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QUALITY CONTROL OF OIL SHALE PRODUCTION IN ESTONIAN MINES

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The basic parameters of oil shale quality are heating value and grain-size composition. Heating value can vary considerably within the location in a deposit and depends on concretions and limestone content. Grain-size distribution and heating value depend directly on mining technology: breakage, transporting and processing. Energy distribution when using different technologies was determined. New boilers of oil shale power plants and oil retorts require a relatively constant quality of raw materials and fuel. The possibility of improving oil shale separation was investigated.

Introduction

Calorific value of oil shale has been discussed in many studies. The chances of obtaining a higher heating value have been examined. Previous studies have shown that quality management of oil shale production is mostly an economic problem [1].

The Estonia oil shale deposit is located in North-Eastern Estonia. The mineable oil shale bed consists of oil shale layers and limestone interlayers of various thicknesses. The basic quality parameters of oil shale are lower heat value as mined (Q^w) and grain-size range. Heating value and layer thickness fluctuate from place to place of the oil shale deposit. Heating value decreases by 0.07 MJ/kg per one kilometer in the lateral direction of the Estonia deposit. Heating value of oil shale layers can vary considerably within the location of the deposit and depends on concretions and limestone content [2].

Oil shale is used as fuel for electricity generation and shale oil production. For power generation, grain size of oil shale has to be 0–25 mm or 0–300 mm of lower heat value Q^w = 8.4–8.6 MJ/kg, depending on the mode of production. Grain size for oil production must be in the range 25–125 mm and lower heat value Q^w = 11.3–11.6 MJ/kg.

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The natural (geological) energy rate of a bed and layers has been determined in different systems by heating value in calorific bomb Q in kcal/kg. The lower heat value can be calculated as follows:

$$Q^w = (0.941 - 0.00941W)Q - 45 - 5.55W, \text{ kcal/kg}, \quad (1)$$

where W is moisture content, %.

Heating value as transferred into the modern system

$$Q^w \text{ (MJ/kg)} = 0.004186Q^w, \text{ kcal/kg}, \quad (2)$$

where Q^w is lower heat value.

Calorific value depends on oil shale layers and place where it is mined. At different parts of a mine different calorific value of oil shale can be determined. Therefore, enrichment and mixing of oil shale in concentration plant are needed.

Quality of an oil shale seam may deteriorate due to two factors – increasing share of limestone in layers and decreasing heating value of oil shale. This factors influence separation effectiveness. Firstly, decreasing oil shale share in run-of-mine (ROM, rock mass) reduces the yield of production. Secondly, decreasing heating value of oil shale will deteriorate the quality of fuel and oil.

Quality requirements for fuel raw material should be defined by both technical opportunities of extraction and consumption, and economic efficiency – the ratio of expenses for quality improvement to the effect received by using high-quality raw material [3].

The study was aimed at investigating the possibilities to increase calorific value of oil shale used for electricity generation and selecting a suitable equipment.

Methods

The main tool for analysis of the separation process is computational modelling with spreadsheet models and designing the process with CAD (equipment drawings and dimensions to fit them into existing concentration plant).

Oil shale separation process depends on grain size, heating value, moisture content, particle size distribution and secondary ingredients such as karst clay. Distribution of grain size and heating value depend directly on excavation technology.

In order to carry out the calculations for a mine field one has to know oil shale properties, geological and mining conditions, as well as those limiting the technical process. The main factor determining oil shale quality is its variable calorific value (heating value).

Great changes in oil shale heating value are explained by declining of oil shale seam from the center to the periphery of the deposit. For determination of average heating value in every oil shale layer with concretion (Q_l) the following formula is suggested:

$$Q_l = (Q_{os}\, m_{os} + Q_c\, m_c) / m_l, \tag{3}$$

where Q_{os} and Q_c are heating values (Table 1), m_{os} and m_c productivity of oil shale and concretions in mass. Mass productivity of the layer m_l

$$m_l = h_l\, d_l\,. \tag{4}$$

Geological testing can provide the data for m_l, Q_l and d_l, but for determination of the concretion amount the drilling data will be inaccurate.

