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SUBSTANTIATION OF PARTICLE-SIZE DISTRIBUTION OF SOLID PHASE OF STRUCTURED SUSPENSIONS ON THE BASIS OF SELF-OSCILLATING CONCEPTION OF MATERIALS FAILURE

The most important technological factor, which determines behavior of structured suspensions, is particle-size distribution of coal after its grinding. The results of research of lead specialists of our country [1] and world experience of implementation of technologies of coal-water fuel preparation [2,3] indicate that obtaining of peak concentration and therefore of structured suspension power-generating potential is feasible only in the case of bimodal particle-size distribution of solid phase, which ensures the maximal packing of particles [4]. Structured suspensions with bimodal particle-size distribution of solid phase have optimal rheological properties namely mobility and flowability, static and dynamic sedimentation stability as well as aggregative stability [5 – 7]. Therefore the most rational area of optimization of technologies of structured suspensions preparation is selection of such parameters of technology of source coal crushing and grinding, which ensure bimodal particle-size distribution of solid phase. The tumbling and rod mills are usually used nowadays for coal crushing and grinding when preparing structured suspensions [8 – 12]. This induces high energy output of preparation process. Electric power usage makes up from 90 to 110 kilowatt-hours per ton of crushing coal [13]. The ball-tube and rod mills with different standard sizes, design and production capacity are common in world practice for coal wet grinding. Wet grinding rattlers primordially were purposed and now are used in metal mining, building and cement industry. Such mills were little used in coal industry until recently. At the same time many researchers in our country and abroad tested other types of crushing machines (disintegrators, spiral spring mills and so on) in laboratory conditions and at the pilot plants. In all these cases the specificities of structure of crushing product as well as effects related to its resonant destruction with consecutive breaking of chemical bonds between atoms and formation of detached solid fragments appearing as a result of material interaction with grinding bodies are not taken into account. But taking into account exactly these factors makes it possible to obtain required bimodal particle-size distribution of solid phase with minimal power inputs.

The purpose of the paper is substantiation of the way of modernization of technology of structured suspensions preparation on the basis of self-oscillating conception of materials failure at the expense of selection of parameters of technology of source coal crushing and size reduction, which ensure the bimodal particle-size distribution of solid phase taking into account the specificities of structure of crushing product and the effects of material interaction with grinding bodies.

Solution of the problem of assurance of bimodal particle-size distribution of solid phase is restrained by absence of scientific substantiation of particle-size distribution parameters defining its bimodal nature and ensuring all required rheological and sedimentation properties. For such substantiation first of all it is necessary to explain why bimodal particle-size distribution of solid phase ensures optimal rheological properties and secondly it is necessary to answer such questions:

- what proportion of modes of particles diameters does ensure optimal rheological properties of structured suspensions;
- what particles mode distribution of fractions is rational;
- what content of fractions, which are situated between the modes of particles diameters, must be in the crushed coal.

Any of these questions has no unequivocal answer. The existing scientific methods of approach contradict one another and can explain either dense packing of particles in the case of bimodal particle-size distribution of solid phase or rational rheological properties of structured suspensions.

Some authors explain dense packing of particles and optimal rheological properties of structured suspensions with bimodal particle-size distribution of solid phase by possibility of placing of particle with small diameter among particles with greater diameter, which form the structure with cubic packing of particles in the liquid phase [5 – 7]. The essential difference in average diameters of fractions is necessary for obtaining of dense packing of particles (table 1). Porosity of crushed material in the case of cubic packing decreases only by 10 %. The globules of the same size may be also packed into pyramidal or tetragonal structure with porosity of 26%. In this case porosity of crushed material decreases to 15 – 19% in the presence of particles with lesser diameter. Such decreasing of porosity for material with bimodal particle-size distribution is possible only under condition that the size of lesser fraction particles is considerably lesser than the size of holes formed by particles of greater fractions. For example in concretes ratio of diameters of particles comes up to 16 but yield of fractions must be 7:3. This method of approach allows explanation of high density and power-generating potential of structured suspensions but it doesn't allow explanation of their high mobility, flowability, aggregative stability, static and dynamic sedimentation stability.

