a capacity of 3.7 MW was built in Püssi. After WW II Tallinn and Kohtla-Järve power plants were renovated. Ahtme power plant was started in 1951. New plants were equipped with powder units that were capable of burning fine oil shale. During this period the development of the oil shale industry was driven by Russian interests in north-eastern Estonia. Two large power plants were constructed close to Narva, both capable of burning oil shale with high mineral content. For supplying these power plants, the Viivikonna surface mine was reconstructed and the Sirgala and Narva surface mines were opened. For the same reason the Viru and Estonia mines were opened, the Aidu surface mine was opened, and the Tam-miku and Ahtme mines were reconstructed. Separation plants were built in the new and reconstructed mines and in the Aidu surface mine that allowed finishing handmining techniques and handsorting and started high production levels for power plants and oil factories.

Oil shale development decreased when the nuclear power industry developed. Until the accident at the Tshernobyl Nuclear Power Plant, it had been planned to shut down the large Estonian power plants by the end of the millennium. Only the Püssi plant was actually closed.

Oil shale-based construction materials

The first building material industry segment that started using oil shale was the cement industry. The content of oil shale ash is similar (clay minerals) to the raw material of cement. The feedstock for Portland cement that was made from oil shale ash came from flyash that had been collected in electrostatic flue gas cleaners at the power plants. Light brick products from flyash and sand heated in autoclaves became popular. The waste rock from oil shale separation units has constantly been used as a building material. Due to the low resistance to freezing and the occurrence of micro-fractures from blasting this aggregate is suitable only for road or construction site ballast material. Lately (since 2006) oil shale wasterock has become beneficial due to road construction activity and limitations to limestone mining, crushing and sorting. The main method of beneficiation is crushing the softer part of oil shale, i.e. organic material, and screening it out.

Conclusions

The future of oil shale mining is closely related to the past and current situation in Estonian deposits and international oil prices. Mining and processing technology has been continuously developed but further development is required for meeting environmental and economic requirements.

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Surface Miner technology impact on the Environment

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Abstract

More and more conditions of mining are changing for the worse and more strict environmental requirements engender situation where mining companies have to apply new methods of mining. Methods in the result of which environment would be threatened as little as possible and high quality products could be got. One of such methods is high selective mining of oil shale by surface milling cutter Wirtgen 2500 SM.

Surface Miner 2500 SM allows to mine oil shale environmentally sustainable, to reduce losses, to improve oil shale calorific value as well as helps Power Stations to decrease the volumes of SO2, NOx, ash and CO2 by environmental requirements.

Keywords

Surface mining, Wirtgen 2500 SM, oil shale mining, high-selective mining

Introduction

The Estonian oil shale deposit stretches from the Russian border at the Narva River 130 km west along the Gulf of Finland. Oil shale is a yellowish-brown, relatively soft sedimentary rock of low density that contains a significant amount of organic matter and carbonate fossils. The thickness of the oil shale seam, without partings, ranges between 1.7 m and 2.3 m. The compressive strength is 20 MPa to 40 MPa compared to 40 MPa to 80 MPa for limestone. The density of oil shale is between 1.4 g/cm3 and 1.8 g/cm3 and that of limestone is between 2.2 g/cm3 and 2.6 g/cm3. The calorific value of oil shale deposit is fairly consistent across the deposit.

There is a slight decrease in quality from the north to the south, and from the west to the east across the area.

Oil-shale resources of Estonia are state-owned and lie in the Estonian deposit which is of national importance. State has issued mining licenses to the mines and pitches allowing them to perform mining works. About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Power stations can burn oil shale with net calorific values of around 2.050 kcal/kg or 8.4 MJ/kg. Net calorific values of oil shale used for retorting and chemical processing must be approximately 2.700 kcal/kg or 11.4 MJ/kg.

Mining conditions are degreasing continuously, therefore new technologies must take in use to increase output materials quality, to protect environment and to make mining more effective. One effective way is to use high selective mining method, such as mining with Surface Miner.

2. Technology overview

2.1. Current technology

Draglines are used for overburden removal (1) (Figure 1). After the overburden is drilled and blasted (2), stripping equipment excavates the overburden from the oil shale and handles it in the previous mined-out strip (3). The roof of the oil shale is first cleared by dozers to minimize dilution. The oil shale is then ripped by large dozers and loaded into trucks by shovel for transportation to the crusher stations located at the surface facilities. After crushing, the oil shale is loaded into railway cars and shipped to the Estonia Power Plant [4].

2.2. New technology

Surface Miner breaks, crushes and loads material in one operation. Productive oil shale seams and limestone interbeds are extracted layer by layer, oil shale is loaded directly to the dump trucks or is handled on to the extracting seam and then is loaded by bucket loaders into the dump trucks (Figure 2). Further, trucks to the Power Plant transport oil shale. Barren rock is removed by Surface Miner directly to the pit heap or is handled on to the limestone layer and then is rehandled by bulldozer or bucket loader into pit heap.

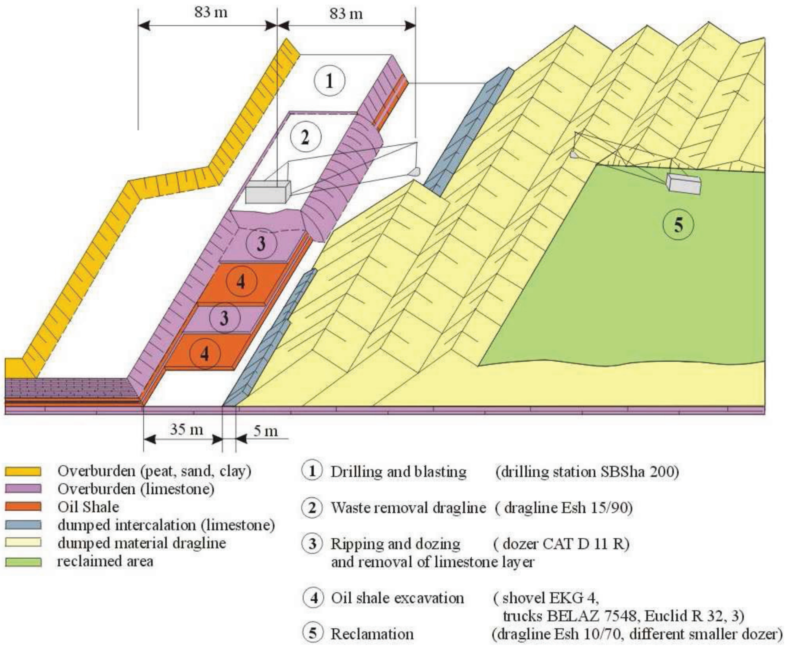

Figure 1. Schematic mining scheme

Figure 2. Surface miner loading technologies: windrowing (A) and direct truck loading (B)

3. Surface mining technology advantages compared with current technology

Mining process carried out by Surface Miner is changed considerably in comparison with current technology. Number of the machines required for extraction of mineral resources is reduced. In addition to SM, bulldozers are used for overburden removal and dump trucks for extracted material transportation. Seismic vibrations available in blasting are absent during SM mining. Dust is emitted in minimum during cutting and loading, noise does not disturb. The SM has got high productivity (Wirtgen 2500 SM more than 1 million ton of oil shale per year), that reduces mining process impact on the environment and shortens duration of mining. Quick and comparatively noiseless and dustless mining gives possibility to extract mineral resources next to the settlements and to reclaim mined areas in acceptable way for population.

There are some opened and partially opened mine fields at the present mineral deposit (Ubja, North-Kiviõli, Kohtla-Vanaküla, Kose-Tammiku). They are situated next to the populated areas where oil shale of a bit lower quality deposits under thin overburden and allows to use high-selective extraction.

3.1.Decreasing losses

The most perspective advantage of SM is high-selective mining. Surface Miner can cut limestone and oil-shale seams separately and more exactly than rippers (2…7 cm) with deviations about one centimeter. It is estimated that precise cutting enables Surface Miner to increase the output of oil shale up to 1 ton per square meter. It means, that oil-shale looses in case of SM technology can be decreased from conventional 12 up to 5 percent.

The oil yield increase by 30%, up to 1 barrel per tone during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning at Power Plants because of less limestone content in oil shale. It results to higher efficiency of boilers, because up to 30% of energy is wasted for limestone decompose during the burning process. Positive effect would result in lower carbon dioxide and ash emissions.

4. Oil shale quality, environmental impact, CO2 capture and storage technologies

Stratified structure of oil shale seam specifies that content and properties of the fuel supplied to the Power Plants largely depend upon the conditions of oil shale mining and enrichment. Limestone interbeds attending to saleable oil shale are the decisive factor. Estonian Power Plants are trying to upgrade calorific value of oil shale used as well as to reduce content of ash and CO2.

More and more strict environmental requirements produce new challenges to Power Plants to reduce emissions discharged into the environment. The main requirements for Power Plants are as follows:

- ash vehicles reconstruction should be executed by 16 July, 2009.
- overall limit amount of SO_2 emitted by the oil shale burning plants should be about 25 000 t/per year since the 1st of January, 2012.
- ash disposal should be carried out according to Landfill Directive by January,1st, 2013.
- all boilers should meet the requirements of LCP Directive by January,1st, 2016.

This gave an impetus to Power Plants to research oil shale use of different calorific values.

One of the possible alternative solutions for Power Plants is to research usage of oil shale of 10.5 MJ/kg or 11.5 MJ/kg calorific value. Alternative capacity in electric power generation of a new complex is 2x300 MW or 2x400 MW and calorific value of oil shale used at EEJ (block of fluidized bed) and at shale oil plant (TSK-140) is 8.5, 10.5 or 11.5 MJ/kg.

When using oil shale of the above mentioned calorific value in the blocks of fluidized bed sulphur dioxide (SO2) emissions into atmosphere are very small. They make up some percent from 25 000 ton. In the mode of pulverized burning emissions of SO2 of four blocks make up maximum 13 000 ton. In addition to this it is necessary to install NOx equipment by 2016.

During burning carbon dioxide (CO2) is emitted into atmosphere too. During oil shale burning in addition to CO2 emerging from carbon burning there is surplus amount of CO2 arising from limestone decomposition. Under conditions where prices for CO2 quotas are high it is necessary to actuate all possibilities for CO2 reduction. Emitted CO2 has to be caught and stored.

In the world roughly 60% of the CO2 emissions takes place at large stationary source, such as electric power plants, refineries, gas processing plants and industrial plants. In the majority of these processes, the exhaust flue gas contains diluted CO2 (5% to 15%) One options is to separate the CO2 from other gases. Another option is to remove the carbon before combustion, as in the case where hydrogen and CO2 are produced from natural gas (CH4).

