Oil Shale, 2000, Vol. 17, No. 1
pp. 45-50
ISSN 0208-189X

https://doi.org/10.3176/oil.2000.1.07

EVALUATION OF VARIABILITY OF ESTONIAN OIL SHALE QUALITY CHARACTERISTICS

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This paper reports the results of statistical analysis of oil shale production and consumption for lots of oil shale delivered by the Company Eesti Põlevkivi *(1996-1998) and variability of low specific calorific value in 1998.*

Based on the analyses of quality characteristics, statistical analyses of samples, data from mining and power enterprises, and considering the degree of variability of oil shale quality characteristics in space and time, recommendations are made to improve sampling methods and measures for increased stability of oil shale quality for consumers.

General

The most important mineral wealth of Estonia is oil shale, used as fuel for thermal power generation, as raw material for producing shale oil, impregnation oil, as well as cement, concrete and other products.

The quality of oil shale is characterised by calcrific value Q, moisture W, ash content A, and carbon dioxide content CO_2, which all influence the efficiency of its use in power and thermal processing plants and building material production. Therefore it is crucial to elaborate standards of oil shale quality characteristics and to investigate how consumers can be guaranteed the required stable quality of oil shale. It is also essential to check the number of samples from mines, opencasts, power plants and other consumers, to evaluate uncertainty and precision of sampling and to determine the quality characteristics.

Standards for moisture and ash content have been developed by the management of *Eesti Põlevkivi* (*Estonian Oil Shale*), as official Estonian standards in 1995. At investigating the methods for determination of averages and primary increment variance of testing gross samples, the coefficients of variation for moisture content W did not exceed 1.5 %, and the results determining ash content A were

For the shortened method	52.38 ± 0.03 %
For the basic method	50.40 ± 0.04 %

The shortened method had a bias (systematic deviation) and therefore was not included in the verified standard.

These and other standards of oil shale quality are necessary and correspond to the ISO standards, creating systems of quality that satisfy consumer needs and security and promote the efficiency of quality policy.

Evaluation of Oil Shale Quality

Research made at the Department of Mining of Tallinn Technical University, based on the experiments of sampling in mines, opencasts and power plants, statistical analyses of the samples, data from mining and power enterprises, and the degree of variability for oil shale quality characteristics in space and time has resulted in the following:

(1) Comparing the coefficients of variation V and the correlation matrix, Estonian oil shale quality characteristics may be arranged in the following order of significance [1]:

High and low calorific value Q_b^d and Q_i^r	V<16 %
Moisture content W_t^r	V<12 %
Carbon dioxide content $(CO_2)_M^d$	V<10 %
Ash content A^d	V< 8 %

(2) Standard deviation of oil shale quality characteristics depends on the size of the oil shale quantity delivered, the number of primary increments and the time between taking the samples [2]. Therefore, in addition to evaluating common statistics for oil shale quality (average, variance, standard deviation, skews and kurtosis), information about sampling conditions: time, place, equipment and sample preparation is required.

(3) Sampling experiments made at mining enterprises and power plants indicated that the coefficient of variation of calorific value in small portions of oil shale (100-200 t) was 7.5-16 %, which means that the precision of determination of calorific value of samples taken at power plants varies between 180 and 300 kJ/kg. All quality characteristics of oil shale samples showed that statistics had a normal distribution and time series random variability [1, 2].

(4) Analysis of distribution tables of sold oil shale lots and Q values in 1996-1998 (Tables 1 and 2) indicated that production and consumption have decreased, statistics of lots was stable and coefficients of variation of specific low calorific value did not exceed 8 %.

