

## Experience in coal sampling parameters calculation

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### *Skúsenosti s výpočtom parametrov vzorkovania uhlia*

*This paper describes the selection of parameters necessary for the calculation of minimal representative quantity of coal sample for various investigations in the field of mineral processing. The procedure is illustrated on the example case of the Drmno coal field, from where the coal is delivered to the thermal power plant Kostolac. Two primary samples of coal, crushed down to different sizes and prepared (homogenized and divided), are analyzed for the ash content and the results were statistically processed. The analytical results are statistically processed. Analytical and graphical solutions, at the lowest sampling error, give an optimum range of the representative minimal sample mass for the given coal size. The coefficient of proportionality,  $k$ , which characterizes the kind of mineralization in the given material, and  $\alpha$  exponent for the Drmno coal type, are determined.*

**Key words:** primary sampling, coal, representative secondary sample, statistical errors

### Introduction

Klenovik, Ćirikovac, and Drmno are three open-pit mines of the Kostolac coal basin, which produce significant quantities of coal. The run-of-mine (ROM) coal is crushed and screened prior to its conveying to the Kostolac B thermal power plant (TPP). The steam coal for the TPP is permanently sampled to control the coal quality for coal quality control. Both, the coal producer and the user (TPP) are equally interested in the operative-control sampling and the quality control due to technological demands and mutual commitments.

In the coal preparation plant a mechanical sampling system, was used designed to perform the sampling and the sample partition, on the spot, with a minimal representative mass for the required analyses. The sampling system was planned to operate according to the valid standards and some empirical knowledge of coal sampling of similar properties. Unfortunately, though needed, the device has not been put into operation.

The aim of this work is to identify the sampling parameters for the Kostolac coal type mined at the Drmno open pit, providing the sampling principles, which determine the minimal quantity of the representative sample for the given raw material properties. For the experimental selection of parameters and the statistical data processing, two samples of different size and weight were taken and used in this investigation.

### Sampling

According to the designed and partly completed technology, the coal preparation process consists of the following:

- separation of lump coal (for domestic purposes) on roller rosts and a further classification,
- crushing of the undersize in hammer crushers down to -30 mm (for TPP) and conveying to the TPP stockyard,
- alternatively, the ROM coal can be routed to crushing for the steam coal production, which is usually performed during a winter season, when fuel is increasingly demanded by the TPP.

After crushing, the grain class of steam coal -30+0 mm, which is the subject of our test, is conveyed by the belt system to the TPP

The task of the test was taking the sample from the crushed coal stream, size -30+0 mm, and its preparation with the purpose of establishing the minimal sample quantity for the given analytical error for the specific type of coal.

An experimental of sampling parameters for this coal a significant mass of the primary sample. The principal assumption of the sampling theory is based on the fact that the sampling error is inversely related to the sample mass, which means that an increase in the sample mass will provide a lower sampling error.

For the primary sampling, the well-known method [1-6] was used, which basically assumes the relation

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$$Q_{\text{prim}} = m \cdot n \quad (1)$$

meaning primary sample mass is proportional to the minimal mass of individual samples (increments)  $m$  (kg) and to the number of individual samples required  $n$ . The minimal mass of individual samples will depend, in the given case, on the conveyor-belt capacity ( $Q = 2700$  t/hr), its width ( $b = 1600$  mm), moving speed ( $v = 3,9$  m/s), and the total length ( $L = 30$  m). The sampling interval is calculated from the sampling consignment ( $M$ ), the conveyor-belt capacity ( $Q$ ), and the empirically determined number of individual samples. The mass of the individual sample can be expressed as:

$$m = \frac{Q \cdot b \cdot \sin \alpha}{3,6 \cdot v} \quad (2)$$

where,  $b$  is the slot width of the sampler (mm),  $\alpha$  is the angle between the conveyor centreline and the sampler and  $v$  is the conveyor velocity (m/s). The sampling interval for the individual sample separation from the conveyor will be:

$$t_i = \frac{60 \cdot M}{Q \cdot n} \quad (3)$$

where,  $M$  is the consignment to be sampled (t),  $Q$  is the belt capacity (t/hr), and  $n$  is the number of the individual samples.

