Theoretical study of the regularities of wet coal grinding in ball mills at the preparation of water-coal fuel

Yuriy Syomin, Tatyana Bondar

[2]Volodymyr Dahl East-Ukrainian National University
Molodizhny bl., 20a, Lugansk, 91034, Ukraine, e-mail: ot_snu@ukr.net

Received January 09.2014: accepted February 03.2014

Summary: Theoretical investigations of the regularities of coal grinding in ball mills are executed. The main parameters influencing the kinetics of grinding at the preparation of water-coal fuel are determined. The matrix model of grinding and dependences, allowing to conduct the classification of the process of material failure in ball mills are considered.
Key words: coal-water fuel, density of grinding bodies, grinding, kinetics of grinding, ball mills, matrix model of grinding.

INTRODUCTION

The last years in Ukraine the problem of energy carriers is becoming more and more actual and solution of this problem to a large extent determines the economic and financial security of the country. The works on the investigations of the use of alternative, renewable, non-traditional energy sources are finding in the field of promising long-term searches. At the same time, the country has significant reserves of coal which is the basic organic fuel not only in our country, but in the world. However, the traditional use of coal, that is, its direct burning in various furnace devices causes a number of problems: incomplete burning of the coal (burns to 60% of the combustible mass), necessity of the creation of systems for dust suppression, aspiration, a high degree of pollution of environment by the emissions of nitrogen oxides, sulphur , dust and soot (100-300 g/m^3 of a dust, 400-800 g/m^3 of SO_2, 250-600 g/m^3 of NO_2) [1]. The transition from direct burning coal on preparing and use of water-coal fuel (WCF), including from the waste of coal concentration, can become the fundamentally important decision for the coal power engineering.

OBJECTS AND PROBLEMS

The idea of the coal-water fuel is not new one. From the early 70-ies of the last century a number of countries, such as USA, Canada, Italy, Sweden and China are working on research and creation of pilot experiment-industrial, demonstration and commercial installations on production and use of WCF. The greatest achievements in this direction were obtained in China (the first place in the world on extraction of coal - 1.3 billion tons per year) [2, 3, 5, 19]. On these subjects in China three research centers are working, six plants are producing WCF on boiler-houses and electric power stations, burning WCF It is planned to build a large plant for preparation of water-coal fuel. Delivery of fuel is carried out in railway containers.

The technology of preparing WCF abroad, including in China, is traditional and consists of two-stepped wet grinding in ball mills with the addition of plasticizing and stabilizing chemical additives, feed of the resulting product for storage and subsequent burning in boiler furnaces. The main element in the process of preparation of water-coal fuel is the ball mills. And a matter of their downloading by coal, by certain granulated size of balls, by chemical additives as well as the time grinding for different grades of coal is not divulged. In addition, two-stepped grinding increases the cost of technological lines, preparing WCF. So the transition of the technology of preparation of WCF on one-stepped system will require conducting the theoretical and experimental researches of the processes of coal grinding, rationalization of the ball loading and modes of operation of mills that allows to lower power inputs. With the aim of significantly reducing the total cycle of grinding and producing WCF the method of one-stage wet grinding of hard coal was developed and studied. The essence of this method consists in the following. Source coal is crushed in the hammer crusher up to size 0-3 mm and loaded in the ball mill, where it undergoes directly wet grinding to obtaining WCF. Coal during grinding gradually passes from the large lump size in a state of suspension, thus the suspension density is increasing and comes nearer to a calculated. Water in the initial period of grinding in the mill is redundant, since the coal has large lumps. And as much as coal grinding, water goes on the wetting of the newly formed coal surfaces at grinding of coal. Thus, the density of the suspension during the grinding increases, and the effective density of grinding bodies, equal to the difference in the density of grinding bodies and suspension, gradually decreases, that is [20]:

$$\Delta\rho = \rho_b - \rho_s \,, \quad (1)$$

where: ρ_b – density of grinding bodies (balls), ρ_s – the density of the suspension.

In addition, when the density is increased, and therefore viscosity of the suspension, is increased [21], the impact mode at the grinding is gradually passing into abrasive.

