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RESEARCH OF WATER- COAL FUEL PREPARATION BY THE METHOD OF RATIONAL LOADING OF BALL MILL

Tatyana Bondar, Yuriy Syomin, Alina Syomina

Volodymyr Dahl East- Ukrainian National University, Lugansk, Ukraine

Summary: The methodology for experimental studies of highly concentrated water-coal suspensions prepared with the necessary rheological characteristics in a ball mill by way of the rationalization of the granulometric composition of coal fines is described.

Key words: water-coal fuel, the ball loading, experimental design, dynamic viscosity, sedimentation stability.

INTRODUCTION

Producing the artificial composite ecologically cleaner water-coal fuel (WCF) is one of the trends of the search of alternative fuels to replace conventional oil and gas. Preparation of WCF is a complex process associated with the requirements for it, such as - a high concentration of coal up to 70% or more (by weight), relatively not a high dynamic viscosity up to 1 Pa.sec at a shear velocity gradient from 10 to 16 sec^{-1} and sedimentation stability for 15 days and more [17, 8, , 21, 22]. These parameters are achieved by adjusting the granulometric bimodal composition of coal and by the use of surfactants.

ANALYSIS OF PUBLICATIONS, MATERIALS AND METHODS

The technological schemes developed by the firms "Snamprogetti" (technology «Reocarb», Italy); «Fluidcarbon» (Sweden) [17]; Salzgitter Industriebau GmbA (technology "Denskoul" [8] "Karbogel"); "Coal," Young WCF (China) [25] have found the most wide application in the world practice. All these technologies are aimed at obtaining highly concentrated water-coal suspensions (65-75% solids) with ash content of fuel to 2-5% of WCF [4].

THE OBJECTIVE AND EXPERIMENTAL PROCEDURE

The investigations have shown, that at producing the water-coal fuel it is necessary to achieve the maximum possible concentration of coal and ability of WCF easily to be pumped through pipelines. Maximum package of WCF is achieved through the adoption of bimodal distribution by size of particles, that is, the combined system consisting of two discrete fractions by the size of the particles, the more coarse and fine fractions. The lowest viscosity and the highest concentration is achieved when the ratio “ more fine: more coarse fractions” makes 40:60 (in recalculation on an anhydrous mixture).

In connection with the necessity to obtain bimodal distribution of fractions of coal in the WCF, above mentioned technologies of WCF making have two- staged process of coal grinding. This complicates the technology of WCF preparation, increases its capital and operating costs. In addition, the loading technology and mode of operation of mills at the WCF preparation is the " know-how ".

With the aim of reducing the cost on producing the WCF we will consider the use of one-staged technology of preparation due to the rationalization of the ball loading and operation mode of the mills. The main tasks are: selection of rotational speed of the drum, determination of the size of the grinding bodies, determination of the grindability impact and grain size of the source material, grain size of grinded product and determination of the loading factor of drum of the mill. The correct solution of these problems depends on the technological and economic efficiency of the mill operation.

RESULTS AND ANALYSIS

Research has shown that to obtain a highly concentrated coal-water suspension with the desired rheology, sedimentation and thermal properties, the granulometric composition of coal particles must be bimodal, including the particles of size 80 ÷ 250 μm (coarse grinding) and coal particle size 0 ÷ 40 μm (fine milling) [15, 7].

When designing the experiment, the task was to load rationally the ball mill with three standard sizes of balls, charcoal and water, adequately describing the process of grinding.

The dynamic viscosity is chosen as the response function of the investigation.

The drum rotational speed, time of grinding and three diameters of balls are taken as varied factors (see Table 1).

The analysis of factors affecting the rational loading of the ball mill has allowed to identify five independent variables that determine this process, that is, the balls of three diameters: 42, 52, 62 mm, the drum rotational speed and time of grinding. Analysis of factors affecting the WCF preparation in ball mills had shown that the main factors are the rotational speeds of the mill drum n_{min}, n_{mid} and n_{max}; the granulometric composition and mass of loaded balls d_{min}, d_{mid} and d_{max}; grinding time. All these factors have a quantitative assessment, are measurable, manageable and compliant ones. Each of them has its own local area to carry out the experiment.