In the case of sampling by the mechanical sampling system, from the standing or moving conveyor belt, the sample mass (kg/hr) can be calculated from the formula:

$$Q_{\text{meh}} = \frac{Q \cdot b \cdot n_{\text{meh}}}{3,6 \cdot v \cdot T} \quad (4)$$

where  $T$  is the sampling time (hr),  $n$  is the number of partial samples per hour, and  $b$  is the width of the sampler ( $b > 3d$ ).

Certainly, for a manual sampling, when the belt stands still, the calculation takes into consideration the length ( $L$ ) of the conveyor belt on which the material is sampled. The samples for this investigation were taken from the belt conveyer TR - 10, where the mechanical sampling system is located according to the design, and prepared for the laboratory tests. For the reported test, two representative samples of raw coal were separated.

The first primary sample  $^1Q_{\text{prim}}$ , size -40+0 mm, was collected from the conveyor by the partial cutting method. The material was cut on the conveyor belt in a length of 2 m. Individual samples were unified into composite samples within the time interval of one hour. The Sampling proceeded in the same way, each hour through one shift, and the finally collected material formed one composite sample. The total mass of this representative sample was 1200 kg. The second sample  $^2Q_{\text{prim}}$ , was simultaneously collected in the same manner and weighted 600 kg. Prior to the dividing, this sample was crushed down to the size of -10+0 mm in the jaw crusher.

Both representative primary samples: first one  $^1Q_{\text{prim}}$  of 1200 kg weight, size -40+0 mm, top size 37,4 mm; and the second one  $^2Q_{\text{prim}}$  of 600 kg, size -10+0 mm, top size 5,83 mm, were equally homogenised and divided into eight individual samples in six sets of secondary samples. The treatment procedure of the two representative raw coal samples is shown in Fig. 1. In each of the six stages of the preparation (homogenisation, quartering, homogenisation, chessboard sampling), the primary sample was divided and eight representative samples were obtained for chemical analysis. After the treatment, six sets of eight single representative samples were separated. Each sample in a set was analysed for the ash content, statistically processed, and average ash content  $\bar{p}_i$ , the average deviation  $\sigma_p$ , ash variation coefficient  $K_V$  were expressed for each set. Finally, the mean error of the ash content determination or the laboratory analytical error was determined. The respective mean values are given for each of the six sets of the samples in tables for  $^1Q_{\text{prim}}$  on the left and  $^2Q_{\text{prim}}$  on the right of the diagram (Fig. 1).

The average ash content for the first sample  $^1Q_{\text{prim}}$  was 24,74 %, which was used to calculate the deviation from the average rate for each set of samples. It proved, as mentioned in the beginning, that with the increasing masses of individual samples from 2,34 to about 75 kg, the mean determination error of ash content in samples decreases from 2,55 to 1,62 %, which was extremely helpful in the analysis of the representativeness of the minimal sample mass. Ranges of other calculated parameters, from the set I to VI, were from 1,83 to 3,35 for the standard deviation, and from 7,59 to 14,71 % for ash content variation coefficient.

The average ash rate for the second sample  $^2Q_{\text{prim}}$  was 24,75 %. Like for the first sample, the deviation from the average content was calculated for each set. With the increasing mass of individual samples from 1,17 to 37,5 kg, the mean deviation decreased from 2,67 to 1,68. Ranges of other calculated parameters, from

set I to VI for the second sample, were from 2,12 to 3,14 for the standard deviation and from 8,05 to 12,03 % for the ash content variation coefficient. As before, the highest deviation from the standard ash content was in the set VI (inadequate sample weights).