Captured CO2 can be either stored or reused (e.g. resource for producing soft drinks or in greenhouses to help plant growth). Because the market for CO2 reuse in currently limited, the majority of CO2 extracted needs to be stored. CO2 can be stored in geologic formations (including depleted gas reservoirs, deep saline aquifers and unminable coal seams). CO2 can also be fixed in the form of minerals

In Estonian there are two ways of storage CO2. One is open-cast, ash field storage and another is open-cast storage or underground back filling.

I version: CO2 open-cast, ash field storage

Ash and minimal quantity of water is bumped into tank, which is next to pot. Ash and water are mixed and then CO2 is carried into the mixture. Unnecessary CO2 is lead to chimney. Dry pulp form mixture is transported to open-cast or ash fields.

II version: CO2 open-cast storage or underground back filling

Ash and water is bumped into tank, which is next to pot. Ash and water are mixed and then CO2 is carried into the mixture. Unnecessary CO2 is lead to chimney. As appropriate pulp and CO2 mixture is transported to open pit, ash field or underground mine. When pulp and CO2 mixture is transported to mine, then tails are added and the mixture becomes petrify fill. In such case it is possible to make new pillars in the mine and to extract more oil shale from pillars.

5. Conclusions

Mining conditions changing for the worse more and more make a claim for new and environment-friendly mining technologies. High selective mining by Surface Miner 2500 is one of such possibilities. Surface Miner 2500 allows to mine oil shale close to the towns and populated areas quickly and with small disturbance, to mine oil shale without blasting, to restore mined areas with suitable microrelief, to get higher productivity, to produce oil shale of higher quality. Calorific value of the raw material remains in the range of 8.4-11.4 MJ/kg. Surface Miner 2500 allows to use extracted oil shale without preparation and to generate electric energy in new fluidized bed boilers. Because of that emissions of CO_2 are reduced by 20 % and ash amount is reduced up to 15 %.

Strict environmental standards gave an impetus to Power Plants to research oil shale use of different calorific value. Alternative solution is to study oil shale use of 10.5 or 11.5 MJ/kg.

Use of oil shale of that calorific value in fluidized bed blocks and pulverized burning boilers keeps sulphur dioxide (SO_2) content in the permitted limits of 25 000 ton. In addition to that NO_x emissions into the air should be reduced by 2016.

More and more attention is turned to decrease CO_2 problems and to work out new solutions.
In Estonian there are two ways of storage CO_2. One is open-cast, ash field storage and another is open-cast storage or underground back filling.

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ANALYSIS OF OIL SHALE HIGH-SELECTIVE MINING WITH SURFACE MINER WIRTGEN 2500SM IN ESTONIA

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Surface miners (further SM) can find their natural applications in projects where drilling and blasting is prohibited or where high-selective mining of mineral seams required. Selective mining improves the quality of oil shale. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower. The present paper introduces a highly selective oil-shale mining technology and results of an analysis on cutting and quality parameters. Size distribution and calorific value of oil shale is in dependence on cutting thickness and cutting (advance) speed. It is possible to achieve required average size of mined oil-shale particles, which was confirmed by the present investigation data. The information obtained enables specialists to improve the quality of mining works by means of fuel consumption optimisation.

Introduction

Estonia is currently an independent energy producer due to existing of oil-shale deposit and favourable mining and processing conditions. At present Estonia is the only Baltic state, with its own oil shale resources used as fuel by local independent energy producers. Situation in energy market of Estonia will be changed in the nearest future, especially after deregulation of regional energy from 2013. Situation in energy market is changing day by day, there is a great pressure for "green" energy using, which is subsidised

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by the government. In the nearest future (from 2013) the energy market of Estonia will be deregulated and it will affect local energy market greatly. Therefore every oil-shale producer should think today how to be successful in the future.

Due to environmental restrictions and social pressure, testing of high-productive and environmentally friendly high-selective mining is needed for successful continuation of independent energy supply (oil shale) for an EU state country, Estonia. New flexible and powerful mining technology – the best available technology (BAT) – will guarantee independence of Estonian energy sector [1]. Development of mining machinery and mining technology by the way of high- selective mining will improve environmental situation in the Baltic Sea region and Europe. Effect can be achieved in decreasing CO_2 pollution, ash pollution and water pollution.

Selective mining and especially high-selective mining enhances the possibility to mine out mineral with needed quality. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower, which was proved by offered methods.

The methods include theoretical and practical research of proposed modern mining technology. The main aims are analysis and comparison of different cutting schemes and parameters, collecting and interpretation of actual technological data, creating a database and elaboration of calculation and optimisation methods, monitoring and analysis of main technological parameters. The adequacy of the proposed methods is proved by the in-situ tests and laboratory investigations.

One of the major parameters in cost prise of extracted oil shale is fuel consumption. In oil shale cost price (SM technology without transportation cost) the fuel makes up about 30%. It is important to optimize fuel consumption for minimizing SM technological oil shale cost price to 15%.

The analysis is focused on two main factors that greatly affect on quality and price cost of oil shale: cutting tools and fuel consumption.

Advantages of continuous surface miners (SM)

There are some perspective advantages of continuous surface miners today. The most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2–7 cm) with deviations about one centimeter. It is estimated that due to precise cutting surface miner enables to increase the output of oil shale up to 1 tonne per square meter. It means that oil-shale losses in the case of SM technology can be decreased from conventional 12 to 5 percent. The oil yield increases by 30%, up to 1 barrel per tonne during oil shale retorting, thanks to better oil shale quality [3]. The same principle holds for oil shale burning in power plants because of less limestone in oil shale. It results in higher efficiency of boilers, because up to 30% of energy is wasted for limestone decomposition during the burning process. The positive effect would result in emissions of lower carbon dioxide and ash [2, 3].

Another perspective of surface miner would be apparent in places with a relatively small overburden thickness (less than 10 m) and near the towns where the removal of hard overburden with SM should be considered instead of overburden blasting [4]. In these cases SM would "cut" considerably operating costs of stripping and offers the possibility to mine out reserves near densely populated areas.

High-selective mining with Wirtgen 2500 SM

The Wirtgen 2500 SM design with a mid-located cutting drum (diameter 1.4 m, cutting width 2.5 m) was expected to be more promising for hard rock (80–110 MPa) applications than the front-end designs. Here, the whole weight of the machine (100 t) is available for the penetration process, and only a smaller torque resulting from the cutting process (cutting depth up to 0.6 m) has to be counterbalanced [5]. Besides, the surface miner with middle drum concept moves during the winning process. Due to this great moving mass, much more dynamic mass forces can be applied than during the movement of a small mass of the cutting organ mounted on a boom.

Analysis of cutting tools

One of the most important issues is the cutting tool. The selection of a right cutting tool is essential for good cutting performance & high life, since it constitute a major share of operation cost of the machine. Evaluation of oil shale breakability and cutting direction importance for Estonian oil shale deposit was performed by a method developed by A. A. Skotchinsky Institute of Mining Engineering (St Petersburg, Russia) in the 1970–1980-s. For this purpose over a hundred samples produced by cutting of oil shale and limestone, as well as taken in mines by mechanical cutting of oil shale were analyzed. The *in-situ* testing of different drums for longwall mining shearers was held at "Tammiku" mine from August 30 to September 30, 1982 [12]. One of the main results of tests was the conclusion that the number of cutting bits increasing from one to two pieces per cutting line brings about a decrease in specific energy consumption by 44%.

To check in practice the data received in 1982 regarding a modern surface miner, from 2007 to 2009 two milling drums were tested, with one and two cutting bits per cutting line. During the year 2007, there were more than 5000 engine operating hours (mh) with the first drum and during the year 2008 about 4000 mh with the second drum.

For the first milling drum equipped with WSM-19, the average consumption of cutting tools was 2.5 picks per 1000 bulk cubic metres (bm^3) of rock mass. For the second drum equipped with WSM-22 CP (Plasma coated) this number was 2.4 times less and equal to 1.03 picks per 1000 bm^3. In oil shale cost price (SM technology without transportation cost) the cutting tools made up about 3.5% for first and 1.9% for the second drum. But the decrease in energy consumption (fuel) varied from 3% up to 45% and was not stable. To understand the influence of other factors, analysis of size distribution of oil-shale particles for different cutting layers and parameters was held at Narva open cast.

Oil shale size distribution *versus* thickness-to-speed ratio

The Wirtgen 2500 SM surface miner was delivered to AS Eesti Energia Kaevandused (former AS Eesti Põlevkivi) at the end of 2006. The testing of SM began at "Narva" oil shale open pit. The test place "Narva" is located approx. 200 km north-east of Tallinn near the town of Sillamäe in the north-eastern part of Estonia (N59 15; E27 44). The fractional analysis of crushed oil shale was made from 16.04.2008 to 20.06.2008 for a drum with two cutting lines. During the testing period more than 7000 kilograms of mined rock from different layers (Table 1) were analysed. At the same time monitoring of parameters of cutting such as (advance) speed of cutting (V, m/min) and thickness of cutting (h, m) was made. It is important to mention that all calorific values are shown as "wet" (natural, mined-out condition).

The SM testing has shown that size distribution and calorific value of oil shale depend on cutting thickness and cutting (advance) speed [5]. It is possible to achieve the required average size of mined oil-shale particles, as proved the present investigation data, as well.

The oil shale geotechnological data for the test area are given in Table 1.

Table 1. **Oil shale geotechnological data for the test area, calorific values of "wet" shale**

Layer No	Layer index	Geol. thickness, m	Volume density, t/m3	Layer productivity, t/m2	Calorific value, MJ/kg	Cutting nr.	Cutting thickness, m	Cutting speed, m/min
14 13	F2 F1	0.28 0.41	2.07 1.79	0.58 0.73	2.49 5.88	I-EF	0.55	8.2
11	E	0.52	1.58	0.82	9.28	II-EF	0.40	10.0

10	E/D	0.07	2.14	0.15	1.72	III-EF	0.40	9.7
9	D	0.07	1.85	0.13	4.95			
8	D/C	0.23	2.41	–	0.00	4-limestone	0.25	9.5
7	C	0.39	1.52	0.59	10.60	IV-CB	0.55	9.8
6	C/B	0.21	2.02	0.42	2.88			
5	B	0.39	1.33	0.52	16.04	V-CB	0.45	10.0
4	B/A	0.18	2.37	–	0.00	5-limestone	0.20	9.5
3	A'	0.1	1.79	0.18	5.90	VI-AA	0.25	8.1
2	A'/A	0.01	1.97	0.02	0.00			
1	A	0.13	1.42	0.18	11.88			
Total	∑ or AVG	3.0	1.9	4.3	7,72	8	3.0-3.05	9.4

Test results

The results of testing and size distribution of oil-shale particles for different layers are presented on Figures 1 and 2. On size-distribution lines there are values of average particle size (X_{50}) measured in practice marked with white rings. The range of X_{50} varies from 40–50 mm for the complexes EF and CB to 80 mm for the complex AA. The graphs in Fig. 1 show that cuttings I-EF and III-EF do not guarantee high calorific value of oil shale. Oil shale grade depends on the size of extracted oil shale, which, in turn, is closely related to energy (fuel) consumption and, on the other hand, to cutting speed and oil shale quality [6] (see Fig. 2, Table 2).