On the basis of geological data, thickness of the oil shale layer without any concretion can be calculated by the formula:

$$h_{os} = h_l\, (d_l - Q_c\, d_c) / (d_l - d_c), \tag{5}$$

and total thickness and mass productivity of concretions in each layer are calculated

$$h_c = h_l - h_{os}, \tag{6}$$

$$m_c = m_l - m_{os}\,. \tag{7}$$

Basing on the data from Table 1, it is possible to compile the necessary mass and energy balances of run-off-mine oil shale (ROM) as material for separation.

Table 1. **Geological structure of oil shale and limestone and heating values for formulas (3)–(5) [4]**

Layers	Layer index	Heating values, Q_{os} and Q_c, MJ/kg	Volume density *d*, t/m^3
		Q_{os}	
Pure oil shale	F2	6.7	1.72
	F1	11.5	1.51
	E	17.5	1.28
	D	9.4	1.59
	C	14.2	1.38
	B	19.2	1.22
	A'	7.5	1.42
	A	15.1	1.37
Concretions	F, E, C, B	Q_c = 2.9	2.10
Kerogenic limestone	E/F, D/E, B/C, A/A'		
Pure limestone	C/D	0.6	2.45

Technology

For the computational modeling one has to know how oil shale bed is mined and also lumpiness of ROM.

Drilling-and-blasting and mechanical cutting methods demonstrate different properties of ROM. All beds (layers A-F2, excavating thickness 3.2 m) and mineable bed (layers A-F1, 2.8 m) are extracted by blasting. Average size distribution by cutting breakage: layers A, B+C, E+F selective cutting with surface miner Wirtgen SM2500 is shown in Fig. 1.

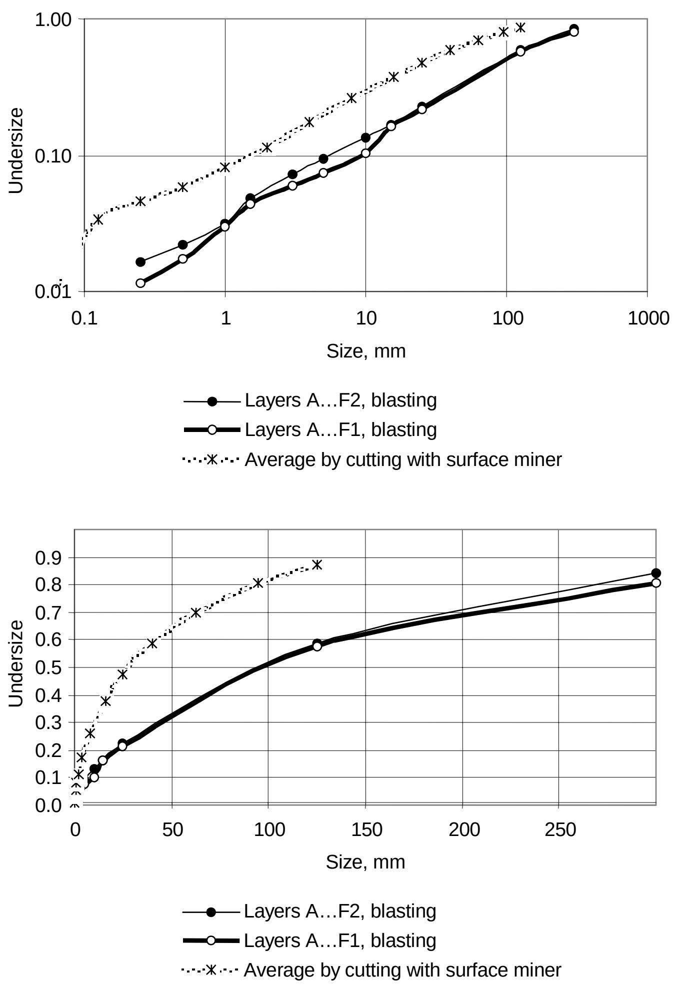

Fig. 1. Particle distribution in run-of-mine; upper – in logarithmic and lower – in normal scale.