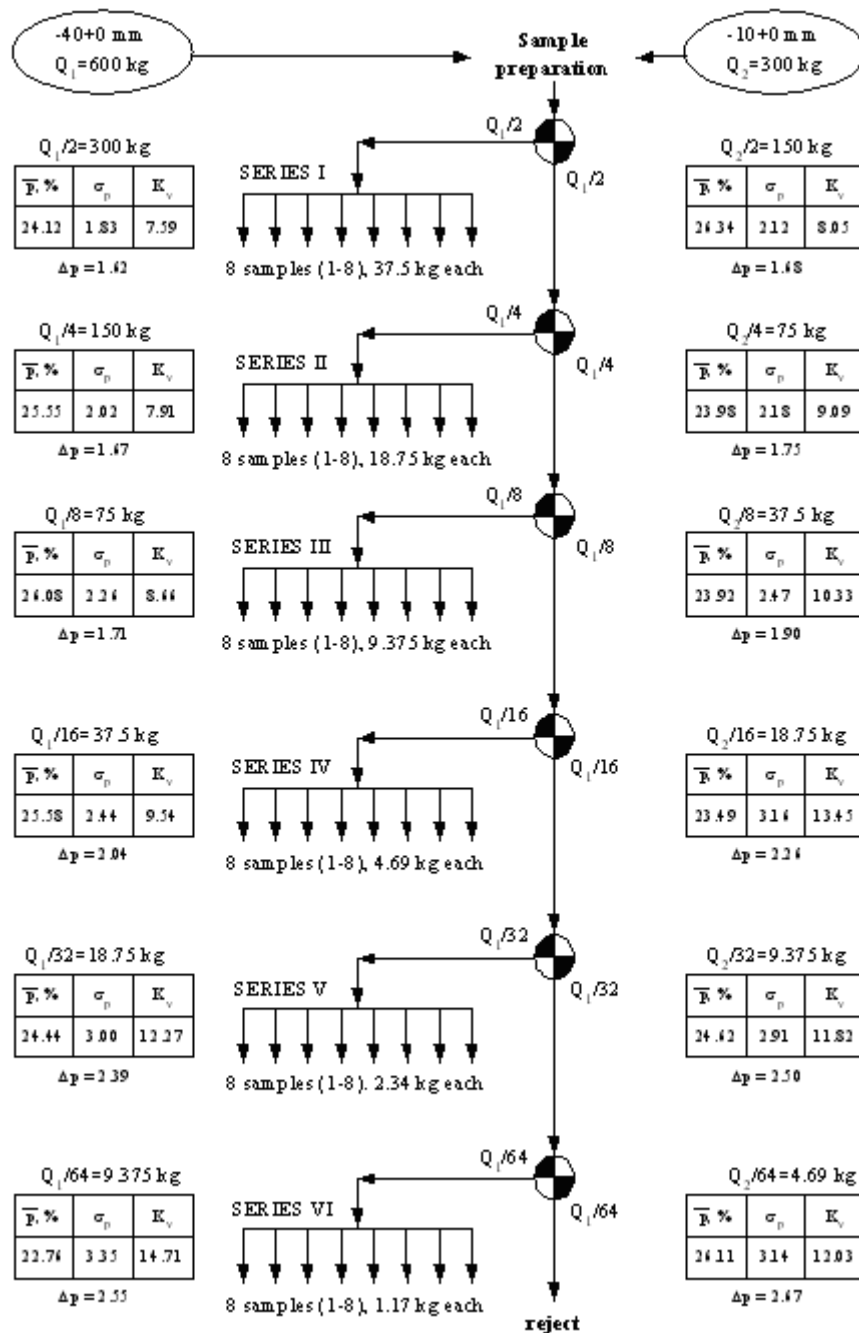


Fig. 1. Summary of sampling stages employed in this examination.

The relationships of individual sample weights and errors, (deviations from the mathematical expectations), for both tested samples are presented graphically in Fig. 2. Beside curves 1 and 2, the analytical error of ash content determination is marked as the minimal value - sensitivity step of the specific laboratory.