Increasing the density of grinding bodies by downloading the balls of different diameter allows to increase grinding ability of the mills and to produce WCF composition consisting of bimodal grain-size composition of coal, which includes coarse (80-250 microns) fine milling (0-40 microns) [11, 20]. For the sedimentation stability and reducing the dynamic viscosity of WCF, the coal plasticizer (SAS) is fed into the mill by weight 1-2% of coal mass [6, 7, 15].

A number of basic factors affect the performance of wet grinding in ball mills affects, which include: rotational speed of the drum, the number, size and density of grinding bodies, the amount, size and properties of the grinded material, the amount of water and chemical additives, degree of filling the mill volume. The main values which characterize a grinding are the degree of filling the drum of the ball mill by grinding bodies and total charge. The latter refers to the ratio of the total volume of grinding bodies of the suspension to the volume of the mill drum:

$$\varphi_d = \frac{V_b + V_s}{V_d}, \quad (2)$$

where: φ_d – the degree of the total charge of the mill,

V_s – volume of the suspension in the ball mill,

V_d – volume of the mill drum,

V_b – total volume of grinding bodies, which is equal:

$$V_b = V_{b1} + V_{b2} + \\ + V_{b3} + \ldots + V_n = \sum_{i=1}^{n} V_{bi}, \quad (3)$$

where: $\sum_{i=1}^{n} V_{bi}$ – the total volume occupied by the mill balls of the $i^{\text{-order}}$ diameter.

The ratio in loading of coal and the grinding bodies is convenient to characterize by the indicators of the active grinding zone α, corresponding to the volume of voids between the grinding bodies and suspension volume:

$$\alpha = \frac{\left(\sum \frac{G_{bi}}{\rho_{gbi}}\right) - \left(\sum \frac{G_{bi}}{\rho_{bi}}\right)}{V_s}, \quad (4)$$

where: ρ_{gbi}, ρ_{bi} – bulk and volume masses of the grinding bodies (balls) of the i^{-order} diameter,

G_{bi} – mass of the grinding bodies (balls) of the i^{-order} diameter:

$$G_{bi} = \varphi \frac{\pi \cdot D^2}{4} \cdot L \cdot \gamma_{bi}, \quad (5)$$

where: φ – permeability factor of mill volume by the balls, φ = 0,6,

D – the inner diameter of the mill, m,

L – the inside length of the mill, m.

In the case when *α =1*, all the voids between the grinding bodies should be filled with (WCF) suspension and its level corresponds to the level of grinding bodies in the mill. If the value *α<1*, the suspension not only fills the void between the grinding bodies, but there is in a certain volume of over them. With the reduction of α-index, the share of the volume of (WCF) suspension, not completed by the grinding bodies, is increased. It leads to reduction of speed of grinding.

The density of the pulp in the mill is determined by the dependence [8, 17, 18]:

$$\rho_c = \frac{\rho_c}{\rho_c - C \cdot (\rho_c - 1)}, \quad (6)$$

where: ρ_c – coal density, t/m^3,

C – the content of solids in the suspension (on mass), share of units, C ≈ 0,8.

Thus, the volume mass of load, taking into account filling the voids by the suspension, is equal, t/m^3:

$$\rho_{b.m} = 0{,}6 \cdot \rho_b + 0{,}4 \cdot \rho_m, \quad (7)$$

Mathematical analysis of the internal dynamics of ball mill was made on the basis of probability theory [14]. The basis of the hypothesis was proposed that there is a circular area of effect around the point of contact of two balls, outside which the particles are not involved in the space between the two balls. Radius of this zone action *Y* is determined by the equation, which has the form:

$$Y = \sqrt{\frac{Dd}{2}}, \quad (8)$$

where*: D* – the ball diameter, m,

d - the particle diameter, m.

The maximum number of particles N_m, which can be located in the zone of action, corresponds to the number of particles forming a ring around the point of contact.

Therefore:

$$N_m \cdot d = 2\pi \sqrt{\frac{Dd}{2}}, \quad (9)$$

or

$$N_m = 4{,}5 \sqrt{\frac{D}{d}}. \quad (10)$$

The maximum number of particles is achieved only when the system has an infinite number of particles. This number is equal zero, when there is not one particle in the system.