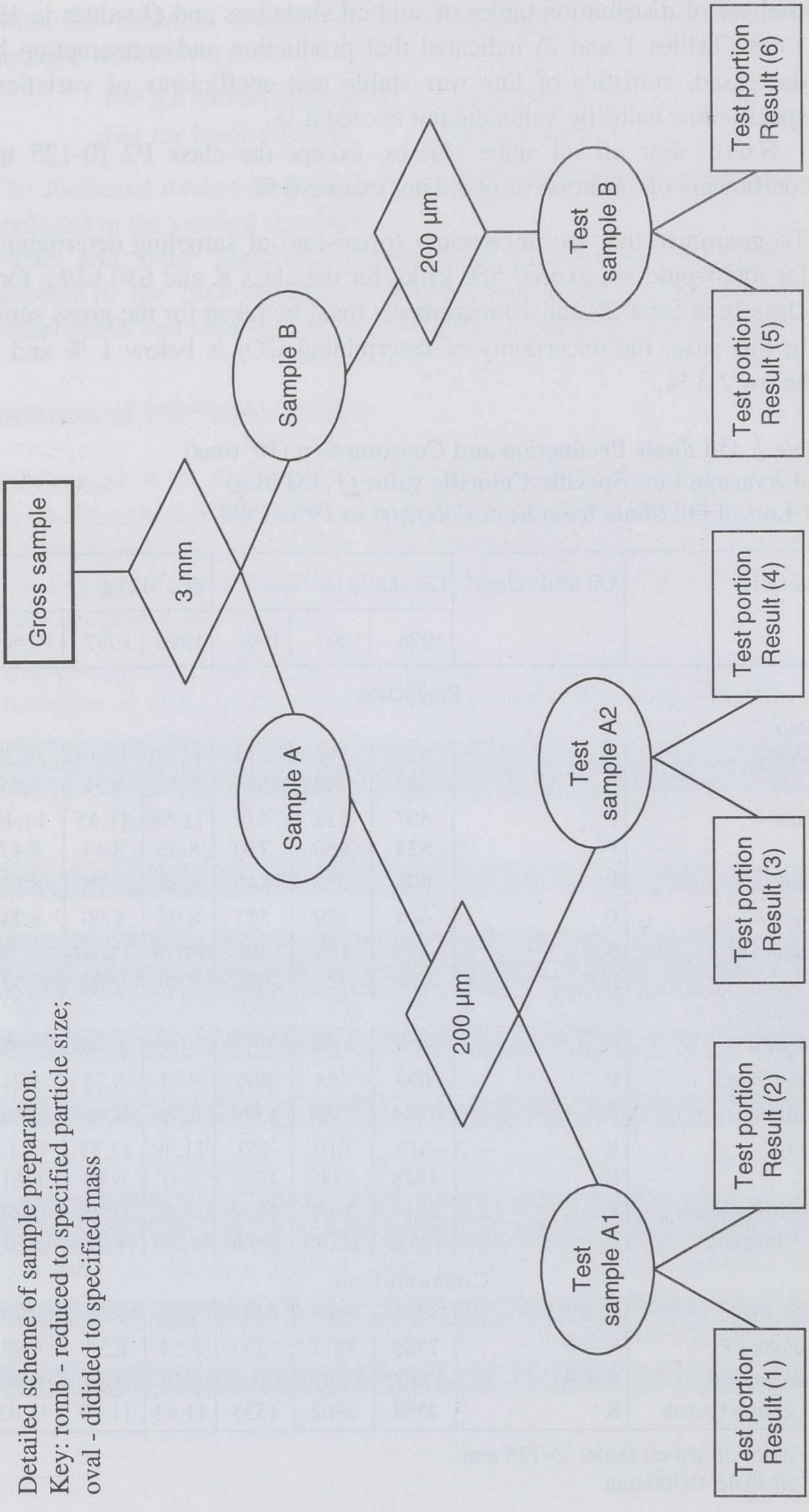
Note: For all oil shale classes, except the class P2 (0-125 mm), coefficients of variation of Q did not exceed 6 %.

(5) To guarantee that the uncertainty (precision) of sampling determining Q for lots would not exceed 550 kJ/kg for the class K and 630 kJ/kg for the class P, at least 25 and 20 increments must be taken for the gross sample. In this case, the uncertainty of determining CO_2 is below 1 % and A – below 2.3 %.

Table 1. **Oil Shale Production and Consumption (10^3 tons) and Average Low Specific Calorific value Q^r_i (MJ/kg) for Lots of Oil Shale from *Eesti Põlevkivi* in 1996-1998**