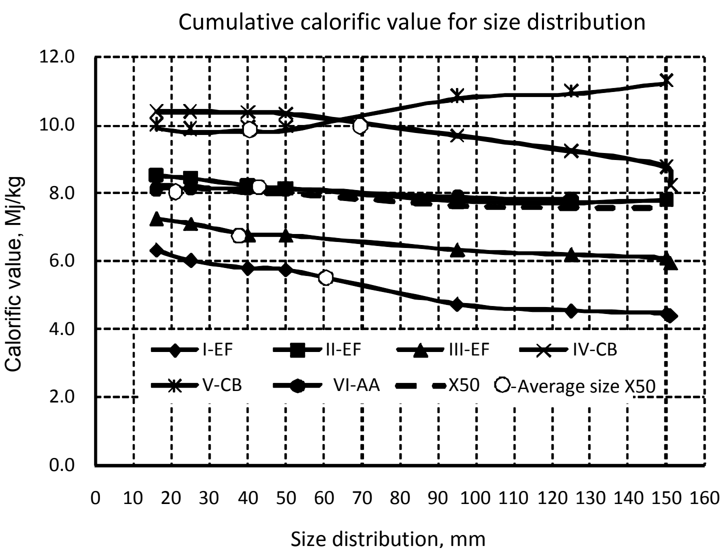


Fig. 1. Cumulative calorific value (“wet”) for oil-shale layers *vs*. size distribution.

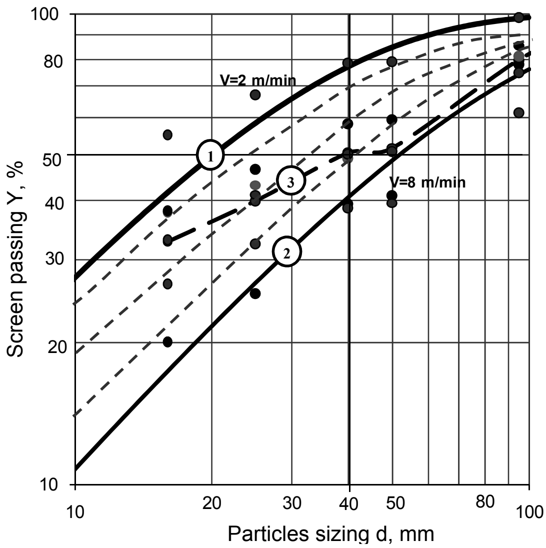


Fig. 2. Oil-shale size distribution at different values of cutting speed where ① – cutting in oil-shale complex AA ($V = 2$ m/min, $h = 0.22$ m); ② – cutting in oil-shale complex CB or EF ($V = 8$ m/min, $h = 0.55$ m) and C/D (0.25 m); ③ – distribution of average-size particles at cutting of all oil shale layers.

Table 2. **Testing of cutting different oil-shale layers**

Layer to cut	Thickness to speed ratio, h/V, %	Output of 50-mm particles, X_{50mm}, %	Output of average-size particles, $X_{50\%}$, mm	Specific energy consumption, kWh/bm^3
I-EF	6.9	41	62	0.21
II-EF	4.5	51	40	0.21
III-EF	4.0	59	28	0.23
IV-CB	5.5	40	70	0.17
V-CB	4.0	51	40	0.23
VI-AA	3.1	79	15	0.45

Surface miner testing results presented in Table 2 show that the data for specific energy consumption are similar, but at the same time average particle size varies greatly.

The conventional method (specific energy consumption *vs* output of average-size particles) gives a logical result but no correct answer as for the reasons. It is logical that increasing average particle size requires less energy for cutting. In other words, such parameters like cutting thickness and advance rate per cutting (cutting advance speed) influence particle size of the output (see Fig. 2, Table 2).

The relationship between cutting thickness (*h*), cutting speed (*V*) and average particle size (X_{50}) can help to find optimal cutting parameters for regulating oil shale quality [6, 7]. Analysis of different cutting speeds and thicknesses for each oil-shale layer shows a good correlation between thickness-to-speed ratio (*h*/*V*) and particle output X_{50} (see Fig. 3B).

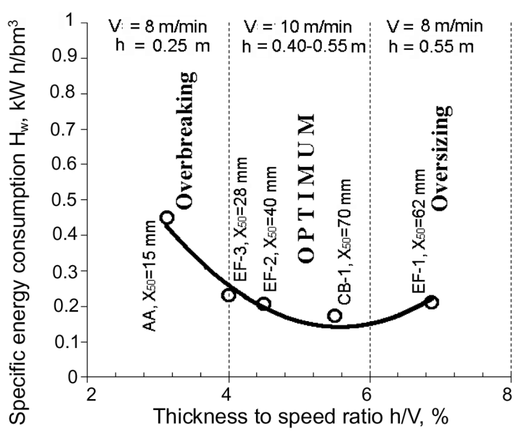
The dependence between specific energy consumption and thickness-to-speed ratio for three basic cases (graph A in Fig. 3) shows that at rock cutting overbreaking and oversizing zones that are characterized by greater energy consumption and the optimum area typically lies between these two zones.

The example of oversizing situation is presented in Fig. 4. The right photo shows large-particle rock between the crawlers as a result of thickness-to-speed ratio. In this case depth of cutting was $h = 0.55$ m and advance rate $V = 8$ m/min, $h/V = 6.9\%$. It is proved in practice that at $h/V > 6\%$ cutted rock remains oversized.

In such cases we need much more energy to crush big lumps, and as a result fuel consumption is not effective.

To control optimum cutting regimes and parameters it is possible to stabilize fuel consumption inside the optimum area. In-situ testing shows that energy consumption during rock cutting can be decreased to 45% not only by the means of the use of right cutting tools but by the regulation of thickness-to-speed ratio (*h*/*V*) as well.

A



B

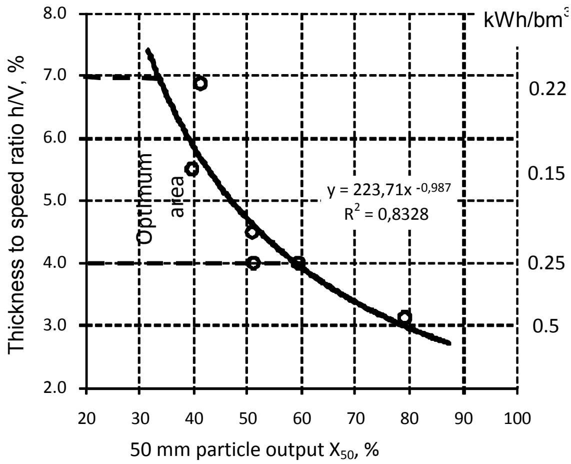


Fig. 3. Dependence of specific energy consumption on thickness-to-speed ratio (A). Dependence of specific consumption (right axis) and thickness-to-speed ratio (left axis) on 0–50 mm particle output (B).

Fig. 4. Effect of cutted rock oversizing in case *h*/*V* ratio >6%.

Conclusions

The distribution of the summarized calorific values determined during the tests do not contradict with the earlier tests for drum with one cutting bit per cutting line, made by Mining Institute of Tallinn University of Technology, (contract Lep7038AK with Eesti Energia AS) [8]. Results obtained by these tests can result in applications in different industrial sectors. The main applications will of course be found in the surface high-selective mining and road construction. New applications could be seen in zones where rock soils could be transformed into soils for agricultural use.

Analyses of Estonian energy systems have shown that higher quality of the fuel in power stations could lower high CO_2 emissions and at the same time increase effectiveness of power or oil units [9]. This goal can be achieved by decreasing CO_2, ash and water pollution through the regulation of quality of oil shale by highly selective mining methods [10, 11].

There are a couple of direct and indirect effects which reduce oil shale cost prise. Various factors relevant to oil shale technology have been determined [12]. The optimisation of cutting parameters is one possible way.

Analysis of the results shows that the used thickness-to-speed ratio method is applicable in Estonian oil shale industry. The obtained information enables specialists to improve the quality of mining works.

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The Surface Miner Sustainable Oil-shale Mining Technology Testing Results in Estonia

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Abstract: The paper introduces a high-selective oil-shale mining technology and the first 9 months of surface miner (SM) Wirtgen SM2500 testing results at "Narva" open-pit in Estonia. The technology allows to decrease oil-shale loses from 10-15% up to 5-7% on in-situ conditions. Mining process of the surface miner has a lower disturbing impact, which is topical in open pits and quarries especially in densely populated areas. The low level of dust and noise emissions and also very low vibration are arguments to mine oil shale with surface miner instead of drilling-blasting operations.

Keywords*:* *Wirtgen 2500SM; surface miner; high-selective mining; rock breakability; mineral loss*

Introduction

Oil-shale resources of Estonia are state-owned and lie in the Estonian deposit, which is of national importance. State has issued licenses to the mines and pitches allowing them to perform mining works, and marked out the portion of the bowels of the earth or the earth allotment. In essence, this allotment is the field that the enterprise has to excavate fully during its lifetime. Terms and requirements for mining are provided in the mining permit and also in lots of legal acts the objects of which are mainly environment, labour safety and health protection.

Down to the depth of 30 m and at places covered with forests and bogs, opencast mining is preferred for economic motives, e.g. relatively cheaper and quicker preparations for production; introduction of highly productive machinery and improved efficiency as a result; safer and healthier working conditions than in mines. That's why opencast pitches were taken into use 30-40 years ago on the territory between Püssi and Kohtla. At present, Narva Pitch Ltd. and Aidu Pitch Ltd. are still in operation. Opencast mining gives about half of the total oil-shale production of Estonia.

In the central part of the oil-shale deposit of Estonia, south of Kohtla-Järve and Jõhvi, where the density of population is higher and oil-shale lies deeper, only underground mining has been performed. During the history of oil-shale mining, 8 mines have been fully exhausted. Estonia Mine Ltd. and Viru Mine Ltd. have the necessary oil-shale resources for underground mining.

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For more than eighty years oil shale has been mined in Estonia. During that period about 950 million t from estimated four billion tonnes reserves have been extracted. About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Mining sector faces challenges to increase the output of mines and to minimize the environmental impact of mining at the same time.

Continuous mining and milling techniques for the hard rock industry are up to now limited through the hardness of rock material. The application limits for the future technique will be placed above the limits of bucket wheel excavating systems with a diggability of normal up to 10 MPa of uniaxial compressive strength (UCS). This can be expanded with special designed excavators for frozen hard coal or soft limestone [1]. Horizontal and vertical ripping techniques are currently used for materials up to 50 MPa UCS, sometimes combined with in-pit crushing systems.

