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MODELING OF THE PROCESS OF COAL GRINDING

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The use of coal in the steel industry, similarly as in the whole national economy, is often preceded by its pre-treatment. Coal is mined in the form of big solids, but, being in such a form, it can't be combusted, sintered, or gasified. Therefore, it needs to be appropriately grinding. In the paper results of the numerical prediction of the grain size distribution of the grinding coals are presented. The numerical computations were performed and then they were compared with grain size analysis results.

Key words: coal, modeling of grinding process, grain size distribution, Maxwell-Boltzmann law, numerical prediction

INTRODUCTION

The development of humankind is inseparably connected with the use of energy, whose generation involves the use of energy raw-materials. Currently, fossil fuels, such as hard coal, brown coal, petroleum and natural gas meet 80 % of the demand for primary energy [1]. This trend will last most probably up to 2030 [1].

The world's reserves of extractive energy raw-materials (2005) are estimated at about 861 Gtoe, of which 62,4 % account for the hard coal and brown coal resources. Hard coal is the most readily available fossil fuel, and its reserves will be available longer than those of petroleum or natural gas. With the assurance of rational management and the meeting of the environmental protection requirements, hard coal might provide a base not only for power and heat engineering, but also for other commercial technological processes.

Grinding is an engineering process of great importance for many branches of industry. It is applied primarily in the processing of minerals, and in particular coal, silica, limestone, sulphur and other useful minerals, as well in metallurgy, pharmacology, materials engineering, the power industry and other fields.

Generally, the study of the grinding process can be divided into two basic areas. The first of these areas is concerned with the energy intensity of this process, while the second one with the determination of the grain size distribution of the grinding product. The study of the energy intensity of the grinding process is very important, because energy intensity is the main measure of the process costs. Thus, it is the criterion for the cost-effectiveness of the process. The grain size distribution is the basic qualitative criterion for the grinding process. The methods of laboratory determination of the grain size distribution of a substance are burdensome. They generally require a long time for making determinations. The determination technique often causes great problems – fine-grained substances coagulate to form agglomerates, and the samples contaminate the measuring equipment; the repeatability of determinations depends very significantly on the selection of the representative sample. When comparing determination results obtained by different methods, often considerable discrepancies between determinations can be found. Modern measuring instruments are very costly and usually require a wide range of accessories.

For these reasons, eliminating the laboratory determination of grain size distribution from the entire grinding process and substituting it with, e.g., a numerical method of grain size composition evaluation would be most desirable. Indeed, this would allow the evaluation of the grain size distribution of brittle solid materials, such as the components of refractories used in metallurgy, pulverized coals combusted in different types of power plants, coking coals, etc.

THE MODEL OF GRINDING PRODUCT GRAIN SIZE DISTRIBUTION

The effect of the grinding process depends on a very large number of parameters. These include quantities related to the material being comminuted, the grinding equipment, the method of supplying energy, etc. Moreover, these quantities are very often characterized by randomness. Thus, the unique deterministic description of the grinding process is very difficult. In many instances, statistical theories are therefore used [2].

In this paper, the Maxwell-Boltzmann statistics is used for the description of the grain size distribution in the grinding process.

The effect of grinding is dependent, e.g., on the energy supplied to the material particle being ground. The

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supplied energy destructs the cohesion forces between molecules in the particle and, at the same time, increases the mean energy of the molecules of comminuted material particles. The mean energy of grinding product molecules will depend on the grain size. The finer the grains, the higher the mean energy level of a single molecule [3]:

$$\overline{\varepsilon}_l = \frac{n_p\varepsilon_p + n_k\varepsilon_k + n_w\varepsilon_w + n_{wew}\varepsilon_{wew}}{n} \qquad (1)$$

where: $n = n_p + n_k + n_w + n_{wew}$ – total number of, respectively: surface, edge, top and internal molecules; n_p, n_k, n_w, n_{wew} - bond energy per surface, edge, top and internal molecule, respectively.

The finer the product grain, the smaller the number of internal molecules compared to internal molecules in a particle. Thus, the mean energy value of a particle molecule increases. The averaged bond energy of a product molecule, $\overline{\varepsilon}_l$, will be closer to ε_{we} for large monolithic material solids, whereas for sub-colloidal comminutions, the value of $\overline{\varepsilon}_l$ will approach ε_w .

The presented model proposes the thesis that the distribution of the mean energy of product particle molecule, and thus the grain size distribution of the grinding product can be described analytically based on the classic Maxwell-Boltzmann statistics. It describes the distribution of ideal gas molecules into different energy levels. In the case of ideal gas, this distribution concerns the kinetic energy of the translational motion of molecules; the energy of potential intermolecular interaction is omitted. It has been demonstrated that a similar situation occurs also for a solid material [4]. However, in this case, there is no kinetic energy of the material's molecules (being at rest), and the total internal energy equals the energy of broken intermolecular bonds of a potential nature [5].