A-F1 – mineable bed, A-F2 – ROM diluted with unconditional layer F2

Grain-size distribution of ROM in the concentration plant can be described by the formula

$$y = A\,x^{n} + \delta, \tag{8}$$

where: y – screen underflow; x – grain size, mm; A and n – parameters of distribution: A – "dustity", part of fine grain less 1 mm, n – granularity range; δ – pieces splitting at transport from the face to the factory.

For drilling-and-blasting method the share of not separated fine grains 0–25 mm makes 30–40% (Fig. 1), and heating value is 3–6 MJ/kg (layers A–F) higher than heating value of bulk ROM (Fig. 2, Table 2). If quality conditions of a commercial deposit are good, there is no need to use oil shale separation. But using this method about 5% (Fig. 2, Table 2) of fine grains <1 mm which include clay material will complicate the separation process.

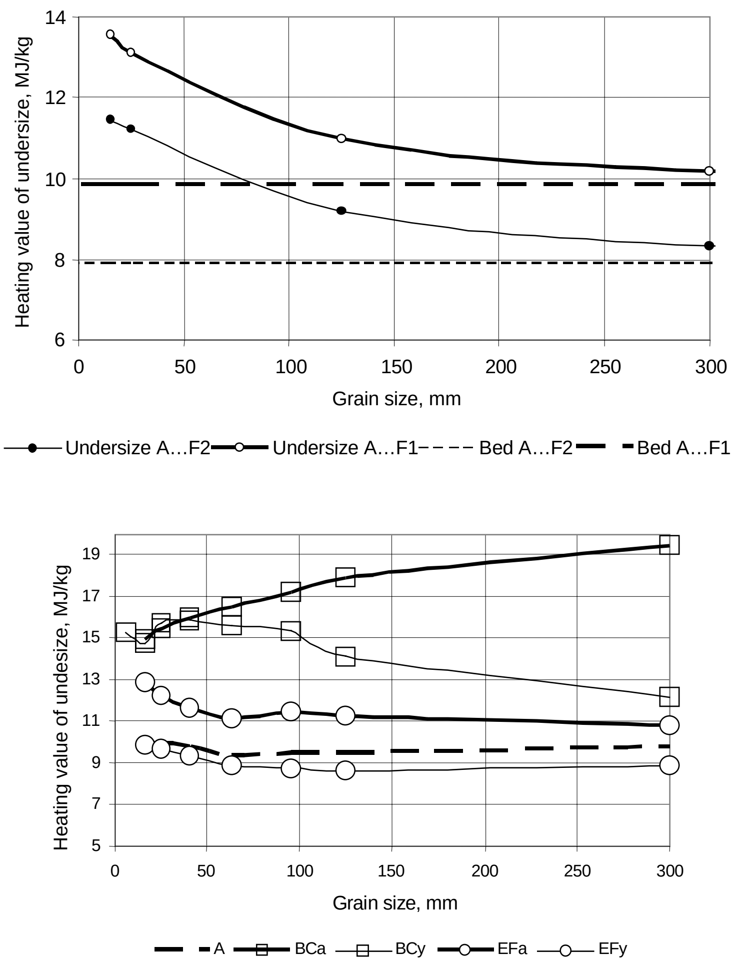

Fig. 2. Energy distribution of ROM: upper – blasting, lower – mechanic breakage with surface miner.

Energy distribution by blast breakage can be described by the formula

$$Q_x = \Delta Q \exp(-kx) + Q_{ROM}, \qquad (9)$$

where: Q_x – heating value of the class 0–x (mm), ΔQ_x – effect of selective crushing, k – parameter of distribution, x – grain size, mm, and Q_{ROM} – heating value of ROM, weighed average of heating values of extracted layers and interlayers.