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 (SM) was used for limestone mining from 1989 to 1991. From the recent tests for oil shale mining in 2004 and 2006 with MANTAKRAF and Wirtgen surface miners and the Vermeer terrain leveller (T1255) is testing on limestone quarry from the end of August 2007 [2].

Technology Overview

Current technology: low-selective mining

Surface mining is carried out in open casts with maximum overburden thickness of 30 m. Draglines with 90 m boom length and 15m^3 bucket sizes are used for overburden removal. Hard overburden consists of limestone layers and is blasted before excavation. Oil shale layers are blasted as well or broken by ripping (low-selective mining). Disadvantage of ripping is excessive crushing of oil shale by bulldozer crawlers. Excavated rock is transported with 32-42 or 55 tonnes trucks (Belaz and Euclid) to the processing or crushing plant depending on opencast (Figure 1).

Surface Miner Wirtgen 2500SM: high-selective mining

Continuous surface miner, which are designed to cut softer rock materials like sandstone, clay, bauxite, hard coal, phosphate, gypsum and marl are operating between 10 MPa and 70 MPa compressive strength. Nowadays, road cutting machines are working materials up to 100-110 MPa compressive strength. The very recent developments show that there is a need for investigations to enlarge the mentioned application limits.

The Wirtgen 2500SM design with a mid-located cutting drum (diameter 1.4m, cutting width 2.5m) was expected to be more promising for hard rock (80-110 MPa) applications than the front-end designs. Here, the whole weight of the machine (100 t) is available for the penetration process and only a smaller torque resulting from the cutting process (cutting depth up to 0.6m) has to be counterbalanced. Besides, the surface miner with middle drum concept moves during the winning process. Due to this great moved mass, much more dynamic mass forces are possible than during the movement of the small mass of the cutting organ mounted on a boom.

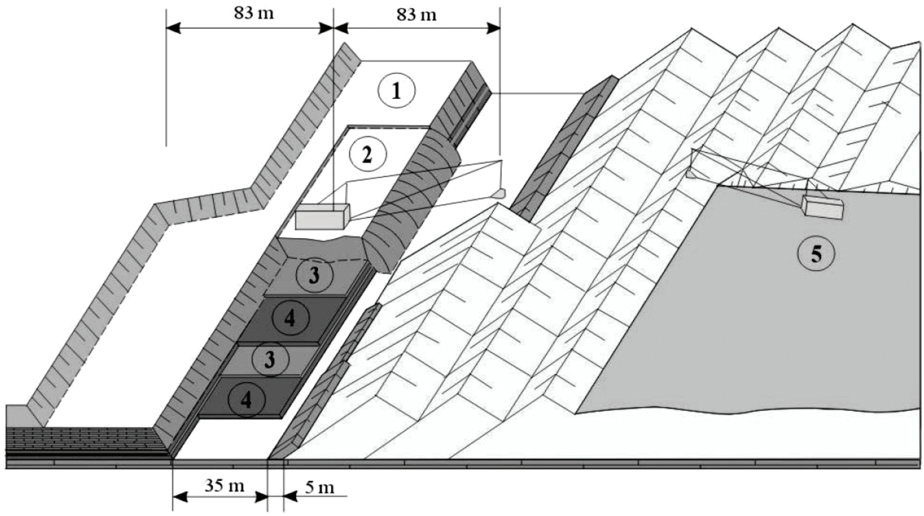
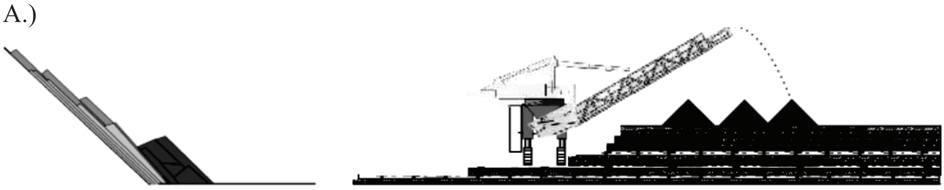


Figure1. Schematic mining scheme of the oil shale excavation

Note: ①–Drilling and blasting; ②–Waste removal dragline (ESh 15/90); ③–Ripping and dozing (dozer CAT D 11 R); ③+④–Oil shale excavation (shovel EKG 4, trucks BELAZ or Euclid R32); ⑤–Reclamation (dragline ESh 10/70, different smaller dozer)

Modifications and development work for the tested SM focused mainly on the corresponding cutting drums (number of cutting lines) and specifications of the cutting tools, different loading technologies (windrowing or direct truck loading) also (Figure 2 A, B).

A.)



B.)

Figure 2. Different loading technologies: windrowing (A.) and direct truck loading with Wirtgen 2500SM (B.)

Perspective Advantages of Surface Miner Technology

Surface miners can find their natural applications in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Besides they offer further advantages as for example:

- Less mineral loss and dilution.
- Improved mineral recovery especially in areas sensitive to blasting.
- Less stress and strain on trucks due to minimum impact of the excavated material.
- Primary crushing and fragmentation of mineral rock.
- Reduced capacity requirements for preparation plants.

The most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2-7 cm) with deviations about one centimeter. It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. Its mean, that oil-shale looses on the case of SM technology can be decreased from conventional 12 up to 5 percent (Table 1).

Table1. Comparison data of Ripping and SM oil-shale technological looses

Layer nr.	Layer index	Geol. Thickness	t/m3	t/m2	Mj/kg	Cutting nr.	Looses Wirtgen, m	Looses Wirtgen, t/m2	Looses Ripping, m	Looses Ripping, t/m2
14	F2	0,21	2,07	0,4347	3,46	1				
13	F1	0,38	1,73	0,6574	8,50		0	0	0	0
11	E	0,52	1,59	0,8268	11,32	2	0	0	0	0
10	E/D	0,07	2,12	0,1484	2,82	3	0	0	0	0
9	D	0,07	1,81	0,1267	7,09		0,02	0,04	0,05	0,09
8	D/C	0,24	2,37		0,36	4	0,01	0,01	-	-
7	C	0,48	1,54	0,7392	12,71	5	0,02	0,03	0,06	0,09
6	C/B	0,18	2	0,36	4,20	6	0	0	0	0
5	B	0,43	1,32	0,5676	20,23	7	0,02	0,03	0,06	0,08
4	B/A	0,18	2,36		0,45	8	0,01	0,01	-	-
3	A'	0,1	1,65	0,165	10,01		0,02	0,03	0,06	0,10
2	A'/A	0,01	1,97	0,0197	4,60	9	0	0	0	0
1	A	0,13	1,42	0,1846	16,01		0,02	0,03	0,05	0,07
Total		3,0	1,8	4,23	10,6		0,11	0,20	0,28	0,52
Looses Total							5 %		12 %	
Effect Total							7 %			

The thickest and harder limestone seam "C/D" (60-80 MPa) has sufficient quality to produce aggregate for road building and concrete. Separately extracted limestone (C/D and A'/B) can be left directly in mine, which reduces haul costs and increase run-out oil shale heating value without additional processing.

The oil yield increase by 30%, up to 1 barrel per tone during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning in power plants because of less limestone containing in oil shale. Its results higher efficiency of boilers, because up to 30% of energy is wasted for limestone decompose during the burning process. Positive effect would result in lower carbon dioxide and ash emissions [2].
Another perspective of surface miner would apparent in places with relative small overburden thickness (less than 10 m) and near the towns where the removal of hard overburden with SM should be considered as well instead of overburden blasting. On these cases the SM would "cut" considerably operating costs of stripping and possibility mine out reserves near the densely populated areas.

"Narva" Open-pit Test Results

The Wirtgen 2500SM surface miner was delivered to AS Eesti Põlevkivi at the end of 2006. The testing of SM was beginning at "Narva" oil-shale open pit. The test place "Narva" is located approx. 200 km north-east of Tallinn near the city of Sillamae in the north-eastern part of Estonia (N59 15; E27 44). The SM testing was held from 01.01.2007 to 30.09.2007 and was divided onto winter and summer periods. The machine was operated in two or three-shift systems.

Shift-hours distribution

During the first, so-called winter-period (01.01-31.03.2007), 1248 total operating hours from 1808 available shift-hours the SM with 18% of windrowing method was applied. During the second summer-period (01.04-30.09.2007) 2882 total operating hours from 3608 available (windrowing 30%) and during the all periods (01.01-30.09.2007) 4130 from 5416 available shift-hours the SM with about 26% of windrowing method was applied. The real cutting time was 41 and 48 from available shift-hours for the two first periods correspondingly. For the while period this number is about 46%, where on average during the shift-time 33% SM operated on oil-shale layers and 13% on limestone (layers C/D and B/A). The Figure 3 illustrate the shift-hours distribution graphics for the while testing period.

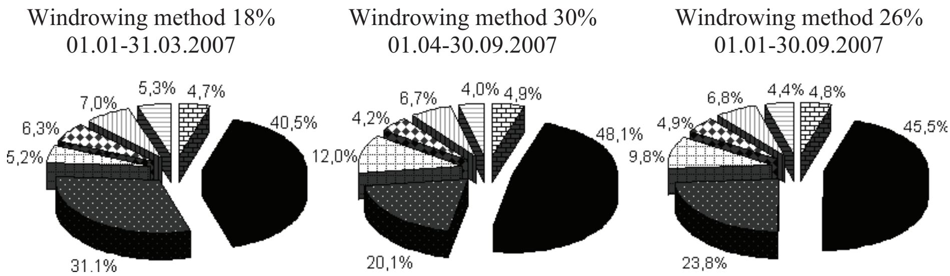


Figure3. Shift-hours distribution graphics for three testing periods

Where, – repairing; – real cutting; – other downtimes; – manoeuvres; – pick replacement/control; – maintenance; – refueling.

During the first period registered “other downtimes” is about 31% for the next periods this number about 20%. The percent of “other downtimes” (from 20% up to 30% on average) include about 7% of time looses for trucks exchanging, about 6% for SM upper conveyor manoeuvres, then about 6% for spade-work (SM controlling before and after the shift) and up to 10% time looses due to the ground water problems.

Rock Breakability Results

To be able to transfer the achieved results to other rock mines, it is necessary to identify the SM and cutting rock parameters responsible for the breakability factor of a deposit. The development of such a generalised classification system is therefore an important objective of the project as well.

Concentratibility and trade oil shale grade depend on sizing extracted oil shale, which, in its turn, is closely related to energy consumption and the selected method of oil shale breaking. Applying statistical distribution according to Weibull, the function of size distribution of oil-shale particles may be assumed as follows:

$$W = 1 - \exp[-(d/d_0)^m] \quad (1)$$

where $d_0 = d_{0.63}$ is diameter of screen opening to pass 63.2% of broken oil shale; m is breakability factor.