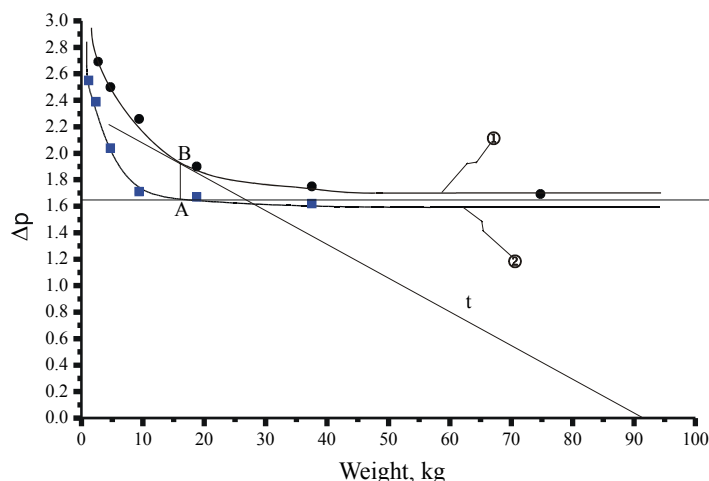


Fig. 2. Sample weight versus the error of the determination of representative sample minimal mass.

### Selection of sampling parameters

The two obtained curves can be approximated by the analytical relation  $y=a/x+b$ . The curves show that with the increasing mass of individual sample, the mean deviation gradually decreases to a constant value, (irrespective of the further increase of the sample mass) which represents the analytical error or sensitivity threshold for the applied method. The absolute value of deviation cannot be reduced under the given conditions below this minimum (rectilinear part of the curve). Since the rectilinear parts of the curves, do not concur, their mean value is drawn as a line between them.

The mean value of 1,65 is the analytical error, unavoidable for the given technique of the sample treatment and the chemical analysis in the given laboratory. The minimal masses of representative samples are determined on this intermediate line. The minimal mass of the representative sample  $^1Q_{min}$  is obtained as follows: A vertical line is drawn from the point A (the intersection of the line *a* - the mean deviation from the average rate and the curve 2) up to the curve 1. In the point B (intersection of the vertical line and the curve 1), the tangent *t* is set intersecting the line *a* and the abscissa  $w_i$ . The minimal mass of representative sample  $^2Q_{min}$  is obtained in a similar way: the vertical line is drawn from the intersecting point A of the line *a* and the curve 2 to the abscissa where the value of the minimal mass is read for the representative sample  $Q_2$  16,70 kg. In this way, the applied statistical data processing and the graphical method provided the minimal mass of the representative samples adequate to the given conditions and the known analytical error.

These values, were used for the determination of basic parameters in the equation  $Q_{min} = k \cdot d_{max}^\alpha$ .

The first primary sample  $^1Q_{prim} = 1200$  kg  
 Size fraction -40 + 0 mm  
 $\bar{p}_i = 24,74$  %  
 $m_i = 2,34 \div 74,5$  kg  
 The mean determination error  
 $\Delta p = 2,5 \div 1,62$  %  
 $\sigma_p = 1,83 \div 3,35$   
 $K_V = 7,59 \div 14,71$  %

The second primary sample  $^2Q_{prim} = 600$  kg  
 Size fraction -10+ 0 mm  
 $\bar{p}_i = 24,75$  %  
 $m_i = 1,17 \div 37,5$  kg  
 The mean determination error  
 $\Delta p = 2,67 \div 1,68$  %  
 $\sigma_p = 2,12 \div 3,14$   
 $K_V = 8,05 \div 12,03$  %

