Utilising selective extraction, crushing and separation of sedimentary mineral resources

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The requirements for the quality of rock are changing from time to time depending on the customers. In Estonia, several selective methods have been tested for managing the flow of the run of mine. The main methods for selective extraction of limestone, oil shale and phosphate rock have been selective blasting, bulldozer and excavator ripping and cutting by surface miners. Selective crushing has been achieved by axle crusher and separation by jigging. All methods have shown promising results for changing the waste rock balance in the product. The working principle of the separation methods is based on physical properties of various materials. Some other tests have been performed, like crushing with Bradford breaker and fine separation. The main hypotheses are related to usability of dry selective crushing and in situ separation of oil shale and limestone in the mine to support effective management of calorific value and backfilling.

Keywords: Oil shale, separation, crushing, breaking, selective mining
Introduction

In relation to quality management of run of mine technologies like selective breaking and crushing could be used. This is closely related to backfilling and waste rock usage. Our recent studies in oil shale, phosphate rock and limestone production lines have shown that investigating waste balance and handling techniques requires a complex study beginning from the geological investigation and continuing with opening mining fields, preparation process, overburden removal, extracting mineral resource, processing, separating and transporting. The minerals being studied are oil shale, limestone, dolostone, black shale and phosphate rock. In addition, coal and brown coal lines are being compared with the help of international cooperation. The focus in the study is set to two inter-dependent processes – breaking and separating. Several fieldworks and modelling are made to reach the minimal amount of mineral losses and waste and separating waste rock and to increase yield of mineral resources.

In case of the Kukersite oil shale in Estonia, the seam of mined oil shale is relatively stable over the deposit. In the areas of outcropping and deposit wings, some upper or lower layer’s outcrop or the thickness of some layers varies. The calorific value, oil yield and limestone content vary as well. Several extraction technologies have been used for mining oil shale during the last 98 years. During the first years, high selective hand mining was used due to the absence of machines. Oil shale and limestone layers and pieces were broken by grub axe and hammer and loaded by hand shovel. The main problem related to the losses and dilution was the rock that contained both oil shale and limestone and thus could not be separated by hand. That rock was either left to the mine, sorted out later by hand and left to the waste deposit or used in oil generators. Later, when drilling and blasting was applied, only sorting or selective blasting influenced losses and dilution. Both full seam and selective seam blasting were used. In case of underground mining full seam and partial seam blasting was used. In the years 1970 to 2000 partial seam longwall mining was used. Due to weak limestone layers on top of the underground room and pillar mining sections in the Estonia oil shale mine, dilution is high and not only full seam, but in some cases 1.3 times of the seam thickness is extracted. At the same time, several separation technologies have been used for processing the run of mine. Due to the complex chain of mining processes, optimisation is performed in some cases for finding the optimal solution between losses, dilution, yield and other factors. At the same time, extraction technology has not been well analysed.

During last decades, ranges of tests and theoretical studies have been carried out for analysing possibilities of selective mining. Tests of high selective mining have been carried out in Estonia in limestone, phosphate rock, dolostone and oil shale mining areas.

Tests

Selective extraction has been performed by mechanical shovel, bulldozer ripper and hydraulic excavator ripping in several oil shale mining fields. Greatest experiences have been gained from Narva oil shale surface mine with bulldozer ripper, from Ubja open cast with excavator ripper and from Kohtla Vanaküla open cast with mechanical shovel. In addition, hydraulic hammering is used in Ubja and Põhja Kiviõli oil shale mining fields in addition to previous tests in the limestone mining sites. The particle size of crushed material was analysed with two methods: sieving with mechanical magnetic shaker and digital analysing with optical sieving software WipFrag.

Several selective breaking techniques that are not currently used can be utilized – ripping, cutting, shearing and augering. Cutting with surface miners could be applied by changing overburden removal sequence. In case of prolongation of mining trench, the area of cutting or ripping could increase remarkably and productivity and results of mechanical breaking could be improved.

With the help of selective separation techniques – dry separation underground, dry separation with axle crusher and sizer can be used for decreasing losses and increasing yield. As a result, the amount of non-useable fine particles will be reduced. In situ separation can improve backfilling possibilities and ground stability as a result.

The sequence of the study is following:

1. Crushing tests with axle crusher of various minerals – oil shale, limestone, dolostone,
phosphate rock, coal and others. Chronometry of technological productivity, geometric and geological measurements, and measurements of rock quality in case of ripping and cutting mentioned minerals is conducted. The analysis include selective extraction of mineral resources with ripper bulldozer, ripper excavator, surface miner, hydraulic hammer and selective mineral separation with mechanical bucket crushers, impact and rotary crushers and jigging (Figure 2).

2. Modelling the flow of the run of the mine, including modelling of limiting processes like overburden removal in case of surface mining and supporting and backfilling in underground mining.