The results from sieving analysis made for limestone and oil-shale layers show that for “Narva” open pit test site conditions breakability factor $m = 1.1$. Hence, the share of oil shale δ passing the 25 × 25-mm screen in the total mine-run shale equals to

$$\delta_{-25} = d_{-25} = 1 - \exp[-(25/d_{0.63})^{1.1}] \quad (2)$$

where, $d_{0.63} = 0.333\sigma + 3.6Vt\sigma/\pi nz$ for SM up-cutting direction; V is cutting speed; t is cutting step; n is drum rotation ratio; z is number of cutting lines on drum (z=1 for previous tests); σ is uniaxial compressive strength of rock.

Cutting tools consumption

Estonian oil-shale bed consists from oil-shale and limestone seams with different thickness and compressive strength. Oil shale is relatively soft rock with UCS 15-40 MPa but limestone is 40-80 MPa. There are also places near the karsts zones with 100-120 MPa compressive strength. During the cutting process the loads in cutting tools vary greatly due to the differences in rock physical and mechanical parameters, which lead increased loading of the cutting drum.

The cutting tools average consumption is 2.3 picks per 1000 bm^3 of rock mass (about 16% is limestone). In oil shale cost price (SM technology without transportation cost) the cutting tools modified about 3.5 %, that not a big number.

The SM direct and indirect effects influence on oil shale cost price

During two technologies comparison it is very important to take into account available indirect effects influence on rock (oil shale) cost price.

From the graph on Figure 4 it is seen that in SM cutting performance range 1100-1200 bm^3 per shift of rock mass (available if containing not more than 20% of limestone with 2.4 t/m^3) the SM high-selective technology on same level with Ripping low-selective technology.

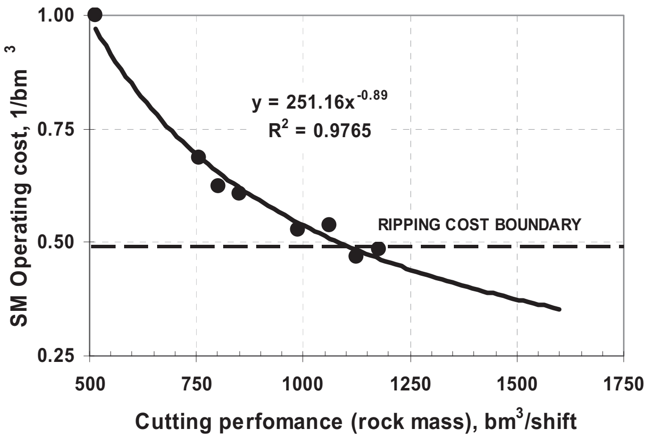


Figure 4. The SM operating cost direct dependence on cutting performance per shift

The SM technology direct effects

Loading method influence

Analysis has shown that by direct truck loading method, truck-waiting downtime decrease real cutting time by 1.0-1.5 hour per shift and average cutting speed by 20-25%. On a Figure 4 below dependence of SM cutting performance on windrowing percentage is presented.

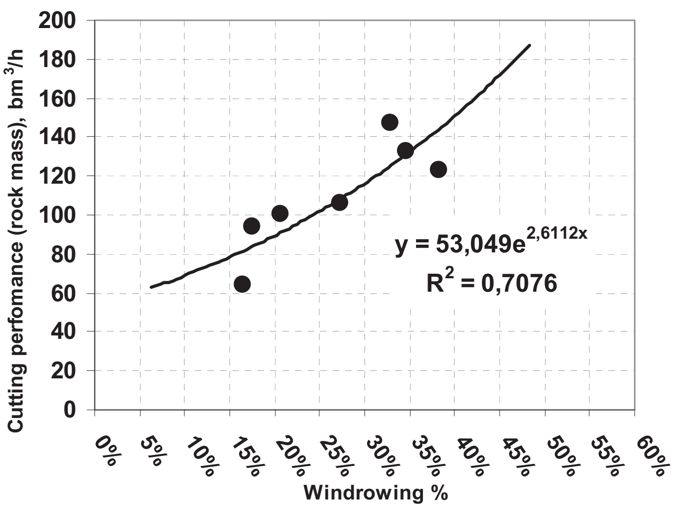


Figure 5. Dependence of SM cutting performance on windrowing percentage

As you can see from the graph (Figure 5), there is a great SM productivity potential when windrowing percent is growing. The additional LHD-machine operating and SM depreciation costs greater oil-shale excavation rate is coating. As a result the oil shale operating cost can be reduced up to 10-15%.

Fuel consumption influence

The average fuel consumption during the testing period was about 0.63 l/bm^3 or 97 liters per engine hour. In oil shale cost price (SM technology without transportation cost) the fuel modified about 30%. It is significant to optimize fuel consumption to minimize SM technological oil shale cost price up to 15%. On the graph (Figure 6) the optimal number 0.45 l/bm^3 achieved inside of cutting effectiveness range 60÷80%. The cutting effectiveness is percent of SM working on cutting from total number of engine hours.

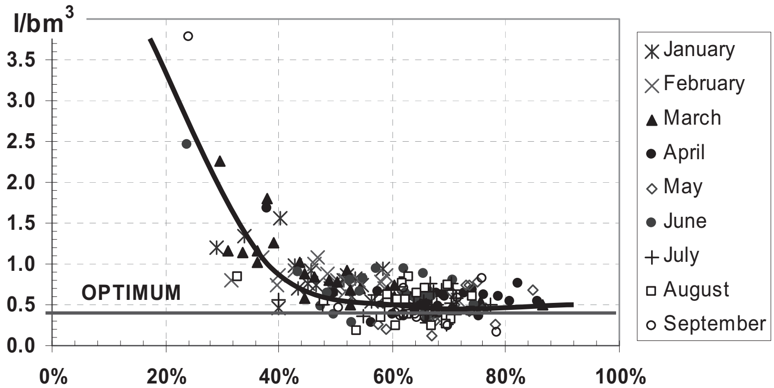


Figure 6. Fuel consumption influence on a percent of cutting effectiveness

The SM technology indirect effects

Due to the less mineral loss (effect 7%) there are indirect effects like:

a) Lesser reclamation cost per square meter
b) Lesser royalty taxes
c) Lesser overburden operating cost per bm^3 of oil shale
d) Additional income from oil shale looses decreasing

It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. Then additional income can reduce oil shale cost price up to 16-20% and effect will growing with oil shale sale price. The lifetime of "Narva" open pit will increase up to one year.

With oil shale output increasing the overburden removing operating cost decreasing and minimizing oil shale cost by 25%.

From year to year the royalty taxes increase up to 4% per year in Estonia. On such situation the effect from lesser royalty taxes per excavated oil shale can be from 7% up to 15%.

The reclamation cost effect on oil shale cost price decreasing is about 1-2%.

So, the total indirect effect is about 50%. As a result the SM high-selective technology on same level with Ripping low-selective technology when 750 bm^3 per shift is achieved (Figure 4).

Discussion

Currently Estonia is independent energy producer thanks to existing of Oil-Shale deposit and favourable mining and processing conditions. Due to environmental restrictions and social pressure testing of high-productive, environmentally friendly, mechanical mining is needed for successful continuation of independent energy supply (oil shale) for EU state country, Estonia. Situation in energy market of EU will be change in the nearest future. Decreasing need for energy import to Estonia will be very helpful for European energy market. New flexible and powerful mining technology will guarantee securing independence of Estonian energy sector [3]. Development of mining machinery and mining technology by the way of selective mining will improve environmental situation in Europe and Baltic Sea region. Effect can be achieved in decreasing CO_2 pollution, ash pollution and water pollution.

Selective mining enhances the quality of oil shale. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower. The disturbing impact of drilling-blasting operations in quarries and open pits next to densely populated areas causes vibration, dust and noise emissions which are arguments to stop operations where blasting is used. Surface miner high-selective technology has perspectives due to reduced dust and noise, non-existent vibration and dust emission levels also.

By extending the applicability of the surface miner/road cutting technology from soft material into semi-hard and hard rocks with UCS of up to 110-120 MPa, an economically and environmentally acceptable alternative to drilling and blasting could be available. By taking into account the rock-mechanical and mine planning aspects of the test application, an evaluation of the overall economical feasibility and the transfer of the results to other hard rock mines can be ensured.

Conclusions

Results which will be obtained by this project can result in applications in different industrial sectors. The main applications will of course be found in the surface mining and road construction sectors. New applications could be seen in zones where rock soils could be transformed into zones with agricultural capacities.

There is a couple of direct and indirect effects which reducing oil shale cost prise up to 80% due to less mineral loss, loading method (windrowing), optimized fuel consumption when high-selective mining technology with surface miner is applayed. The result of this work will be taken into account for the next SM design.

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GEOLOGICAL ASPECTS OF RISK MANAGEMENT IN OIL SHALE MINING

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The paper deals with risk management problems in Estonian oil shale mines. Investigations are focused on application of the method to determination of the quality of geological data. Various factors relevant to mining technology in Estonian oil shale deposit have been determined. For risk estimation, the empirical and judgmental approaches and the event tree were used. They allow determining the probability of the occurrence of geological features and its influence on the mining process. Analysis of obtained results showed that it is necessary to elaborate special methods for determination of the geological conditions in the mining area. The obtained information affords specialists to improve the quality of geological information and consequently the mine work efficiency. The analysis shows that the used method is applicable in conditions of Estonian oil shale industry. The results of the investigation are of particular interest for practical purposes.

Introduction

In Estonia the most important mineral resource is oil shale. Oil shale industry of Estonia provides a significant contribution to the country's economy. Underground and surface mining in the Estonian oil shale deposit causes a large number of technical, economical, geological, ecological and juridical problems, which cannot be solved on conventional theoretical basis. Risk management is a most powerful tool to solve complicated mining problems. The data, which have been accumulating in the last 40–50 years, concern the experience obtained by oil shale excavating and provide a good basis for investigations.

This study addresses risks associated with stability of the immediate roof in the mines Estonia and Viru, depending mostly on the geological feature. The primary interest of this study concerns evaluating the usability of the

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method and estimating the probability of failure without a detailed assessment of its consequences. The study is based on the world's and Estonian experience. As an example of application, the risk analysis of Estonian oil shale mines has been conducted.

Risk management involves making a judgment about taking a risk, and all parties must recognize the possibility of adverse consequences which might materialize [1–4]. Therefore, owners will be required to deal effectively with the consequences of a failure event. Prevention of the hazardous situation is more moral, ethical and economic than facing the adverse consequences. Having received the information, the management of a mine or open cast can come to adequate political and strategic decisions. The mitigation process will reduce the adverse consequences [1, 5]. Investigations have shown that the share of risk relevant to geological data in mining and environmental protection is very large. It is known that rock mass properties vary and depend on its location. It is impossible to determine exactly all the geological features. The reliability of geological data determines the efficiency and safety of mining and environmental impact. It includes bedding, underground and surface water conditions, existence of karst, joint systems, etc.