If we pass from the values of the factors in the natural scale to a code one, then independent variables D_1, D_2, D_3, n and t, varied in the experiment, will be as follows:

$$X_1 = \frac{D_1 - 9}{1};\ X_2 = \frac{D_2 - 9}{1};\ X_3 = \frac{D_3 - 9}{1};\ X_4 = \frac{n - 63}{5},$$

$$X_5 = \frac{t - 40}{20},$$

Preparation of the WCF compositions was produced with using the plasticizing additives manufactured in Ukraine, having the best characteristics of plasticizers considered in the analysis, in the quantitative ratio of 1% on the dry weight of coal. [8, 4, 12, 21, 22, 16].

The ball mill MLK-300 with a rotary axis is selected for the experiment. It has sizes D*L=300*190 mm. Volume of the mill V = 13dm^3. Drive of the mill consists of a electric motor with power 0.65 kWt and a control unit that allows to regulate the rotational speed of the drum.

Source coal of Donetsk coal basin, the "DG" brand, rich, crushed in a hammer crusher, PML-150, to a grain particle size of 0-3 mm. The mass of coal sample weight is calculated as follows:

$$P_i = 0{,}12 \cdot \delta_{ø} \cdot V, \tag{1}$$

where: V-volume mill, m^3;

$\delta_{ш}$ - bulk density of coal, it is taken on Handbook 0.8 t/m^3.

0,12- filling factor of the mill by coal in an amount of 12% from the volume of the mill.

Grinding is carried out wet under solid content 75% by weight with the use of a plasticizer in an amount of 1% on the dry weight of coal.

Filling factor of the mill by balls $\varphi_{ш}$ = 0.4-0.5. Grinding time - from 20 to 60 minutes. The rotational speed of the mill drum, the granulometric composition of loaded balls are determined by the analytical dependences, taking into account the effective work at the boundary and a some reduced layer of balls [19, 20]:

maximum ball size for a given diameter of the drum is in the range, mm:

$$d = \frac{D}{18} - \frac{D}{24}, \tag{2}$$

minimum size of the ball enough to destroy the most big pieces of coal is:

$$d_{ш} = d_m \sqrt[3]{\frac{\delta^2}{1.28\beta c \varepsilon \rho_{ш} D}}, sm. \tag{3}$$

Where: δ - ultimate compression strength, taking σ= 300 kg/sm^2,

ε - Young's modulus, ε = 300 000 kg/sm^2,

c - coefficient taking into account the variability of Young's modulus, c = 1,

β - coefficient taking into account the fraction of energy that goes directly to the grinding of the coal, in the fall of the ball at it, β = 0,5,

D - the size of coal particles,

$p_{ш}$ - density of the ball, $\rho_{ш}$ = 0.00786 kg/sm^3.

$$d_{ш} = 28 \sqrt[3]{d}, \tag{4}$$

or

$$d_{ш} = id, \tag{5}$$

where: d - the average size of a piece of source material, mm,

i- factor depending on the hardness of the material.

Rotational speed of the mill drum, rev / min

for the effective operation of the boundary layer of balls:

$$n = \frac{32}{\sqrt{Df}}, \tag{6}$$

for the effective operation of the entire inner mass of the balls:

$$n = \frac{34.2}{\sqrt{Df}}, \tag{7}$$

for the effective operation of some reduced layer of balls:

$$n = \frac{37.2}{\sqrt{Df}}, \tag{8}$$

where: D - inner diameter of the drum, m,

f - coefficient of friction of the ball on the armor, f = 0,466 [14].

Maximum information in the study about the rational loading of the mill by five given components one can obtain using a full factorial experiment (FFE) of type 2^k. If the number of factors k = 5, planning matrix provides for 32 tests.

To produce the WCF with necessary dynamic viscosity of 1 Pa.sec at a shear velocity gradient from 10 to 16 sec^{-1}, the sedimentation stability for 15 days or more, we hold full factorial experiment of type 2^5, which provides for the planning matrix 32 tests.

The inspection of the homogeneity of variances, measured response functions at each point of experience by the criterion of Cochran, is satisfied for correct processing and use of the experimental results. When the experiment is carried out, the uniform duplication with five parallel experiments at each point of the design matrix is chosen. [1, 26]

We use the scales of measurement accuracy +- 5 g for weighing the balls. Maximum loading of the mill is 30 kg, drum rotational speed 58, 63 and 68 rev/ min. and grinding time of 20, 40 and 60 minutes. The resulting grinding are divided into 5 equal parts, water and plasticizer are added. The rotational speed is measured by speed tachometer. Then the viscosity of the suspension is measured by viscometer "Polymer" 1-M, at a shear velocity of 8 sec^{-1}.The order of the experiments is carried out in accordance with the table of random variables.