Table 1

Structure parameters of suspension solid phase

Structure parameters	**Ratio of diameters of lesser and greater particles**				
	1	0,414	0,225	0,175	0,117
Ratio of diameters	1	2.42	4.44	5.71	8.55
Number of lesser size particles in the pore	0	1	2	8	8
Porosity, %	26,0	20,7	19,0	15,8	14,9

The point of view of other group of researchers is that structured suspensions with bimodal particle-size distribution of solid phase have feebly marked thixotropic properties [1]. The basis of research of these scientists is the theory of stability of lyophobic colloids. This theory assumes that total interaction energy of two globules in thixotropic fine-dispersed water suspension is composed of ion-electrostatic and molecular dispersion (Van der Waals) constituents.

At that may be two types of fixation of nearest-neighbor grains in coagulation structure: irreversible fixation in the first potential minimum and reversible fixation in the second potential minimum [2, 3]. Irreversible coagulation disturbs homogeneity of structured suspension, gives rise to sharp deterioration of aggregative stability and other rheological characteristics. Reversible coagulation ensures thixotropic properties of structured suspension [10, 14]. Thixotropic characteristics of structured suspensions are integrally determined by magnitude and coordinate of second energy minimum of interaction of adjacent particles. Existence of this minimum is stipulated by the circumstance that energy of molecular dispersion interaction declines with rising of distance between particles according to power law, but energy of ion-electrostatic interaction declines according to exponential law. This means that energy of ion-electrostatic interaction declines faster than energy of molecular dispersion interaction. But this theory uses not size of particles but surface potential of solid particle, which may be greater or lesser than energy barrier of repulsion. This energy barrier appears when potential of double electric layer on the surface of solid particle is near to 50 mV. When value of this potential is lesser than 50 mV the structured suspension is aggregately nonstable because of irreversible coagulation of solid particles as a result of dispersion Van der Waals interaction. The result of aggregative instability is suspension stratification. When value of potential of double electric layer is greater than 50 mV two characteristic phenomena are observed. For one thing the height of energy barrier of repulsion considerably increases and as a result the aggregative stability of suspension is increasing. Secondly the coordinate of second energy minimum is displacing to the right and this results in increasing of the distance between solid particles, which are fixed in the second energy minimum of thixotropic structure.

So when analysing the energy state of solid phase of structured suspensions it was established in terms of the theory of stability of lyophobic colloids that irreversible coagulation of solid phase grains is defined by the presence of particles with low energy potential, but the presence of particles with high energy potential defines the distance between particles, at which irreversible coagulation in the first energy minimum is observed. So rheological properties of structured suspensions are defined not by ratio of sizes of solid particles and not by ratio of fraction contents, but they are defined by surface potential of particles. This method of approach explains suspension stability effect but doesn't explain high density of particles packing.

The third group of researchers holds the postulates of self-oscillating conception of materials failure during crushing and grinding [15]. According to this conception the crystal lattice with defects is considered as a self-oscillating system when exchanging by energy and matter with surrounding environment. This self-oscillating system may be defined as relaxation generator with two characteristic time scales, which describe periods of fast and slow relaxation processes. Fast relaxation processes are attributed as processes of destruction, but slow relaxation processes are attributed as processes of interaction of particles with each other and with grinding bodies, i.e. as processes of energy receipt by the system. If duration of these processes in system is comparable the resonance failure occurs, chemical bonds between atoms are sequentially breaking and separate fragments of solid are forming. There are two maximums on the curve of particle-size distribution of crushed or grinded material. One of these maximums is connected with the length of wave radiated during encounter and the second maximum is connected with the size of discontinuities such as cracks or pores. At the same time there is one minimum between two maximums and this allows consideration of such materials as bimodal.

This method of approach considers bimodal particle-size distribution of solid phase as stipulated by material properties and by grinding technology features. At the same time the method of approach accepted in the literature on technologies of structured suspensions preparation considers bimodal particle-size distribution of solid phase as stipulated by possibility of dense packing of solid particles at the expense of placing of particles with lesser size in the space among particles with greater size. Thus any material grinded in every possible way has bimodal particle-size distribution, but for each material the bimodal particle-size distribution exists, which ensures the densest packing of solid particles. One of the tasks of optimal technology of structured suspension preparation is the choice of such grinding way that ensures coincidence of bimodal particle-size distribution using both of these methods of approach.