Table 2. **Parameters of grain-size and energy distribution in ROM for formulas (8) and (9)**

Distribution parameters	Symbol	Extraction method		
		Blasting	Cutting by surface miner	Ripping (after primary crushing)
Particle distribution				
Dustity, dust range	A	0.03–0.06	0.06–0.021	0.1–0.2
Granularity range	n	0.5–0.6	0.3–0.5	0.4
Pieces splitting at transportation from face to factory	δ	0.05–0.15	insignificant	
Energy distribution				
Effect of selective crushing, MJ/kg	ΔQ	3.0–5.8	0	No data, clearly 0
Distribution parameter	k	0.006–0.05	0	
Heating value of ROM	Q_{ROM}	Variable geological characteristic depended on site		

Separation equipment to achieve a higher quality

In the oil shale separation process different types of separation machinery are needed. These are screens, concentration tools, belt conveyors etc. To compose the layout of the machinery one has to know length, height and width of each unit. So we can decide how and where to place the equipment. Knowing the accurate production of material flows and collections one can draw a final layout for the separation plant.

Results

In the case of non-selective mining, oil shale has to be processed in a concentration plant to achieve the desired quality for customers. Oil shale is concentrated in heavy media separation drums.

The stages of the separation process of fine grains which could allow increasing heating value and reduce losses are presented in Fig. 3.

Separation process has multiple steps (a total of six stages). ROM is characterized by size $x \leq 300$ mm and heating value 5.85 MJ/kg. On the first stage of the separation process dry screening (Figs. 3, 4) separates the

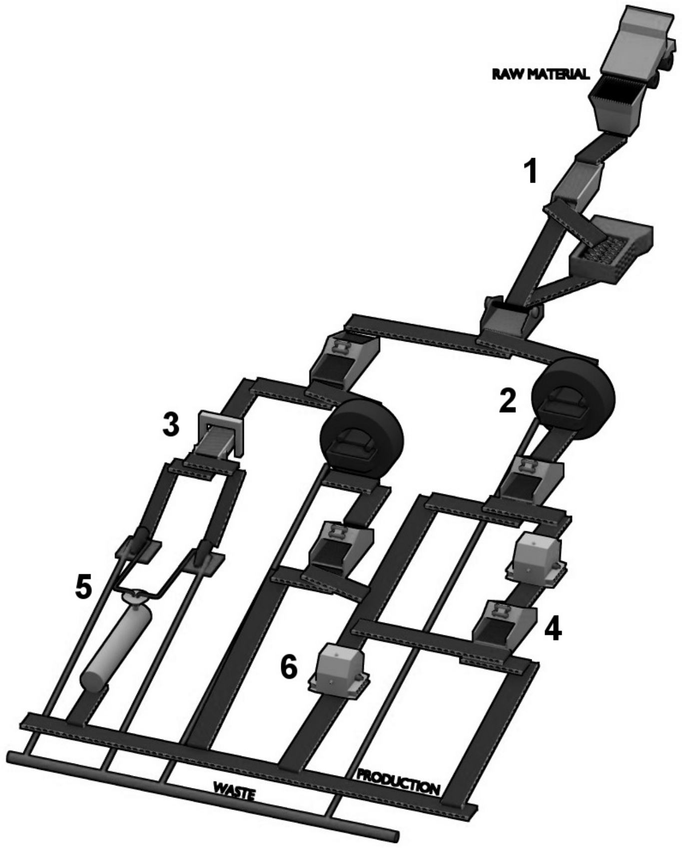

Fig. 3. Principal scheme of oil shale separation plant.

Oil shale separation processes includes: 1 – dry screening, 2 – coarse concentration, 3 – wet screening, 4 – fine concentrating, 5 – dewatering and 6 – production trimming.

material into fine grains 0–25 mm and coarse ones 25–300 mm. According to Eq. (8), fine grains ($x = 25$) make 37% of the total value with energy distribution 9.52 MJ/kg for dry matter and 7.42 MJ/kg for moisture (Fig. 4). Coarse particles ($x = 300$) make 63% and the energy is distributed equally 6.18 MJ/kg to dry matter and 4.98 MJ/kg moisture, respectively.