Some of the various geological factors relevant to Estonian oil shale mines have been determined. For risk estimation, the judgmental and empirical approaches and event tree have been used. The risk management method allows predicting the probability of failure of the immediate roof in the location of interest. Getting the information allows specialists to mitigate negative influence of risks on the excavation process and environment.

Analysis showed that the risk management method used is applicable to Estonian oil shale mines, which are of particular interest for practical purposes.

Theoretical background

In the world, risk management methods are used in different branches of industry and for many different technical systems. In Estonia, including *Eesti Põlevkivi Ltd*, risk management methods are focused on health safety problems. There is less information about the application of risk management methods to geological conditions and technological processes. In spite of the varied terminology, there is general agreement on the basic requirements [1, 3, 5, 6]. The terminology and risk management/assessment methodology used in the frame of this project are presented below.

Risk can be defined as the likelihood or expected frequency of a specified adverse consequences [1, 4]. Risk management is the systematic application of management policies, procedures and practices to the task of identifying, analyzing, assessing, treating and monitoring risk [1, 3, 4]. Having obtained the risk information, a decision-maker must come to a decision.

Risk assessment is the process of deciding whether existing risks are tolerable [1, 3, 4, 7–10]. It involves making judgments about taking the risk (whether the object or process is assessed as safe enough). Risk assessment incorporates the risk analysis and risk evaluation phases. Schematically the process of risk management/assessment is presented in Fig. 1.

Risk analysis is the process of determining what can go wrong, why and how. It entails the assignment of probabilities to the events. This is one of the most difficult tasks of the entire process. Probability estimation depends on the type and quality of the available data: analytical, empirical or judgmental approaches [1, 3, 7]. Component event probabilities may be assessed using a subjective degree-of-belief approach [2, 4].

Attaining an exact value of probability for technical systems and processes is not a realistic expectation. Tools that are often used to help in risk estimation are fault/event trees [1, 4, 11].

Risk evaluation is the process of examining and judging the significance of risk. It is based on the available information and the associated social, environmental and economic consequences.

Risk acceptance is an informed decision to accept the likelihood and the consequences of a particular risk. In some countries, there is a certain risk level that is defined as the limit of unacceptable risk. For failure events with no potential fatalities or irreparable damage to the environment, the target failure probability may be decided exclusively basing on economic condi-

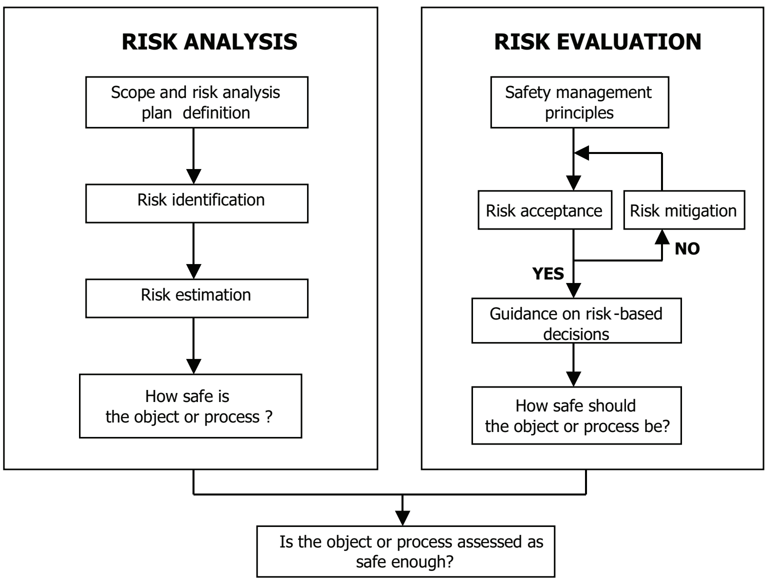

Fig. 1. Risk management/assessment process.

tions and corresponding risk analysis. A target level of 10^{-3} to 10^{-2} for life-time risk of the object or process may be a reasonable criterion [1, 2].

Risk mitigation is a selective application of appropriate techniques and management principles to reduce either likelihood of an occurrence or its consequences, or both [1, 3–5, 12].

Contributing geological factors

Geological and technological aspects of underground mining can influence the efficiency of mine works and environment protection. The share of geological information in these processes is large enough. Some of various factors which are relevant to Estonian oil shale mines and open casts are presented in Fig. 2.

In the first stage of investigations, the contributing factors are divided into two groups: geological and technological factors. Main technological aspects influencing the stability of a mining block (block of rooms at underground mining) concern the quality of mining and blasting works. Feedback control and adaptive design methods guarantee the stability of a mining block [13].

The influence of geological parameters and features on the mining efficiency and environment protection is significant. Stability of an immediate roof in face is determined by geological features. The presence or vicinity of karst, joints and fissures, and aquifer in the overburden rocks in

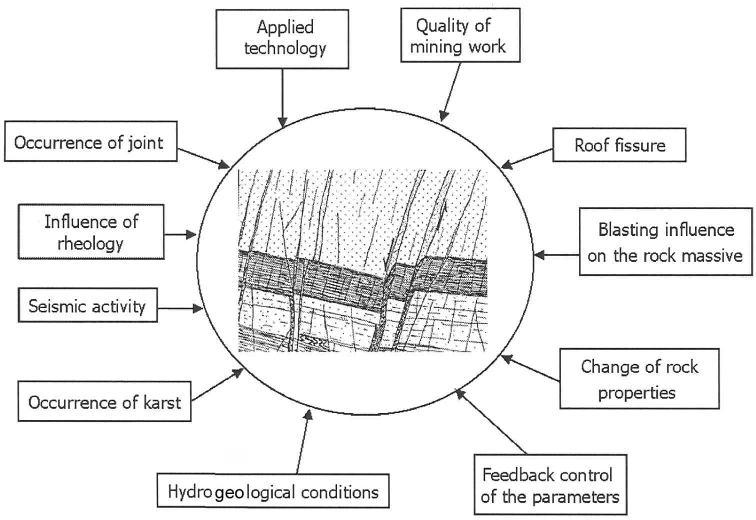

Fig. 2. Factors contributing to the mining process.

face of the mines Estonia and Viru determines the stability of the immediate roof. These factors, in general, have been determined for the Estonia oil shale deposit and are presented in a map. A great deal of the karst and joints inside a mining block area is undetermined, as they are practically impossible to determine. Risk management/assessment methods allow solving these complicated problems.

Seismic activity in Estonia is at such a low level, practically negligible, that it has been considered in this study only to a limited extent.

Immediate roof collapse risk in face, Estonia mine

In the Estonia mine, mining blocks are in different geological conditions. In the southern area the geological conditions are complicated due to the presence of karst, joints, aquifer in the overburden rocks. They influence the stability of the immediate roof. The roof fall risk increases. Figure 3 presents the event tree for immediate roof stability.

Investigation of *in situ* conditions has shown that immediate roof stability depends on two factors: mine work quality (influence 70%) and geological conditions (influence 30%). Investigations have shown that owing to high quality of mine works the probability of roof stability is 90%.

In the Estonia mine the room height is 2.8 m. In normal geological conditions it guarantees the stability of the immediate roof in face. Room height of 2.8 m in complicated geological conditions does not guarantee the stability of the immediate roof. In this case the room height must be increased up to 3.8 m. Investigations showed that the probability of immediate roof collapse in the Estonia mine is 5% (Fig. 3). It is evident that the estimated probability exceeds the limit (10^{-3}–10^{-2}). On the other hand, it is known that determina-

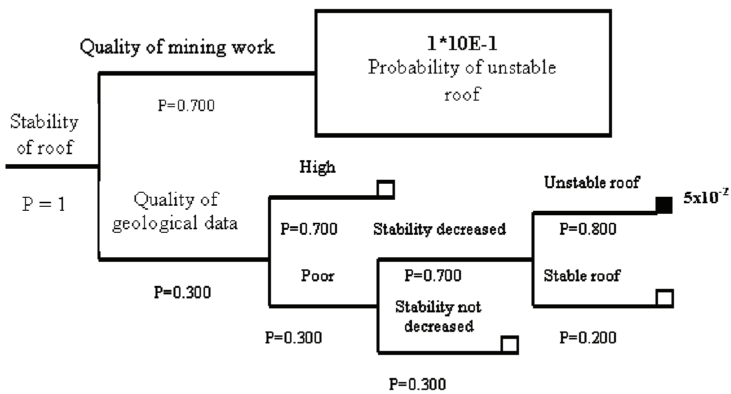

Fig. 3. Event tree for immediate roof stability in face, Estonia mine.

tion of the geological features inside a mining block is practically impossible. It is necessary to elaborate special methods to determine a geological feature inside a mining block. This complicated problem demands additional investigations.

Immediate roof collapse risk in face, Viru mine

The geological structure and features of the immediate roof in stop determines the number and sizes of potential dangerous blocks. Prediction of these factors is practically impossible. Risk management methods allow solution of this problem basing on the experimental data of *in situ* conditions.

The investigation was conducted at the Viru mine in the mining block No. 184 (right wing). 33 collapses of the immediate roof in stop were registered. Caving size ranged from 0.001 m^2 (0.1 by 0.1 m) to 6.0 m^2 (3.0 by 2.0 m). The height of the collapses in the roof varied from 0.05 m to 3 m.

Stability of the immediate roof in stop has been controlled after blasting works. The visible potentially dangerous roof blocks were removed immediately (enforced collapse). Long-term mining experience has shown the efficiency of this method. After that the spontaneous collapses may appear in stop, caused by rheological processes.

For probability estimation an empirical approach was used. All the statistical calculations were based on the actual data of *in situ* conditions. The event tree is presented in Fig. 4.

Analysis of the event tree showed that the probability of spontaneous collapses, which appear during mine works, is negligible (0.015%). The probability of enforced collapses remains below 0.5%. Such collapses are not dangerous because during face inspection the potential dangerous blocks will be removed.

In summary, collapses in stop are not dangerous for workers and equipment. The probability of the collapses is below the limit – 10^{-3}–10^{-2}.

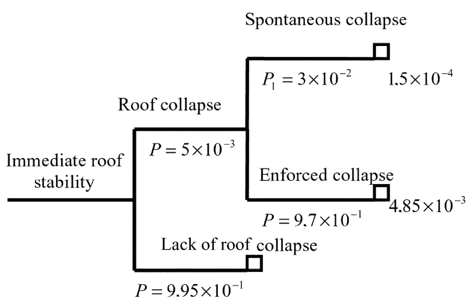

Fig. 4. Event tree for immediate roof stability in face, Viru mine.