Maxwell-Boltzmann law is described by the relation [4]:

$$n_i = n_0 \cdot e^{-\frac{1}{kT}(\varepsilon_i - \varepsilon_0)} \qquad (2)$$

where: n_i – number of the i-th state molecules, n_o – number of the ground-state molecules, k – Boltzmann constant, ε_i – energy of the i-th state molecules, ε_o – energy of the ground state molecules, T – temperature.

Using this relation, particle size distribution can be described [5]:

$$F_i = \frac{m_i}{m} = \frac{n_i}{n_0} = e^{-(\varepsilon_i - \varepsilon_o)\frac{1}{k\cdot T}} \qquad (3)$$

where: F_i – the participation of grains smaller than the size of X_i, X_i – size of i-th grain.

The energy of the i-th and the ground state can be determined from the thermodynamic theory of grinding [3]:

$$\varepsilon_i = \frac{\alpha}{n} \cdot \frac{6}{X_i \cdot \rho} + \frac{\sigma_m^2}{2 \cdot E \cdot \rho \cdot n} \qquad (4)$$

$$\varepsilon_0 = \frac{\alpha}{n} \cdot \frac{6}{\rho \cdot X_{max}} + \frac{\sigma_m^2}{2 \cdot E \cdot \rho \cdot n} \qquad (5)$$

where: α – energy of surface molecules, σ_m – breaking compressive stress, E – Young's modulus, ρ – density of the comminuted substance, X_{max} – size of the largest grain of the grinding product.

Finally, the formula for the size distribution takes the form:

$$F_i = e^{-\frac{6 \cdot M \cdot \alpha}{(MR) \cdot \rho \cdot T}\left(\frac{1}{X_i} - \frac{1}{X_{max}}\right)} \qquad (6)$$

where: M – the mass per unit amount,
(MR) – constant called universal gas constant.

THE RESULTS OF THE NUMERICAL PREDICTION OF PARTICLE SIZE DISTRIBUTION

The coal is a very important raw material in the steel industry [6]. It is extracted in the form of solids of considerable size and as such form may not generally be burned, sintered or gasified. So it must be properly comminuted.

Grinding of coal generally uses two types of crushers, namely, the drum crushers and the hammer crushers. The drum crushers consist of two parallel set of drums stocked on circumferences of the performances in the form of spikes, rotating at high speed in opposite directions. Getting between the rotating drums coal is crushed and falls out of the drums. The hammer crushers are rotating crushers, in which the main working element is a rotating impeller. The motor will surge as a result of the impact of the grain material to be comminuted. In the case of hammer crushers main blow to the grain occurs at the meeting of the jet material with rotating, freely suspended on the rotor hammers. Runaway hammer smashes grain and drops them on the crumbling plate, as part of the housing crusher. In the final stage of process grains fall to the grate, and, if them pass by it, are rubbed by, sliding after them in the direction of motion of the rotor, hammers. Thus, in a hammer crusher three crushing factors run, in order from most to least important: elastic impact, stroke, and abrasion.

Granulation of products obtained from hammer crusher is mainly dependent on the width of the grate slits and the distance the hammers from the surface of the grate. The linear velocity of the hammers is important, also. The linear velocities hammer crusher with this purpose are usually about 20 m / s.

The results of the numerical prediction of grain size distribution of crushed coals are presented in the paper. The coal was crushed in the Coke Department of Czestochowa Plant. The numerical determination of grain size distribution of crushed coal was made, and the results obtained in this way were compared with the results of laboratory analyzes of grain made. In this purpose, the results of the grinding process in a hammer crusher (Figure 1). The hammer crusher was powered by an engine power of 400 kW; he had a peripheral speed of 735 rev/min; maximum capacity - 100 t/h.

The following types of coals were investigated: type 37,1. from the Nowa Ruda mine; the Maj mine, the Anna mine, the Pniówek mine.