The probability function for the examined case in question is:

$$y = 1 - e^{-ku}. \quad (11)$$

The constant *k* is determined, subject to full filling the space between the balls, that is, when *u=1* and 40% of the maximum number of particles gets in the zone of action. From this it follows that *k=0.5*. So we can write:

$$N_p = 4{,}5 \sqrt{\frac{D}{d}} \cdot (1 - e^{-0{,}5u}). \quad (12)$$

For determination of the equilibrium number of particles in contact with the surface of the ball N_e, at the first we consider the number of particles in contact with the surface at any moment of time *t*. The rate of change of the number of particles in contact with a surface per unit of time is equal to:

$$\frac{dN}{dt} = N_i - N_o, \qquad (13)$$

where: N_i – the number of particles, which are pressed to the surface,

N_o – the number of particles destructible near the surface in a unit of time.

The number of particles, which are pressed to the surface of the ball, is proportional to the number of particles in the action zone (N_P) and is determined by the dependence:

$$N_i = k_1 \cdot N_p \cdot f \cdot P_e, \qquad (14)$$

where: P_e – probability of hit of a particle on the surface of the ball,

f – part of the surface of the ball, which is capable of receiving the particle:

$$f = 1 - \frac{N \cdot d^2}{F}, \qquad (15)$$

where: N – the number of particles, which are pressed to the ball surface,

F – the ball surface, m^2.

The probability that the particles will hit on the surface of the ball if we take the attitude of the ball hardness to the hardness of particles H of the grinding material will be equal:

$$P_e = e^{-0.7H}, \qquad (16)$$

and then:

$$N_e = K_1 \cdot \sqrt{\frac{D}{d}} \cdot (1 - e^{-0,5u}) \times \\ \times (1 - \frac{N \cdot d^2}{F}) \cdot e^{-0,5H}. \qquad (17)$$

The number of particles which will be grinded as a result of pressing to two neighboring balls and of a collision with each other is expressed by the following dependence:

$$N_o = K_2 \cdot N \cdot R_e \cdot \alpha. \qquad (18)$$

The probability of collision of particles with each other:

$$R_e = K \cdot \left(\frac{N \cdot d^2}{F}\right)^2. \qquad (19)$$

The probability of failure of the particle:

$$\alpha = \left(1 - 2,5 \cdot H \cdot e^{-H}\right), \qquad (20)$$

then:

$$N_o = K_2 \cdot N \cdot \left(\frac{N \cdot d^2}{F}\right)^2 \cdot \left(1 - 2,5 \cdot H \cdot e^{-H}\right) \qquad (21)$$

Grinding speed $\frac{dG}{dt}$ is proportional to the number of particles in the zone of action and can be determined by the dependence:

$$\frac{dG}{dt} = K_1 d^{-\frac{1}{2}} \cdot D^{-2,5} \cdot (1 - e^{0,5u}) \times \\ \times \{(N_e \cdot \frac{d^2}{F}) + \left[1 - (N_e \frac{d^2}{F})^2 - e^{-0,7H}\right]\} \times \\ \times e^{-K_u N_e - 0,1u^2} \cdot \varphi \cdot V, \qquad (22)$$

where: φ – coefficient of filling the mill,

V – the volume of the mill, m^3.

Kinetics of grinding is described by the exponential equation [4, 8, 9, 13, 16]:

$$R = R_o \cdot e^{-kt^m}, \qquad (23)$$

where: *R* and R_o – masses of the material residual on the drum screen at grinding, and in the crushed product at moment *t*,

t – duration of grinding,

k and *m* – the grinding parameters.

After taking the logarithm of double the kinetics equation will be in the form:

$$\lg\lg\left(\frac{R_o}{R}\right) = m \lg t + \lg(k \lg e). \qquad (24)$$

To determine the values of parameters *m* and *k* of the line which is drawn on the experimental points, there are two points and their coordinates are determined.