Further, fine grains 0–5 mm will be separated by wet screening and transported to dewatering for improving heating value. 2% of slime obtained in the process of fine concentration goes to dewatering. Coarse particles will be separated into 19% productive oil shale (11.51 MJ/kg) and 2% slime also going to the dewatering step. Waste from the coarse concentrate makes 41% with heating value 2.0 MJ/kg. The process yields 19% coarse concentrate (11.51 MJ/kg), 14% fine concentrate (11.43 MJ/kg) and 19% of extra fine and slime (8.42 MJ/kg), what makes totally 52% of oil shale with heating value 10.12 MJ/kg (Fig. 4).

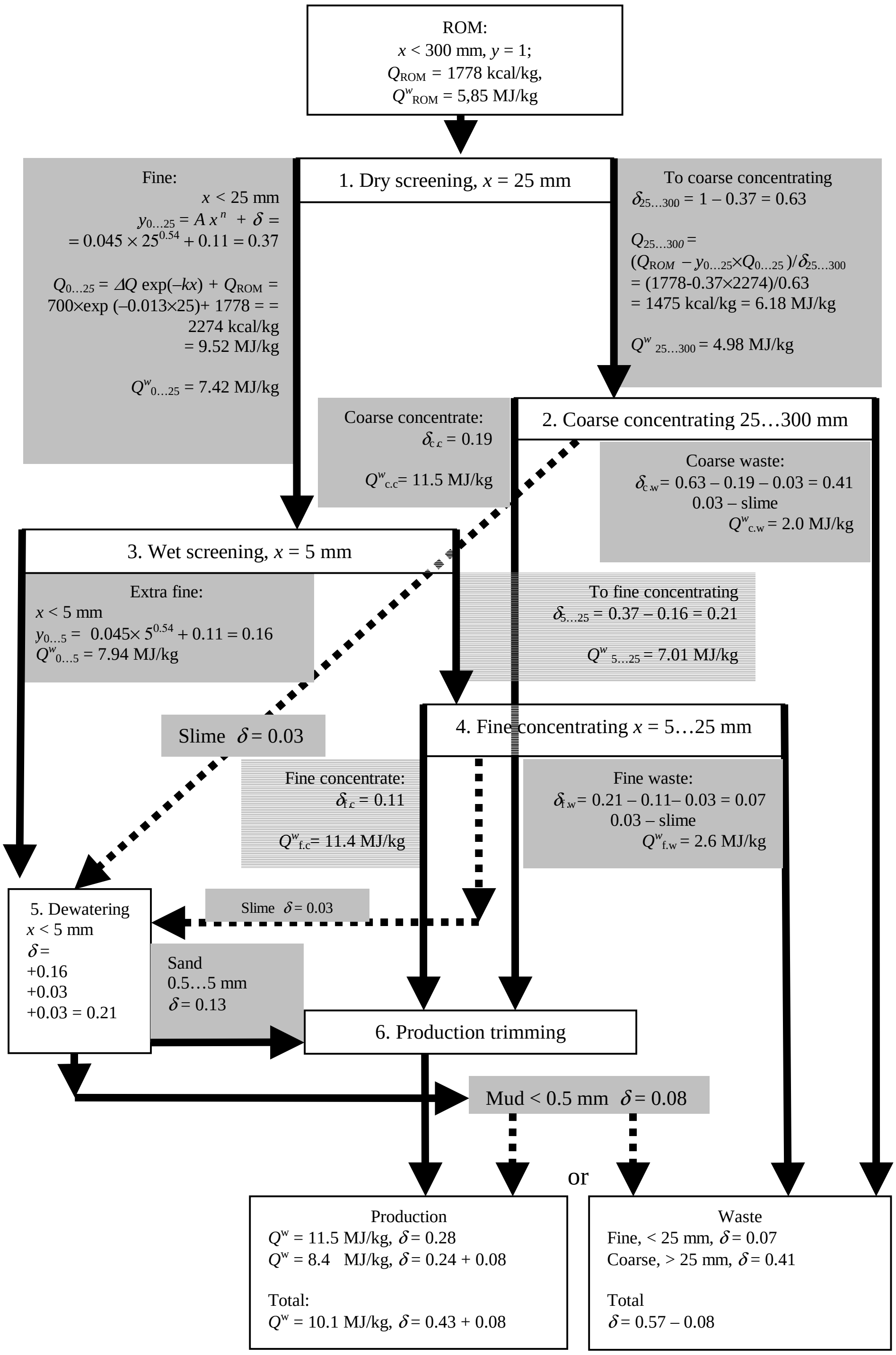

Fig. 4. Separation of oil shale fine grains.