The values obtained for the minimal mass of the samples  $^1Q_{min}$  and  $^2Q_{min}$  were substituted in the above equation to determine the parameter *k* and  $\alpha$  as follows: the established graphical representation of the relationship between the mean error and the sample mass *Q* gives the respective masses of samples  $Q_1$  and  $Q_2$ , and the mean deviation of 1,65 % for samples crushed to sizes  $d_1$  and  $d_2$ . By substituting the respective  $Q_1$  and  $Q_2$  masses in the equations:

$$Q_1 = k \cdot d_1^\alpha \tag{5}$$

$$Q_2 = k \cdot d_2^\alpha \tag{6}$$

and taking the logarithm of these equations, the results will be:

$$\log Q_1 = \log k + \alpha \log d_1 \tag{7}$$

$$\log Q_2 = \log k + \alpha \log d_2 \quad (8)$$

The subtraction of both equations is:

$$\log Q_1 - \log Q_2 = \alpha(\log d_1 - \log d_2) \quad (9)$$

and

$$\alpha = \frac{\log Q_1 - \log Q_2}{\log d_1 - \log d_2} = \frac{\log \frac{Q_1}{Q_2}}{\log \frac{d_1}{d_2}} \quad (10)$$

Substituting  $\alpha$  in the first equation, will give the value of  $k$ :

$$\log k = \log Q_1 - \alpha \log d_1 \quad (11)$$

According to the published papers and references [1,7], the value commonly used for the coefficient  $k$  is 2 or higher. As the determination of sampling parameters requires coefficient  $k$ , which is directly dependent on the type and character of material, the provisionally accepted value of 2 and its substitution in the above equation will give  $\alpha$  0,07.

The overview of the well-known and mostly used principles for determination of the minimal sample mass for various technological investigations is given in Tab. 1.

Tab. 1. Overview of methods for the determination of the minimal mass of representative samples and respective parameters

	Referencee	Equation	Parameters
1.	Richards 1909; G. O. Chechott 1920; 1932	$Q_{\min} = k \cdot d_{\max}^2$	$Q_{\min}$ - minimal quantity of sample, kg; $d_{\max}$ - top size, mm; $k$ - coefficient of proportionality which depends on material characteristics: variation in the valuable component content, mineral size, and the component content in the raw material (0,16-24,00, presently in practice 0,1-0,5-1,0). For coal (0,4-1,5).
2.	Demond and Halferdal 1923.	$Q_{\min} = k \cdot d_{\max}^{\alpha}$	$Q_{\min}$ - minimal sample mass, kg; $d_{\max}$ - top size, mm; $k$ - coefficient of proportionality, which depends on material properties (density, grain shape, content, uniformity and size of minerals) and on the permissible error; $\alpha$ - exponent value which varies in relation to the raw material within the range from 1,5 to 2,7. Coefficients $k$ and $\alpha$ are empirical given in a table.
3.	Veizin 1865.	$q = K \cdot d^3$ $\frac{q}{Q} = \frac{d^3 \cdot \delta \cdot n}{D^3 \cdot \delta \cdot n} = \frac{d^3}{D^3}$	$Q$ - initial sample mass (primary sample); $q$ - sample weighted for the chemical analysis (secondary sample); $d$ - grain top size in the sample for the chemical analysis; $D$ - grain top size in the primary sample; raw material density; $n$ - number of mineral grains.
4.	Brunton 1898.	$Q = \frac{D^3 \cdot \delta \cdot f \cdot n}{10^4 \cdot p} \cdot \left( \frac{\beta}{\alpha} - 1 \right)$	$Q$ - primary sample minimal mass, kg; $D$ - top size of the grains in the sample, mm; $\delta$ - valuable mineral density; $\beta$ - metal content in the valuable mineral; $\alpha$ - average metal content in the sample; $n$ - number (quantity) of grains in the divided sample - suffocate or deficit regarding the primary sample; $f$ - rate of largest valuable mineral grains; $p$ - permissible sampling error, equal to the relative error of the chemical analysis.
5.	Chernenko.	$Q = k \cdot d$	$Q$ - representative sample minimal mass; $d$ - mean diameter of largest grains, mm; $k$ - coefficient of proportionality, 1-1,5 for the uniform and non-uniform mineralisation.
6.	P. Gy 1982.	$Q_{\min} = \frac{C \cdot d^3}{V}$	$Q_{\min}$ - minimal permissible sample mass for the analysis, g; $C$ - raw material constant, g/cm <sup>3</sup> ; $d$ - top size of sampled material, cm; $V$ - variation coefficient of valuable mineral content.
7.	N. Barishev	$Q = q \cdot n = q \cdot \frac{t^2 \cdot V_m^2}{p^2}$	$q$ - mean mass of single samples, kg; $n$ - number of single samples $t$ - probability coefficient equivalent to the sample representativeness ( $t < 1,7-2,0$ ); $V_m$ - variation coefficient of valuable component in the sample, $p$ - given sampling error
8.	I.P. Alimarin	$Q = \frac{(100 \pm P) \cdot d^3 \cdot \delta}{n^2 \cdot P \cdot 10^5}$	$P$ - valuable component content, %; $d$ - top size, mm; $\delta$ - average particle density; $n$ - permissible relative analytical error
9.	Pozharickii	$Q_{\min} = 0,06 \cdot d^2 \quad \text{kg}$ $Q_{\min} = 0,1 \cdot d^2 \quad \text{kg}$ $Q_{\min} = 0,18 \cdot d^{2,25} \quad \text{kg}$	- Uniform mineralisation, valuable component with small intergrown grains - Non-uniform mineralisation, like rare mineral ores. - Extremely non-uniform distribution of mineral component.
10.	G.I.Prejgerzon, M.N.Albov, V.M.Kryter	$Q = q^n$	$q$ - mean mass of individual samples (portions, cuts) to be unified into a general sample, kg; $n$ - number of individual samples, where $n = (tV/p)^2$ ; $V$ - coefficient of metal content variation in single samples, %; $t$ - probability coefficient; $p_o$ - permissible (given) sampling error, % of the component content