The values of *m* and *k* are calculated by the formulas:

$$m = \frac{\lg\lg\left(\frac{R_o}{R_2}\right) - \lg\lg\left(\frac{R_o}{R_2}\right)}{\lg t_2 - \lg t_1}, \qquad (25)$$

$$k = \frac{\lg\left(\frac{R_o}{R}\right)}{t^m \lg e}. \qquad (26)$$

Knowledge of the kinetics of grinding allows to solve theoretically a number of practical tasks: to determine the specific performance of the mill, grind ability of the material, to calculate the amount of circulating load, granulometric composition of the grinded material depending on the grinding time.

Kinetics of grinding in the mills of periodic action by O.N. Tikhonov has the following form:

$$P(y,t) = P(y,0) + \int_0^t \int_y^{x_{max}} \left[dP_{x,t} / dx\right] \cdot S(x) \cdot B(x,y) \cdot dxdt, \qquad (27)$$

where: $P(y,t)$ – total mass portion of material with size less than *y* at time *t*,

$P(y,0)$ – mass portion of *y*-class particles in the source material,

S(x) – selection function, determined as the portion of particles of a given size *x*, selected from the whole mass of the material and destroyed in a unit of time,

B(y, x) – grinding function, determined as the portion of selected particles being ground to a size smaller than *y*, where $y<x$.

The second term of the right side of the equation (17) is mass portion *y*-class, obtained by grinding the particles with size larger than -*y* at the time from *0* to *t*.

The mechanistic approach to the construction of models of processes of reducing the size is based on identifying those physical phenomena, which composite the process. Their description can lead to obtaining the models, suitable for reproduction of the process (imitation modeling). The main principle underlying the mechanistic models is that after *n* steps of reiterative process of destruction, which can be described by means of functions of probability of destruction and distribution of the grinded material, the resulting distribution function asymptotically approaches to a log-normal law. It should be noted that just such characteristic of the distribution by size of the grinded material is often observed in practice. This principle was used in a new direction of research, which became known as the method of matrix models [9].

In the matrix model the process of crushing or grinding is considered as a sequence of cycles of destruction, and the initial material for every such act is the product of the previous one. The longer the period of grinding, then there is more the number of such cycles and higher the degree of reduction of the size [12, 16]. The models of this type are based on the following concepts and representations:

1) the probability of failure, which is named as the selection function or function of the destruction speed,

2) characteristic distribution by size after the destruction called the destruction function, or the distribution function, or a function of occurrence,

3) the difference in particle motion through a continuously acting apparatus or the rate of carrying-out the particles from the unit.

Transfer of material in apparatus is generally based on particle size and is characterized by the function that is called the classification function or function of the speed of unloading, or the diffusion coefficient dependent on the particle size. The phenomenon of reverse mixing in the mills of continuous action can be taken into account by addition of the elements characterizing the flow of material and stirring to the basic matrix determining the probability and distribution of destruction.

The probability of failure of every size class and distribution by destruction product size of every class were presented in the form of the matrix model of crushing and grinding processes, where terms of the destruction and selection functions are used for the distribution function and the probability of failure. In this model the granulometric size supply composition and the product of the process of reducing the size can be expressed by the distributions in paragraphs of *n*-classes (Table 1).

Table 1. Distribution of size supply and product grinding

Size class	Granulometric supply composition	Product of reducing the size
1	f_1	p_1
2	f_2	p_2
….	….	….
n	f_n	p_n
n+1	f_{n+1}	p_{n+1}

Number 1 on the table 1 denotes the maximum size class and number n +1 shows under-the-grate screen residual with the lowest hole of the screen.

In the process of grinding the particles of all size classes are destroyed with a certain probability, the products of destruction may fall either in the original or in any smaller size class. It should be noted that a particle can be subject to such small destruction or chipping, which is not enough for that all the resulting fragments were less than the lower boundary size of the original class. The material balance of the grinding process can be presented as table 2.