Discussion

Risk management/assessment methods allow determining the probability of the immediate roof collapse using the event tree. Having got this information, the mine management may decide about taking risks: are they acceptable or not; are they dangerous for workers and/or for the environment? If this risk is not acceptable, the mine management must preview the risk mitigations methods: use of appropriate techniques or/and management principles to reduce either likelihood of an occurrence or its consequences, or both. In the Estonia mine the room height of 3.8 m reduces the probability of an immediate roof collapse and its negative consequences, being the only true solution.

On the other hand, information about the probability of an immediate roof collapse offers the scientists objects for future investigations.

Conclusions

As a result of this study, the following conclusions and recommendations can be made:

1. Geological and technological factors relevant to immediate roof stability have been determined. The share of geological factors, such as karst, joints, fissures, aquifer, etc. in this process is large.
2. Geological risks by underground mining are estimated by empirical and judgmental approaches. In the investigations the event tree was used.
3. The influence of the quality of geological data on the mining process is significant. It is necessary to elaborate special methods to determine the geological features inside a mining block.
4. The risk management method is a powerful tool to solve complicated mining problems. The analysis showed that the method is applicable in conditions of Estonia oil shale deposit. The results of the investigation are of particular interest for practical purposes.

Acknowledgements

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1-6 October, 2008
Goa, India

Risk Assessment of Surface Miner for Estonian Oil Shale Mining Industry

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Keywords: high-selective mining, risk estimation

The paper deals with risk assessment of a high-selective oil-shale mining technology using surface miner Wirtgen 2500SM. This study addresses risk associated with productivity and cutting quality on example of Estonian oil shale deposit in areas with complicated layering conditions. The risk assessment method allows choosing relevant technology with friendly environment and economic value. For risk estimation the event tree is used. The results of the risk assessment are of practical interest for different purposes.

1 Introduction

About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Mining sector faces challenges to increase the output of mines and to minimize the environmental impact of mining at the same time. Continuous mining and milling techniques for the hard rock industry are up to now limited through the hardness of rock material. The application limits for the future technique will be placed above the limits of bucket wheel excavating systems with a diggability of normal up to 10 MPa of uniaxial compressive strength (UCS). This can be expanded with special designed excavators for frozen hard coal or soft limestone (Wilke at al. 1993). Horizontal and vertical ripping techniques are currently used for materials up to 50 MPa UCS, sometimes combined with in-pit crushing systems.

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 overburden removal. Hard overburden consists of limestone layers and is blasted before excavation. Oil shale layers are blasted as well or broken by ripping (semi-selective mining). Disadvantage of ripping is excessive crushing of oil shale by bulldozer crawlers. Excavated rock is transported with 32-42 or 60 tonnes trucks (Belaz and Euclid) to the processing or crushing plant depending on opencast.

Aim of the research and in-situ SM testing is to introduce continuous mining technology on example of Estonian oil shale deposit in areas with arduous layering conditions. The results of in-situ testing can be used to improve existing situation in mining fields with complicated geological conditions and in densely populated regions.

Continuous surface miners can find their natural applications in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Besides they offer further advantages less mineral loss and dilution, improved mineral recovery especially in areas sensitive to blasting, less stress and strain on trucks due to minimum impact of the excavated material, primary crushing and fragmentation of mineral rock, reduced capacity requirements for preparation plants.

The high-selective oil-shale mining technology introduces by surface miner (SM) Wirtgen SM2500 and the first 9 months of testing results at “Narva” open-pit in Estonia. The technology allows to decrease oil-shale loses from 10-15% up to 5-7% on in-situ conditions. Mining process of the surface miner has a lower disturbing impact, which is topical in open casts and quarries especially in densely populated areas. The low level of dust and noise emissions and also very low vibration are arguments to mine oil shale with surface miner instead of drilling-blasting operations. (Nikitin at al., 2007)

The most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2-7 cm) with deviations about one centimeter. It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tone per square meter. It means, that oil-shale looses on the case of SM technology can be decreased from conventional 12 up to 5 percent

2 Risk analysis of surface miner Wirtgen 2500M technology

Continuous surface miner, which are designed to cut softer rock materials like sandstone, clay, bauxite, hard coal, phosphate, gypsum and marl are operating between 10 MPa and 70 MPa compressive strength. Nowadays, road cutting machines are working materials up to 100-110 MPa compressive strength. The very recent developments show that there is a need for investigations to enlarge the mentioned application limits.

The Wirtgen 2500SM design with a mid-located cutting drum (diameter 1.4m, cutting width 2.5m) was expected to be more promising for hard rock (80-110 MPa) applications than the front-end designs. Here, the whole weight of the machine (100 t) is available for the penetration process and only a smaller torque resulting from the cutting process (cutting depth up to 0.6m) has to be counterbalanced. Besides, the surface miner with middle drum concept moves during the winning process. Due to this great moved mass, much more dynamic mass forces are possible than during the movement of the small mass of the cutting organ mounted on a boom.

Modifications and development work for the tested SM focused mainly on the corresponding cutting drums (number of cutting lines) and specifications of the cutting tools, different loading technologies (windrowing or direct truck loading) also (Figure 1 a, b).

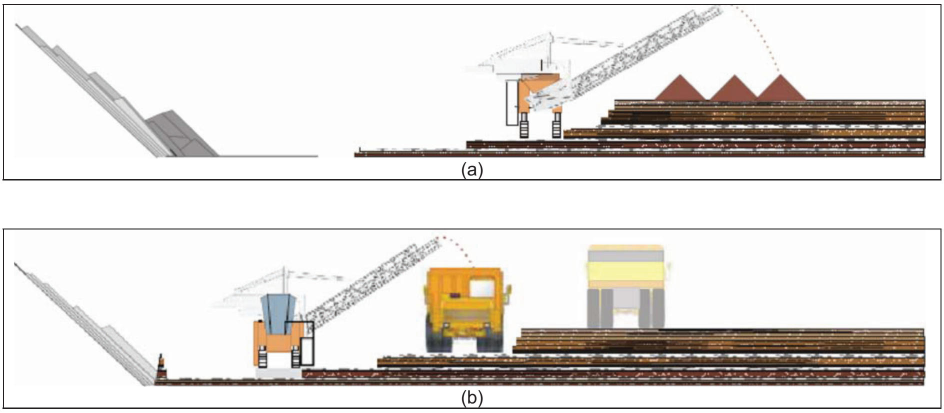


Figure 1. Different loading technologies: windrowing (a) and direct truck loading (b)

2.1 Rock Breakability Results

To be able to transfer the achieved results to other EU rock mines, it is necessary to identify the SM and cutting rock parameters responsible for the breakability factor of a deposit. The development of such a generalised classification system is therefore an important objective of the project as well.

Applying statistical distribution according to Weibull, the function of size distribution of oil-shale particles may be assumed as follows:

$$W = 1 - \exp[-(d/d_0)^m] \qquad (1)$$

where $d_0 = d_{0.63}$ is diameter of screen opening to pass 63.2% of broken oil shale; m is breakability factor.

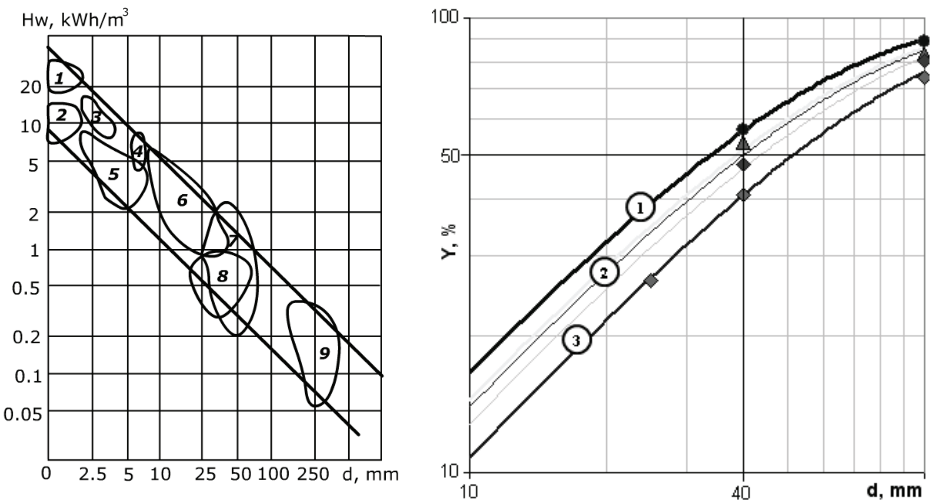
The results from sieving analysis made for limestone and oil-shale layers show that for "Narva" open pit test site conditions breakability factor m = 1.1. Hence, the share of oil shale δ passing the 25 × 25-mm screen in the total mine-run shale equals to

$$\delta_{-25} = d_{-25} = 1 - \exp[-(25/d_{0.63})^{1.1}] \qquad (2)$$

where, $d_{0.63} = 20.0 + 2.16S'$ for SM up-cutting direction (see Figure); S' is cross-section of cut, cm^2.

In 1968 E. Reinsalu had proposed an approximate relationship between energy consumption by different methods of breaking and average size of mined oil-shale particles, which was later completed with the present investigation data (Figure 2).

Concentratibility and trade oil shale grade depend on sizing extracted oil shale, which, in its turn, is closely related to energy consumption and the selected method of oil shale breaking. Equation (3) and Figures 3 a, 3 b demonstrates the correlation of the distribution law parameters and specific energy consumption with the parameters of oil-shale and limestone particles sizing. The tested SM sizing parameters are inside the areas with number 7 and 8 (Figure 2 a).



(a) (b)

Figure 2. Effect of method of breakage on specific energy consumption (A.) and the resulting average oil shale and limestone sizing (B.)

Where, 1 – drilling in limestone; 2 – drilling in oil shale; 3 – cutting machine in limestone; 4 – cutting machine in oil shale; 5 – cutting of layer B with shearer loader UKR-1; 6 – cutting with shearer; 7 – cutting with DKS (a mean for measuring cuttability) in limestone; 8 – cutting with DKS in oil shale; 9 – breaking with ripper (surface mining); Wirtgen 2500SM sizing data (up-cutting direction): ①– cutting in oil-shale complex EF (0.43m); ②–cutting in limestone seams A/B (0.18m) and C/D (0.25m); ③– cutting in oil-shale complex CB (0.36m).

3 Risk estimation of surface miner testing results

The Wirtgen 2500SM was delivered to AS Eesti Põlevkivi at the end of 2006. The testing of SM was beginning at “Narva” oil-shale open cast. The SM testing was held from 01.01.2007 to 30.09.2007 and was estimated by four testing phase (Figure 3). The machine was operated in two or three-shift systems.