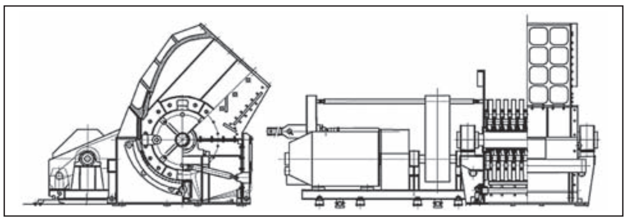

Figure 1 Distribution crusher hammer drill, OKD 1155 with the drive [7]

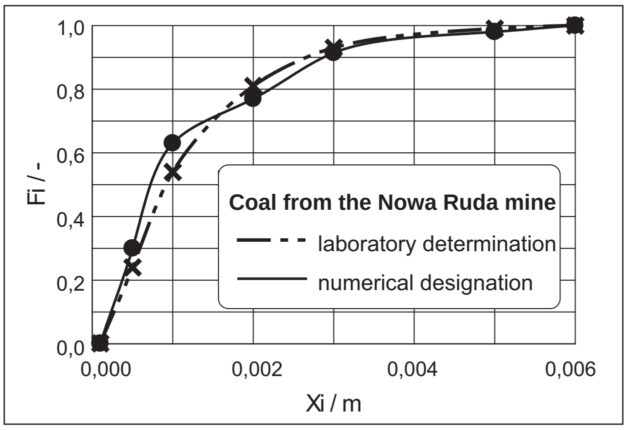

Figure 2 The grain size distribution of the coking coal from the Nowa Ruda mine

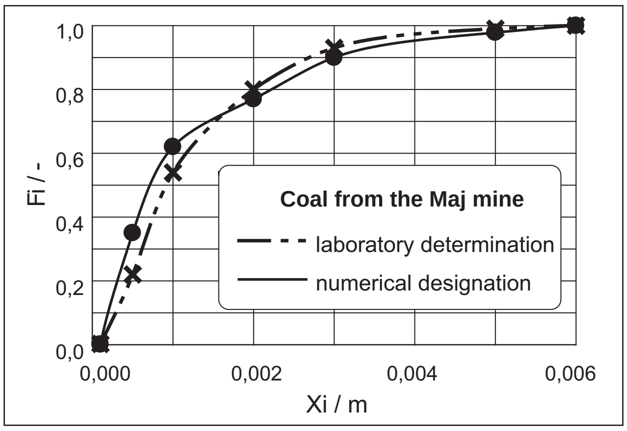

Figure 3 The grain size distribution of the coking coal from the Maj mine

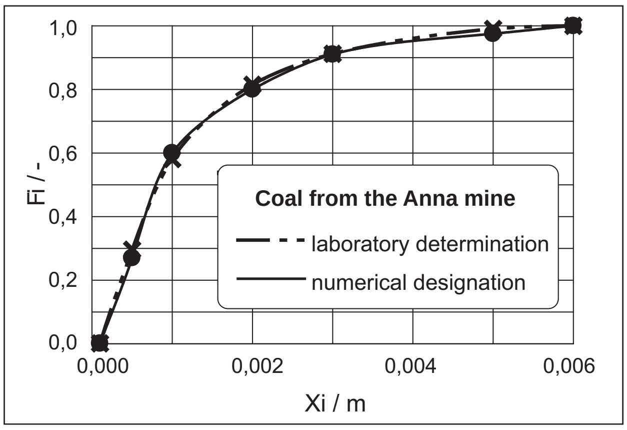

Figure 4 The grain size distribution of the coking coal from the Anna mine

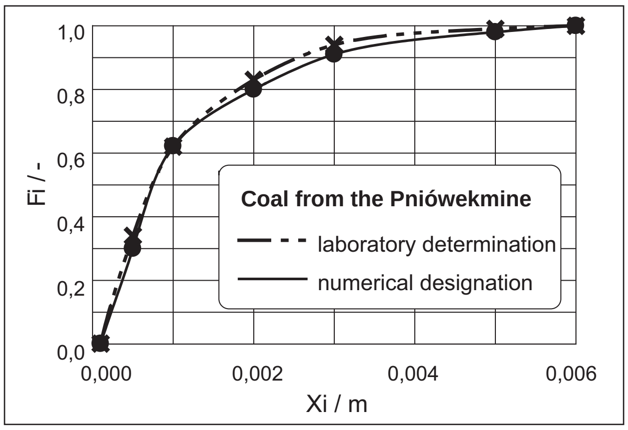

Figure 5 The grain size distribution of the coking coal from the Pniówek mine

The results of numerical and laboratory determinations are shown in Figures 2 and 3, 4, 5.

SUMMARY

Analyzing the results of comparative analyzes of grain size distribution, it can be concluded that the numerical designations are consistent with laboratory signs. Grain analyses of coal are due to its specific properties, particularly burdensome. So the possibility of numerical prediction of grain size distribution of particulate carbon to avoid the inconvenience of laboratory analyzes.

The possibility of predicting grain composition of any brittle substance is most welcome, not only for the steel industry but also other industries, in which coal is a raw material

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Note: The professional translator for English language is Czesław Grochowina, Studio-Tekst, Poland