Table 2. The Material balance of the grinding process

Size class	Granulometric supply composition	Product of reducing the size					
		1	2	3	..	*n*	*n+1*
1	f_1	P_{11}	0	0	..	0	0
2	f_2	P_{21}	P_{22}	0	..	0	0
3	f_3	P_{31}	P_{32}	P_{33}	..		
…	…	…	…	…	..		
n	f_n	P_{n1}	P_{n2}	P_{n3}	..	P_{nn}	
n+1	f_{n+1}	$P_{(n+1)1}$	$P_{(n+1)2}$	$P_{(n+1)3}$	..	$P_{(n+1)n}$	$P_{(n+1)(n+1)}$

Items in columns 1, 2, 3, n+1 in the Table 2, were recorded in the form of P_{ij}, where *i* belongs to the size class, in which this element gets, and *j* - size feed class, from which it was formed.

It should be noted the following features of the submitted form of the elements table characterizing the product of grinding:

1. The granulometric composition of the product can be determined by the summation of the items in consecutive rows in the table,
2. The total amount of supply is determined by expression $\sum_{i=1}^{n+1} f_i$. The mass of the particles in the1^{-st} under- the-grate residual, i.e, in the size class n+1, can always be calculated by subtracting the total mass of the residual on the screen *n*- item from the supply F.

The item P_{ij} may be presented by: $P_{ij} = X_{ij} f_i$, where X_{ij} - mass portion of particles of the i^{-order} size class of supply, transferred into the j^{-order} size grade product. Taking into account the above said, the matrix of the grinding process would be:

$$\begin{bmatrix} x_{11} & 0 & 0 \ldots\ldots\ldots 0 \\ x_{21} & x_{22} & 0 \ldots\ldots\ldots 0 \\ x_{31} & x_{32} & x_{33} \ldots\ldots\ldots 0 \\ x_{41} & x_{42} & x_{43} \quad x_{44} \ldots\ldots 0 \\ \ldots \\ \ldots \\ x_{n1} & x_{n2} & x_{n3} \ldots\ldots\ldots x_{nn} \end{bmatrix} * \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ \ldots \\ \ldots \\ f_n \end{bmatrix} =$$

$$= \begin{bmatrix} x_{11} \cdot f_1 + 0 + \ldots + 0 \\ x_{21} \cdot f_2 + x_{22} \cdot f_2 + 0 + \ldots + 0 \\ x_{31} \cdot f_3 + x_{32} \cdot f_3 + x_{33} + 0 + \ldots + 0 \\ x_{41} \cdot f_4 + x_{42} \cdot f_4 + x_{43} \cdot f_4 + x_{44} \cdot f_4 + 0 + \ldots + 0 \\ \ldots \\ \ldots \\ x_{n1} \cdot f_n + x_{n2} \cdot f_n + x_{n3} \cdot f_n + x_{n4} \cdot f_n + \ldots + x_{nn} \cdot f_n \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ \ldots \\ \ldots \\ p_n \end{bmatrix}$$

The matrix equation that characterizes the grinding process can be written:

$$P = X \cdot f \,. \qquad (28)$$

It should be emphasized that the appropriate items *f* and *p* are relating to the same size intervals. It is convenient for calculations, if the constant geometrical relationship between successive intervals is observed.

The equation (27), although correctly characterizes the process of destruction, can be useful only if the matrix *X* is known. This matrix could not be obtained deductively, i.e., without the additional information. Consequently, it is necessary to consider how the matrix *X* can be divided into components.

The selection function. The particles of all size classes, fed in the grinding process, are destructed with a certain probability, which may depend on the particles size.

In every moment of the grinding process a certain part of the particles of every size class is taken for destruction, whereas the remaining part is not destroyed.

If *S* denotes the portion of particles of the largest class, which is selected for destruction, then the mass of ruined particles of this class will be $S_j f_j$. Similarly, the mass of particles, destroyed in the *n*- size class will be $S_{ij} f_i$, so we can write a matrix equation:

$$\begin{bmatrix} S_1 & 0 & 0 & \cdots & \cdots & \cdots 0 \\ 0 & S_2 & 0 & 0 & \cdots & \cdots 0 \\ 0 & 0 & S_3 & 0 & \cdots & \cdots 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \cdots \cdots & S_n \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ \cdots \\ \cdots \\ f_n \end{bmatrix} = \begin{bmatrix} S_1 f_1 \\ S_2 f_2 \\ S_3 f_3 \\ \cdots \\ \cdots \\ S_n f_n \end{bmatrix}.$$

If to present the selection function as the matrix *S*, then the destroyed particles will be presented by the function *Sf*. The remaining particles during the process will be non-destructed and the mass of those indestructible particles for n- class will be $(l-S_n)f_n$. The total mass of particles, who went through the process non-destructed, can be represented by the product *(1 - S)f*.