3. Economic and ecological evaluation of these processes.

The preparatory tests have been performed with surface miners SM2100 and SM2600 for two years as well as with SM2200, MAN Takraf surface miner and Wirtgen surface miner SM2500 for high selective mining. In addition, jigging, fine separation and axle crusher tests with AllMinerals, CDE Minerals and Allu and Remu axle crushers have been conducted (Figure 1). The main problems that needed to be solved were selective cutting of oil shale (15 MPa) and hard limestone (up to 100 MPa) and separation of fine particles from the product. The yield, losses and their influence to the economic and ecological balance are analyzed. Life Cycle Analyses and other criteria for the Best Available Technology are used for comparisons. Analyses include evaluation to the environmental impact.

Dry separation with crushing buckets helps to accelerate the separation process as the loading and crushing for the power plants take place at the same time. The unit can be used for various solid fuels for power plants: coal, brown coal, oil shale etc.

The dry enrichment of the rock mass results in a higher calorific value of the oil shale and the separated waste rock can be left at site. This separation feature could bring environmental benefits to the mining operation because the separated waste rock is not transported out of the mining site. The material transportation in the mine becomes more efficient because ready uniform material is directly transported in one stage from the mine for local use in power plants or for further transport. Because the material is crushed to uniform size while loading, more material per dump truck is possible to load compared to conventional raw unprocessed run of mine.

Jigging could be used for separating oil shale and limestone. The results show that most of the oil shale was concentrated in top layers (Figure 3, Figure 4). Phosphate rock tests showed that jigging can not be used for sandstone based phosphorite due to similar densities of the minerals.

Figure 1 Selective crushing test with axle crusher
Main objectives of the developments of the study are:

- Real-time assessment of geological parameters and continuous upgrade of process line flow sheet (Figure 5).

- Development of contactless laser-based analytical spectroscopy methods, magnetic and electromagnetic sensing techniques and imaging methods, as well as related instrumentation, applicable to the problem on site.

- Development of contactless impulse-radar based methods for determining grain size and moisture content.

- Development and application of multivariate statistical methods to the real-time evaluation of collected spectroscopy and imaging data in order to increase the reliability and robustness.
Utilising selective extraction, crushing and separation of results, as well as the support of process control.

**Discussion**

Real time data is often more important than very high accuracy point analysis, when the processed material has significant variations. Such fast estimation of the composition and quality of the mineral stream is a bottleneck which limits the required efficiency in the production process of products from mineral ores and rock material. This turn is limited by the lack of online methods suitable for controlling the processes.

Efficient recovery of minerals from the process and waste streams can be achieved by controlling the mineral parameters in each step of the process flow, i.e. in the mining, processing, plant and waste management stages.

Main issue is that in spite of the availability of different contactless measuring solutions in the market for some industries (e.g. coal industry), large number of mining industries don’t or can’t use these for quality management.

The robustness of the mineral product quality analysis methods (LIBS and optical detection) has to be confirmed on real conditions by using the bulk materials at the mock-up the conveyer belt and subsequently in pilot test-bench. These experiments clarify the statistical regularities. Positive results can be expected as LIBS has been successfully used in the case of analysis of inorganic materials on running conveyer belt.

**Grain size measurements from belt conveyer** are giving information about volumes of the measured fuel and fuel optical parameters (particle size and shape).

The input to the pilot installation is fossil fuel or waste rock with a grain size of up to 125 mm. Pilot installation consists of: (1) mini wheel-loader equipped with crushing bucket to crush material down to <40 mm (loading capacity 0.5 m³), (2) dry sieving unit with a set of 5 sieves (supplemented by drying oven), and (3) separation unit for crushed oil shale waste rock which uses process of wet gravity separation - input into this unit have to be certain aggregate grain size fraction: 4-8 mm; 8-16 mm; 16-32 mm; 32-40mm (Figure 6). Photo analysis software for granulation analysis is also a part of the installation.

![Figure 6 Scheme of mobile installation](image)

**Objectives on wet separation**

The working principle of the wet separation method is based on dissimilar densities of the materials. Following gravity, the densest and heaviest mineral material falls into lower layers. Respectively, the material with smaller density remains at top levels. Each layer can be removed separately from the others, to see separation process. This method can be used to evaluate the efficiency of dry separation.
Oil shale waste material (gangue) in Estonia is used as filling material in surface mines restoration process. Gangue is marketed as filling material or product of waste by Eesti Energia Kaevandused AS, OÜ Ahtme Killustik, AS Floccosa and Kiviõli Keemiatoöstus OU. Oil shale ash is used in building block industry by Silbet Plokk OÜ and cement industry by Kunda Nordic Cement AS. Results of the study can be applied in analogue mining conditions (blanket deposits) outside Estonia, particularly in the case of oil shale (Russia, Ukraine) but also for coal, brown coal, salt, phosphate rock and others.

References