The natural (geological) energy rate of the bed and layers has been measured by different systems basing on dry heating value *Q* in kcal/kg. Therefore heating value in kcal/kg is used.

The main problem of the oil shale separation process

Thanks to the feature of Estonian oil shale, the nature of accompanying limestone strongly differs from the properties of oil shale, and the raw material can be easily separated by gravitational methods. ROM is preliminarily selectively crushed, screened and transferred into the dense-media suspension. Part of the material will be sent after screening for separation of fine grains of high heating value [6]. The results of investigating enrichment of fine-grain oil shale in hydrocyclones, pneumatic separators and settling centrifuges demonstrate a principal possibility for increasing heating value of energetic oil shale [1]. Actual improvement of separation flow sheets and selection of suitable equipment can serve investigation of the oil shale concentration and transportation process from developments in mining to the storage of the finished product.

Discussion

To obtain a higher calorific value for oil shale as fuel we have to use selective mining in oil shale mining fields. In the case of underground mining it is complicated, but in surface mines it is applicable (selective extraction is technically supported by using mechanical cutting method). Using selective mining (using surface miner) in an open cast outlet of fine grains (0–25 mm) is approximately 50% (Fig. 2, line: average by cutting) with heating value of 11.8–12.5 MJ/kg. The best quality (high heating value of ROM) can be achieved if using selective extraction of the seam BC_a . With concretions of pyrite heating value of raw wet oil shale does not exceed 10 MJ/kg. Therefore in case of selecting only layers of limestone, the heating value of product will be 10 MJ/kg. For obtaining high-quality oil shale with heating value 11–12 MJ/kg it is necessary to realize selective cutting not only to separate limestone from oil shale layers, but oil shale has to be cleaned from concretions. To achieve heating value 11.5 MJ/kg, it is necessary to exclude cutting of layers A/B; B/C; C/D; D/E; F1 and selectively cut the upper part of the layer F2, where content of concretions makes up to 37%. Consequently, for 10.5 MJ/kg the layers A/B; C/D; D/E; F1 must be excluded.

During the process of an experimental test on a pilot filter press it was determined that the finest fraction of oil shale slime can be collected by pressure filtration so receiving a transportable sediment with dampness of 30%. Thus, for receiving a transportable technological sediment it is possible to use settling centrifuge and filter press which exclude slime emission to the slime pond. Investigations have shown that in the case of dewatering of slime by centrifuge it is possible to exclude about 60% of slime with particle size of 0.7–1.0 mm. At the same time, slime with dampness 25–30% will be transported together with the rest of unseparated material. The solids of the size of 0.01 mm represent 50%. Experimental testing of a hydrocyclone in the separation factory of the Estonia mine demonstrated the possibilities to separate the slime whose heating value is low, and add to the production about 1% of material with high heating value [7]. On the other hand, there is also the possibility to leave slime in the settling pond and extract it in the further process.

Prospects of extraction development in the Estonian oil shale basin are related to the modern-mechanized mining [5]. For example surface miners (SM) can find their natural application in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers as the deviations are only about one centimeter [3].

Conclusions

The proposed calculation method allows selecting a suitable way for enhancing the heating value in oil shale processing using different mining technologies. The method is suitable for various parts of the Estonia deposit and offers the ability to solve problems in accordance with technical opportunities of extraction and separation processes. Quality control helps to carry out a correct selection of technological solution for future development of mining under various mining conditions.

Calculation model and visualization also helps to better prepare the new oil shale mines such as Ojamaa mine and Uus-Kiviõli mine.

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