In the case where the matrix *X* relates only to the grinded particles of feed which are really destroyed, i.e. not to the whole mass of supply, the *X* - symbol may be replaced by symbol *B*, and the equation process will obtain the form:

$$P = B \cdot S \cdot f + (1 - S) \cdot f \quad \text{or}$$
$$P = (B \cdot S + 1 - S) \cdot f \,. \tag{29}$$

The classification function. Crushing or grinding usually consists of many cycles of destruction, which can act both simultaneously and sequentially. Thus in every cycle the selection and destruction is realized. However, the process can proceed in such a way that the product of every cycle will be divided by size before some portion of this product would be subjected to the consecutive cycle of destruction. The result of classification of grinding the material can be written by the following dependencies:

$$P = (1 - c) \cdot q \quad \text{or}$$
$$P = (1 - c) \cdot (B \cdot S + 1 - S) \cdot m \,, \tag{30}$$

where: *c* - classification function,

q - supply of classifier,

m – power supply of the mill $. m = f + cq$.

After the transformation, we obtain:

$$m = f + c \cdot (B \cdot S + 1 - S) \cdot m \,,$$

$$f = [1 - c \cdot (B \cdot S + 1 - S)] \cdot m \quad \text{or}$$
$$m = [1 - c \cdot (B \cdot S + 1 - S)]^{-1} \cdot f \,. \tag{31}$$

From the equations (29) and (30) we obtain

$$P = (1 - c) \cdot (B \cdot S + 1 - S) \times \times [1 - c \cdot (B \cdot S + 1 - S)]^{-1} \cdot f \,, \tag{32}$$

If the classification is non-significant, then the c≈0, and the equation (31) are reduced to the equation (28).

The material having a momentary act of destruction is described in the base of all the models of crushing and grinding. This description is called a function of destruction. Research has shown that the destruction function can be approximated as stepped matrix that is the destruction nature of the material particles does not depend on the initial particle size. And then the destruction *F* and the selection *S* functions describe the grinding process of the material in the ball mill.

CONCLUSIONS

The basic parameters influencing the operation of ball mill are determined. They include: rotational speed of the drum, the number, size and density of grinding bodies, the amount, size and properties of the material, the amount of water and chemical additives, degree of filling volume of the mill, time of the grinding operation.

The question of interaction of the grinding bodies with the grinded material is considered. The imitation simulation requires the solution of the following tasks:

1. The selection of the technological scheme and size of equipment to obtain required parameter of highly concentrated coal-water suspension,
2. The provision of conditions providing for subsequent extension or modification of the grinding cycle,
3. The opportunity to minimize the capital and operational expenses

