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ANALYSIS OF OIL SHALE HIGH-SELECTIVE MINING WITH SURFACE MINER 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 by the government. In the nearest future (beginning with 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

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successful continuation of independent energy supply (oil shale) for a 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 lower emissions of 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 constitutes 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 the 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 (59° 15′N; 27° 44′E). 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 by 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/m^3	Layer productivity, t/m^2	Calorific value, MJ/kg	Cutting nr.	Cutting thickness, m	Cutting speed, m/min
14	F2	0.28	2.07	0.58	2.49	I-EF	0.55	8.2
13	F1	0.41	1.79	0.73	5.88			
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	$\sum$ 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 in 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).

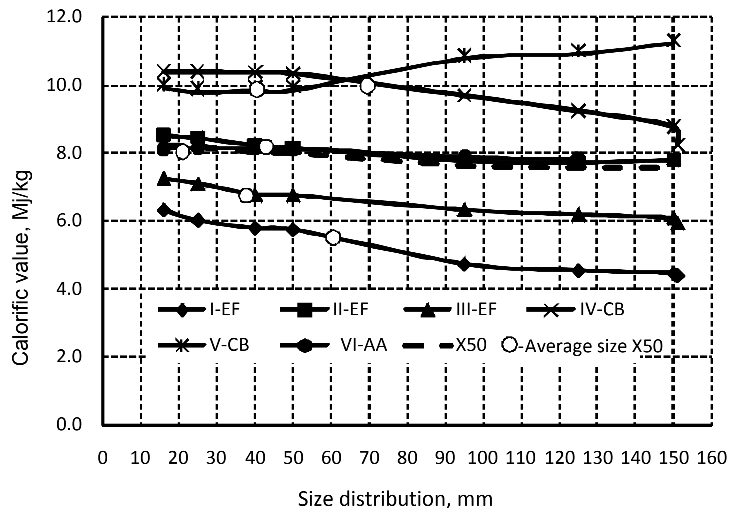

Fig. 1. Cumulative calorific value (“wet”) for oil-shale layers *vs*. size distribution.

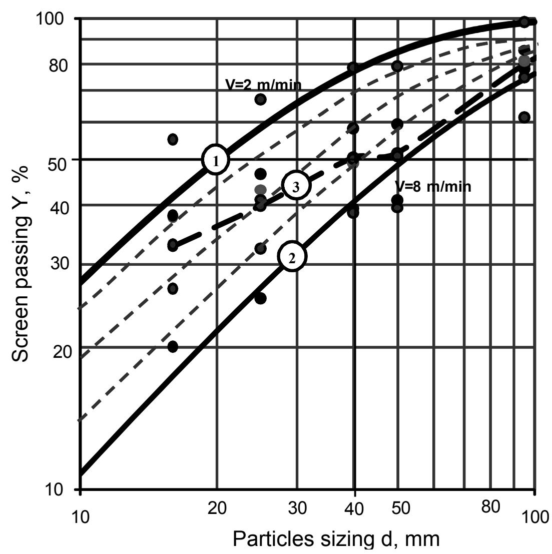

Fig. 2. Oil-shale size distribution at different values of cutting speed where ① – cutting in oil-shale complex AA (V = 2 m/min, h = 0.22 m); ② – cutting in oil-shale complex CB or EF (V = 8 m/min, h = 0.55 m) and C/D (0.25 m); ③ – distribution of average-size particles at cutting of all oil shale layers.

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 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.

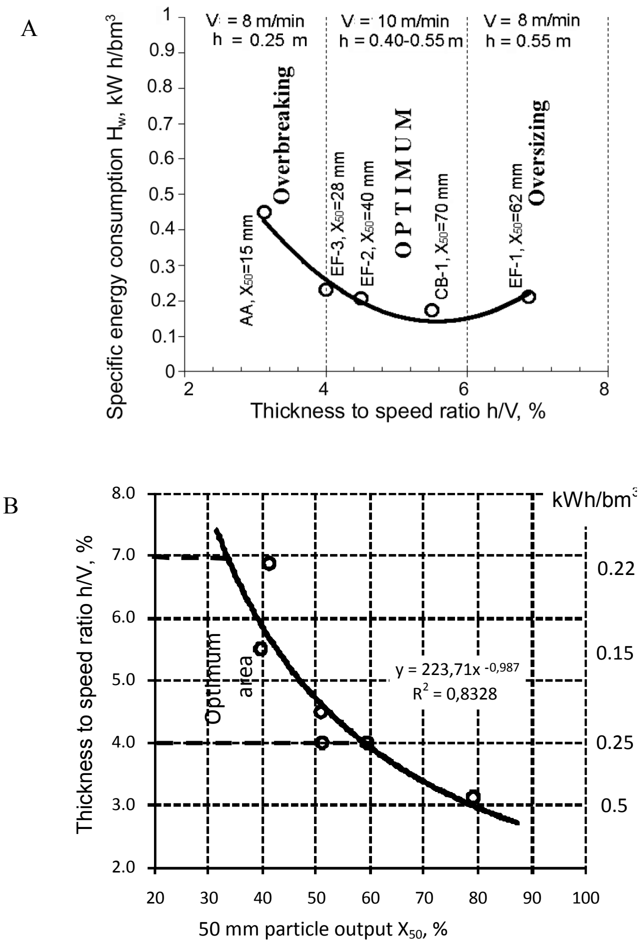

Fig. 3. Dependence of specific energy consumption on thickness-to-speed ratio (A). Dependence of specific consumption (right axis) and thickness-to-speed ratio (left axis) on 0–50 mm particle output (B).

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 does 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]. The 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 price. 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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