The number of measurements in each experiment is reduced to five, holding a total amount of 160 measurements and calculations. The mathematical model of the process is built on the results of measurements.

Table 1. **Matrix with coded and natural values of factors**

Area of Planning	№ of experience	The coefficients of the factor levels					Natural numbers				
		X_1 D_1	X_2 D_2	X_3 D_3	X_4 n_{min}	X_5 t_{min}	X_1 D_1, mm	X_2 D_2, mm	X_3 D_3, mm	X_4 n_{min}, ob/min	X_5 t_{min}, min
Fractional replica 2^{5-1} (core of plan)	1	-1	-1	-1	-1	+1	8	8	8	58	60
	2	+1	-1	-1	-1	-1	10	8	8	58	20
	3	-1	+1	-1	-1	-1	8	10	8	58	20
	4	+1	+1	-1	-1	+1	10	10	8	58	60
	5	-1	-1	+1	-1	-1	8	8	10	58	20
	6	+1	-1	+1	-1	+1	10	8	10	58	68
	7	-1	+1	+1	-1	+1	8	10	10	58	68
	8	+1	+1	+1	-1	-1	10	10	10	58	20
	9	-1	-1	-1	+1	-1	8	8	8	68	20
	10	+1	-1	-1	+1	+1	10	8	8	68	60
	11	-1	+1	-1	+1	-1	8	10	8	68	20
	12	+1	+1	-1	+1	-1	10	10	8	68	20
	13	-1	-1	+1	+1	+1	8	8	10	68	60
	14	+1	-1	+1	+1	-1	10	8	10	68	20
	15	-1	+1	+1	+1	-1	8	10	10	68	20
	16	+1	+1	+1	+1	+1	10	10	10	68	60
Star points	17	-2	0	0	0	0	7	9	9	63	40
	18	+2	0	0	0	0	11	9	9	63	40
	19	0	-2	0	0	0	9	7	9	63	40
	20	0	+2	0	0	0	9	11	9	63	40
	21	0	0	-2	0	0	9	9	7	63	40
	22	0	0	+2	0	0	9	9	11	63	40
	23	0	0	0	-2	0	9	9	9	53	40
	24	0	0	0	+2	0	9	9	9	73	40
	25	0	0	0	0	-2	9	9	9	63	40
	26	0	0	0	0	+2	9	9	9	63	80
Center of Plan	27	0	0	0	0	0	9	9	9	63	40
	28	0	0	0	0	0	9	9	9	63	40
	29	0	0	0	0	0	9	9	9	63	40
	30	0	0	0	0	0	9	9	9	63	40
	31	0	0	0	0	0	9	9	9	63	40
	32	0	0	0	0	0	9	9	9	63	40

Table 2. **The levels and variation intervals of factors listed in the table below**

Factors	Levels of variation		
	-1	0	+1
Loading weight of balls in the mill d_1=42mm	8	9	10
Loading weight of balls in the mill d_1=52mm	8	9	10
Loading weight of balls in the mill d_1=62 mm	8	9	10
Drum rotational speed, n, rev / min	58	63	68
Grinding time, t, min.	20	40	60

CONCLUSIONS

The basic factors, affecting the process under study and their calculation, are shown. The laboratory equipment and instrumentation are described. In order to study the process, the full factorial experiment such as 2^5 is selected, a matrix of its planning in coded and natural values is constructed. The implementation of the experimental investigations will improve the preparation of water-coal fuel with prescribed rheological and sedimentation characteristics.

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ИССЛЕДОВАНИЕ ПРИГОТОВЛЕНИЯ ВОДОУГОЛЬНОГО ТОПЛИВА МЕТОДОМ РАЦИОНАЛЬНОЙ ЗАГРУЗКИ ШАРОВОЙ МЕЛЬНИЦЫ

Татьяна Бондарь, Юрий Сёмин, Алина Сёмина

Аннотация. Приведена методика экспериментальных исследований приготовления высококонцентрированных водоугольных суспензий с необходимой реологической характеристикой в шаровой мельнице путем рационализации грансостава мелющих тел.

Ключевые слова: водоугольное топливо, шаровая загрузка, планирование эксперимента, динамическая вязкость, седиментационная устойчивость.