Enterprise	Oil shale class*	Oil shale, 10^3 tons			Q^r_i, MJ/kg		
		1996	1997	1998	1996	1997	1998
		Production					
Mines:							
Ahtme	K	417	392	274	11.16	11.14	11.22
	P	792	742	696	8.78	8.58	8.65
Viru	K	507	512	473	11.54	11.65	11.46
	P	824	830	710	8.66	8.44	8.47
Kohtla	P	696	633	549	8.68	8.68	8.67
Sompa	P	604	589	527	8.96	8.90	8.74
Tammiku	K	253	123	95	11.78	11.76	11.27
	P	656	715	629	9.26	9.07	9.25
Opencasts :							
Sirgala	P	2191	2208	1978	8.73	8.71	8.69
Viivikonna	P	699	628	500	8.71	8.71	8.71
Narva	P	1774	7769	1572	8.37	8.41	8.39
Aidu	K	618	610	463	11.89	11.77	12.13
	P	1828	1545	1289	8.41	8.48	8.61
Eesti Põlevkivi	K	2717	2702	1932	11.46	11.43	11.49
Company	P	12520	11745	10494	8.57	8.55	8.63
		Consumption					
Baltic PP	K + P	4278	3461	2745	8.59	8.58	8.73
Estonian PP	K + P	7733	7811	7253	8.55	8.53	8.63
Eesti Energia	K + P	12407	11701	10547	8.57	8.55	8.66
Processing branch	K	2372	2362	1535	11.42	11.40	11.43

*K - concentrated oil shale, 25-125 mm.
P - oil shale, 0-300 mm.



Detailed scheme of sample preparation.
Key: romb - reduced to specified particle size;
oval - didided to specified mass

Table 2. **Variability of Low Specific Calorific Value Q^r_i (MJ/kg) Lots of Oil Shale from *Eesti Põlevkivi* in 1998**

Enterprise	Oil shale class*	Average Q^r_i, MJ/kg	Standard deviation, MJ/kg	Coefficient of variance, %
		Production		
Mines:				
Ahtme	K1	11.22	0.35	3.1
	P2	8.67	0.44	5.0
	P3	8.64	0.20	2.3
Viru	K1	11.46	0.35	3.1
	P3	8.47	0.23	2.7
Kohtla	P4	8.67	0.03	0.4
Sompa	P2	8.74	0.43	4.9
Tammiku	K1	11.27	0.50	4.5
	P2	9.47	0.42	4.4
	P3	8.55	0.34	4.0
Estonia	K1	11.16	0.34	3.0
	P2	8.62	0.63	7.3
	P3	8.11	0.44	5.4
	P4	9.02	0.50	5.6
Opencasts:				
Sirgala	P4	8.68	0.36	4.1
Vivikonna	P4	8.71	0.43	4.9
Narva	P4	8.39	0.36	4.4
Aidu	K1	12.18	0.39	3.2
	P3	8.61	0.32	3.7
Eesti Põlevkivi Company	K1	11.49	0.48	4.2
	P2	8.79	0.63	7.2
	P3	8.53	0.30	3.5
	P4	8.60	0.37	4.3
		Consumption		
Baltic PP	K + P	8.73	0.66	7.5
Estonian PP	K + P	8.63	0.47	5.5
Eesti Energia	K + P	8.66	0.52	6.0
Processing branch	K	11.43	0.48	4.2

* Classes: K1 - concentrated oil shale, 25-125 mm.
P2 - oil shale, 0-125 mm.
P3 - oil shale, 0-25 mm.
P4 - oil shale, 0-300 mm.

(6) Detailed checking of the variances of sample preparation and testing (Figure) showed that the variances were:

at the first stage of sample division V_1 = 1225 kJ/kg
at the second stage of sample division V_2 = 101 kJ/kg
at the analysis V_3 = 216 kJ/kg
at sample preparation and testing V = 1541 kJ/kg

The uncertainty of sample preparation and testing was established as 177 kJ/kg and did not exceed 20 % of the total uncertainty by sampling, sample preparing and analysing. Therefore, it is very important to investigate in detail the procedures of taking increments for the gross sample to guarantee representative and reliable sampling. It comprises methods of checking random and normal distribution of increment statistics, statistical hypothesis for comparison of means and of variances.

(7) Analyses indicated that the low calorific value Q^r_i as the main quality index has a high and significant coefficient of correlation with all other quality indices and therefore this index is recommended to be used for classification and determination of the price scale for selling oil shale to consumers [1].

(8) Experiments showed that the stability of oil shale quality could be considerably increased by storing oil shale in depots of opencasts and power plants. A decrease in the standard deviation of the calorific value of oil shale for power plant boilers resulted in reduced specific quantity of oil shale for power generation [2].

(9) A relationship predicting boiler performance depending on oil shale quality has to be developed to predict the costs and price of power generation.

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Presented by E. Reinsalu
Received June 22, 1999