REFERENCES

1. **Andreev S.E., 1980.:** Petrov V.A, Zverevich V.V. Crushing, grinding and screening of the minerals. – M., Nedra. – 415. (in Russian).
2. **Bragin B.F., 1996.:** Kolomiets A.S., Krikunov A.P., Markuntovich F.D., Syomin Y.G. Ecologically friendly the water-coal technologies and systems. // Visnyk East-Ukrainian National University, Lugansk. Jubilee issue. – 70-76. (in Ukrainian).
3. **Bragin B.F., 1995.:** Kolomiets A.S., Pulp and suspension. (technologists, installation, calculations) Study guide. – K. ISDO. – 464. (in Ukrainian).
4. **Bilenko L.F., 1984.:** The regularition of the grinding drum mills. – M. Nedra. – 200. (in Russian).
5. **Chernetskaya N.B., 2010.:** Ecological aspects of water coal fuel transportation and application. // Teka Kom. Mot. Energ. Roln. – OL PAN, Vol. 5. – 97-104.
6. **Chernetskaya N.B., 2010.:** Shvornikova A. Kuschenko A. Choice of technology and the equipment for preparation of water-coal fuel in laboratory conditions. // Teka Kom. Mot. Energ. Roln. – OL PAN, Vol. X. – 33-38.
7. **Delyagin G.N., 1993.:** Kornilov V.V., Kuznetsov Y.D., CyernegovY.A., The improvement of the water-coal fuel and perspectives of its application. The supplement to the scientific and technical journal «The economy of the fuel and energy complex of Russia». // M., VNIIOENT. – 31. (in Russian).
8. **Golubinskaya I.V., 1989.:** Tarakanov V.M. Experimental study of high-concentrated water coal suspensions in static and dynamic conditions. // Physic-chemical fundamentals of structural-rheological properties and stability of high-concentrated water coal suspensions in the process transportation of the pipeline. The collection of scientific works. NPO «Gidrotruboprovod». – M. – 85-99. (in Russian).
9. **Hodakov G.S., 1972.:** Physics of crushing. – M., Science. – 307. (in Russian).
10. **Karmazin V.N., 1974.:** Sergo E.E., Szendrinskiy A.P. Processes and machines for enrichment of minerals. – M. Nedra. – 560. (in Russian).
11. **Kondratiev A.S., 1988.:** Ovsyannikov V.M., Oflonskiy E.P. Transportation of water coal suspensions: hydrodynamics and temperature mode. M. Nedra. – 213. (in Russian).
12. **Ling A., 1980.:** Cycle crushing and grinding: modeling, optimization, and planning (in China).
13. **Pivinskiy Y.E., 1974.:** Romashin A.G. Quartz ceramics./.– M., Metallurgy,– 264. (in Russian).
14. **Rozse Giyo., 1964.:** The problem of grinding materials and its development. - M. publishing house of literature on construction. – 112.
15. **Rukin E.I., 1976.:** Gorskaya T.P., Delyagin G.N.. Study of the properties of water coal suspensions in the presence of surfactants. – M. « Chemistry of solid fuel » №4. – 152-158. (in Russian).
16. **Regourd, M.:** Cracking and grindability of clinker. M. Regourd, H. Homain // Ciments Beton Platre Chaux. – Vol.727.
17. Regularities of grinding in ball mills: the collection of the reports international Congress on mineral processing. – L., state public library. 1968. – 6. (in Russian).
18. **Shuplyak I.A., 1972.:** The grinding of the solid materials in the chemical industry. – L. Chemical. – 64. (in Russian).
19. **Sergo E.E., 1975.:** Crushing breakage and screening minerals. – K. Higher school. – 240. (in Ukrainian).
20. The production of the water-coal fuel «Fluidcarbon» and use in Sweden. Inst. Chem. lng. Symp. Ser., №95, 1985. – 325-331.
21. The water-coal suspension of the high concentration. –Dansecoal. Translation № 3/88 - 2, institute «VNIPIGidrotruboprovod». M., 1988. The source. BWKV. 39, №5. – 246-247. (in Russian).
22. **Wang Zu-Na., 1986.:** Zang - Rong - Zeng. Research and development of coal-water fuel technology in China, International seminars on Nuclear, War – 6-th Session: International Cooperation: The Alternatives (in China).

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ ЗАКОНОМЕРНОСТЕЙ МОКРОГО ИЗМЕЛЬЧЕНИЯ УГЛЯ В ШАРОВЫХ МЕЛЬНИЦАХ ПРИ ПРИГОТОВЛЕНИЯ ВОДОУГОЛЬНОГО ТОПЛИВА

Юрий Семин, Татьяна Бондарь

Аннотация: Рассмотрены технологии приготовления водоугольного топлива (ВУТ) его параметры и гранулометрический состав, процессы измельчения и размола угля, теоретические исследования закономерностей измельчения в шаровых мельницах.
Ключевые слова: водоугольное топливо, транспорт, энергоэнтропия, шаровая мельница, термодинамическая система.