The method determining  $k$  and  $\alpha$  is based on the assumption that with the increasing sample mass (for given size of material) the sampling error decreases to a value which depends on the accuracy of chemical analysis and the sample preparation method. Thus, the summary or the total error of sample preparation, excluding the sampling error, consists of the error of the sample division due to the inadequate homogenisation during the treatment and error from insufficient number of pieces in the sample, i.e. the inadequate sample mass, as well as the error of the chemical analysis [8]. Since the error from the insufficient sample mass is included in the total error, and because the error resulting from the inaccuracy of the sample division is insuperable, the former error is not possible to determine. Still, a careful operation of the sample division during the homogenisation can reduce the specific error to a constant value. Consequently, the variation of the total error from one set to another will be a result of the disproportion between the sample mass and the grain size in the mixture.

### Conclusions

The described method of the determination of the parameter  $\alpha$ , and even more of proportionality coefficient  $k$ , is a quite complex and tedious procedure due to a large number of samples to be treated, which is time and money consuming. In turn, it provides parameters whose values are accurately determined characteristics of the given coal type, applicable to the given deposit for a long time (uniformity and constancy of mineralisation).

A primary sample, which would be separated in the designed sampling system at the transfer point of conveyor belt T-10, would weigh about 1730 kg (single samples of 57 kg, sampling interval of 16 min).

The mass of the representative sample of the given coal size, hauled to the TPP stockyard, is calculated, on the principles which assume that  $Q_{\min} = k \cdot d_{\max}^2$ , to be  $k=0,10$  and  $\alpha=2$ , and amounts 160 kg.

The preparation of the primary sample, specially separated for this investigations, with the total mass of 1800 kg ( $^1Q_{\min}=1200$  kg and  $^2Q_{\min}=600$  kg), the statistical processing, i.e. the calculation of the deviation from mathematical expectation at the given level of data reliability (analytical error), and the application of the graphical method, all gave the representative sample minimal mass of 16,70 kg for the finer coal or 92,75 kg for the steam coal, with the size of -40+0 mm.

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