During the first testing phase (I) 145 total operating hours from 200 available (9.4 m/min) and during the second testing phase (II) 151 from 208 available shift-hours (9.0 m/min) the SM with direct truck loading was tested. But the real cutting time was 35 and 41% from available shift-hours for the each period correspondingly. During the third testing phase (III), 4130 total operating hours from 5416 available shift-hours the SM with about 26% of windrowing. For the fourth testing phase (IV) 111 total operating hours from 112 available shift-hours the SM windrowing achieved 100%. The average cutting speed during the real cutting time was 11.5 m/min. For the while period real cutting time is about 46%, where on average during the shift-time 33% SM operated on oil-shale layers and 13% on limestone (layers C/D and B/A). The Figure 3 illustrates the shift-hours distribution graphics for the testing phases.

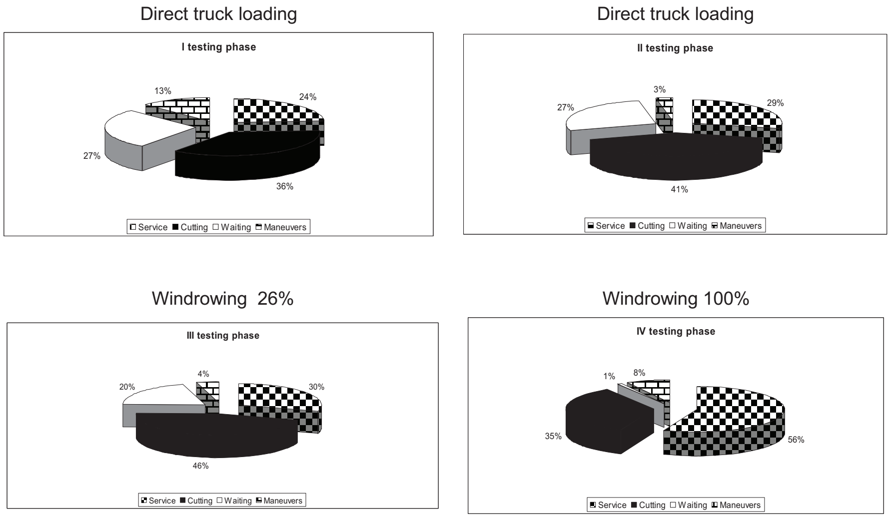


Figure 3. The shift-hours distribution graphics for the while testing period.

During the testing phase registered "waiting" is about 27%. Obviously, the main reason is direct truck loading method. Analysis has shown that by direct truck loading method, truck-waiting downtime decrease real cutting time by 1.0-1.5 hour per shift and average cutting speed by 20-25%. The percent of "waiting" include about 7% of time looses for trucks exchanging, about 6% for SM upper conveyor manoeuvres, then about 6% for spade-work (SM controlling before and after the shift) and up to 10% time looses due to the ground water problems.

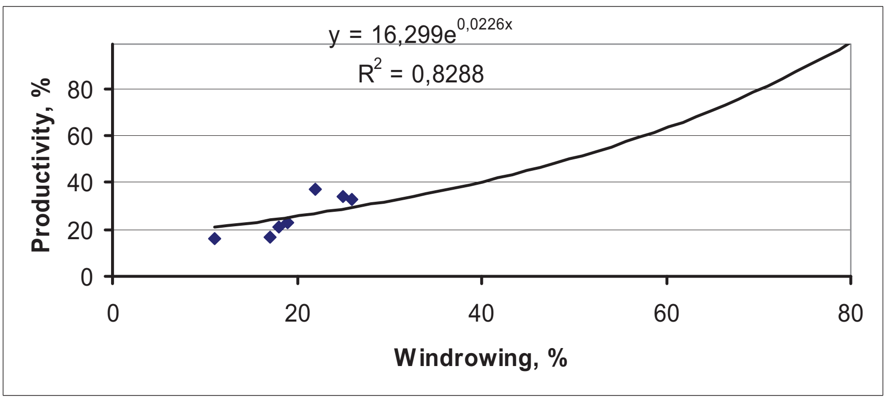


Figure 4. Dependence of SM productivity on windrowing percentages

As you can see from the graph (Figure 4), there is a great SM productivity potential when windrowing percent is growing. The additional LHD-machine operating and SM depreciation costs greater oil-shale excavation rate is coating. As a result the oil shale operating cost can be reduced up to 10-15%.

Main aspects influencing the efficiency of the combine work concern the duration of the processes. Cutting different layers, track dumper loading (waiting), manoeuvres and maintenance processes are the most important factors. Investigations have shown that duration of the processes influence on productivity. The main quantitative approach used in risk estimation is the event tree method (Calow, P. 1998). This method was selected as the most appropriate one for the risk estimation of the SM. In the first stage of the project time factor was taken into consideration. For probability determination the empirical approach was used (Williams at al. 2004). The event tree indicating the probabilities of the SM processes and spent time. It is possible to select different variants and to determine the probability of one.

The event tree allows determining time deviations from average value (Figure 5). Four different testing phases (I-IV) of the SM were observed. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Application of the fault tree is presented in Table 1. Selected variant of the tests give different value of the probabilities and deviations from the average value. For determination the higher productivity is necessary to give attention on processes with positive value and improve it quality (Figure 5).

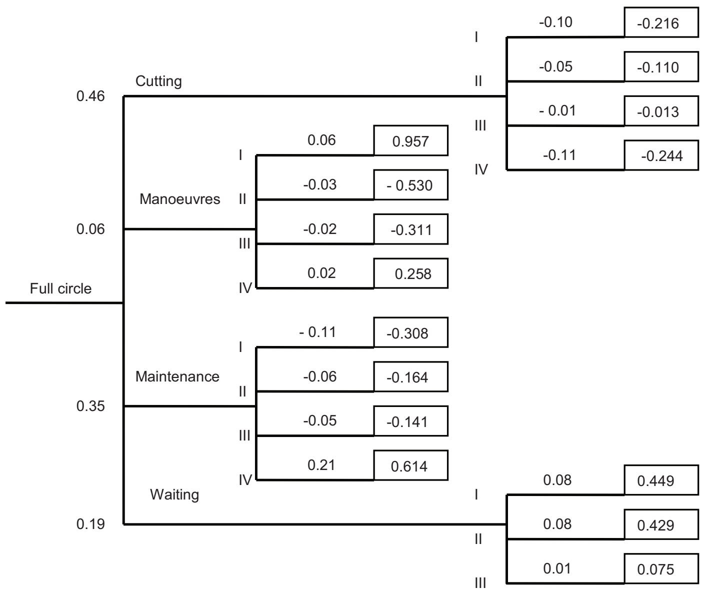


Figure 5. Event tree of different processes

In case of excluding complicated geological condition higher productivity can achieve owning to the windrowing method.

Table 1. Time deviations from the average value

Testing phases	I	II	III	IV
Maintenance	-0.308	-0.164	-0.141	0.614
Cutting	-0.216	-0.110	-0.013	-0.244
Waiting	0.449	0.429	0.075	-
Maneuvers	0.957	-0.530	-0.311	0.258

4 Risk evaluation

The thickest and harder limestone seam “C/D” (60-80 MPa) has sufficient quality to produce aggregate for road building and concrete. Separately extracted limestone (C/D and A'/B) can be left directly in mine, which reduces haul costs and increase run-out oil shale heating value without additional processing.

The oil yield increase by 30%, up to 1 barrel per tone during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning in power plants because of less limestone containing in oil shale. Its results higher efficiency of boilers, because up to 30% of energy is wasted for limestone decompose during the burning process. Positive effect would result in lower carbon dioxide and ash emissions (Adamson at. al 2006).

Another perspective of surface miner would apparent in places with relative small overburden thickness (less than 10 m) and near the towns where the removal of hard overburden with SM should be considered as well instead of overburden blasting. On these cases the SM would “cut” considerably operating costs of stripping and possibility mine out reserves near the densely populated areas.

Another problem is the oil-shale bed geological characteristics. Estonian oil-shale bed consists from oil-shale and limestone seams with different thickness and compressive strength. Oil shale is relatively soft rock with UCS 15-40 MPa but limestone is 40-80 MPa. There are also places near the karsts zones with 100-120 MPa compressive strength. During the cutting process the loads in cutting tools vary greatly due to the differences in rock physical and mechanical parameters, which lead increased loading of the cutting drum.

The applicants have recently encountered many situations where manufacturers cutting drum/head designs could be significantly improved upon, as they were not tailored to the actual geotechnical conditions predominant at the mine. However, without more user-friendly tools, the opportunity to make such improvements in practice has been limited. Improved designs have the potential to increase cutting speed and efficiency, reduce pick replacement costs, reduce machine down time through gearbox failure and pick changing, improve machine reliability by reducing excessive vibration during cutting, improve loading efficiency and reduce fine oil shale and dust production. Research program to develop design of cutting tools/drums to minimise cutting tools consumption and machine down time on the basis of testing data will be develop. New design of cutting drums will lead to improved tool cutting (pick) loading efficiency with less fine rock and dust production. The result of this work will be taken into account for the next SM design.

Development of mining machinery and mining technology by the way of selective mining will improve environmental situation in Europe and Baltic Sea region. Effect can be achieved in decreasing CO_2 emission, ash and water pollution.

Selective mining enhances the quality of oil shale. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower. The disturbing impact of drilling-blasting operations in quarries and open casts next to densely populated areas causes vibration, dust and noise emissions which are arguments to stop operations where blasting is used. Surface miner high-selective technology has perspectives due to reduced dust and noise, non-existent vibration and dust emission levels also.

By extending the applicability of the surface miner/road cutting technology from soft material into semi-hard and hard rocks with UCS of up to 110-120 MPa, an economically and environmentally acceptable alternative to drilling and blasting could be available. By taking into account the rock-mechanical and mine planning aspects of the test application, an evaluation of the overall economical feasibility and the transfer of the results to other hard rock mines can be ensured.

5 Conclusions

Event tree allow determining suitable variant of different processes for continuous surface miner. For determination suitable variant greatest negative numbers were chosen in comparison analysis with maximal possible productivity received during the tests. Surface miner higher productivity in testing phase (IV) was achieved on account of 100 % windrowing method. The high cutting performance can be explainable absence of waiting time. This information allows finding adequate decision to improve quality of the processes and avoid negative influence.

Results obtained by this project can be using in different industrial sectors. The main applications will be found in the surface mining and road construction sectors. New usage could be in zones where rock soils will transformed into zones with agricultural capacities.

There is a couple of direct and indirect effects which reduce oil shale cost prise on 20% due to less mineral losses, loading method (windrowing) can optimize fuel consumption when high-selective mining technology with surface miner is applied. The result of this work will be taken into account for the next surface miner design.

6 Acknowledgements

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