The analysis of particle-size distribution of materials grinded in different work cycles allows the conclusion that material grinding way determines the possibility of obtaining of bimodal particle-size distribution. Taking this into account the bimodal particle-size distribution may be characterized by such parameters:

$$d_1 = K_b d_2; \quad d_m = K_m d_2; \quad K_b = \frac{1}{K_d}; \quad K_m = \frac{1+\sigma(K_d - 1)}{K_d}, \tag{1}$$

where d_1 – minimal primary size in particle-size distribution; d_2 – maximal primary size in particle-size distribution; d_m – particle diameter, which corresponds to minimum on the curve of particle-size distribution between two primary sizes; K_d – constant of multiplicity of primary sizes in particle-size distribution equal 3 ± 1 [15 – 17] σ – parameter, which characterizes location of minimum relative to the maximum; $\sigma = 0.419$ for particles of talc-magnesite rocks under jet grinding and $\sigma = 0{,}276 \pm 0{,}147$ for particles of iron ore.

The experiments in control of particle-size distribution of water-coal fuel solid phase are known [9]. In these experiments the size distribution of ball load of mill was changed (tables 2 – 4) [9]. The authors assert that this allows obtaining of particle-size distribution with different bimodality degree and obtaining of structured suspensions with different sedimentation stability (table 5).

Table 2

Coal particle-size distribution before grinding [9]

Size, mm	+ 3,0	1,0-3,0	0,3-1,0	0,25-0,3	0,1-0,25	0,08-0,1	0,04-0,08	0-0,04
Yield, %	0,76	7,71	19,52	14,24	12,35	10,24	4,41	30,77

Table 3

Particle-size distribution of grinded coal [9]

Size, mm	**Yield of classes for different variants of ball load of mill, %**				
	I	II	III	IV	V
+ 0,50	0,7	–	–	–	–
0,30-0,50	0,8	–	–	–	–
0,25-0,30	0,6	0,1	0,5	–	1,1
0,20-0,25	2,8	2,8	2,7	–	3,3
0,10-0,20	9,9	8,0	8,5	4,3	9,2
0,08-0,10	23,0	18,5	19,5	15,5	21,9
0,04-0,08	7,1	6,5	6,8	4,5	6,1
0,02-0,04	30,1	33,8	34,0	33,2	31,9
– 0,02	25,0	30,3	28,0	42,5	26,5

Table 4

Characteristics of variants of ball load of mill [9]

Load variants	**Size distribution of ball load of mill, %**			
	Diameter of balls, mm			**Average diameter, mm**
	40	20	10	
I	100	–	–	40,0
II	50	25	25	27,5
III	60	20	20	30,0
IV	40	30	30	25,5
V	70	15	15	32,5

Calculation of parameters of particle-size distribution of solid phase of structured suspensions for given results shows (table 6) that material destruction occurs in accordance with self-oscillating conception. This obviously follows from magnitude of constant of multiplicity of primary sizes in particle-size distribution. In addition value of this parameter impacts also on sedimentation stability of structured suspension. The greater is value of K_d (table 6) the greater is sedimentation stability (table 5).

Table 5

Sedimentation stability of water-coal fuel with different particle-size distribution of solid phase [9]

Coal particle-size distribution	**Sedimentation stability**
Variant I	not more than 1 day
Variant II	not more than 3 days
Variant III	not less than 15 days
Variant IV	30 days
Variant V	not more than 1 day

Table 6

Parameters of grinded coal particle-size distribution

Parameter	**Values of parameters for different variants of mill load**				
	I	II	III	IV	V
d_1	0,03	0,03	0,03	0,02	0,03
d_2	0,09	0,09	0,09	0,09	0,09
d_m	0,06	0,06	0,06	0,06	0,06
K_d	3	3	3	4,5	3
K_b	0,33	0,33	0,33	0,22	0,33
K_m	0,66	0,66	0,66	0,66	0,66
σ	0,499	0,499	0,499	0,571	0,499

The analysis of particle-size distribution of materials that are used in geotechnological systems for preparation of structured suspensions (tables 2 – 4) as well as analysis of their rheological properties show that rheological characteristics of such suspensions are described by Bengham-Shvedov law. The values of parameters in this dependence are determined by suspension concentration and by ratio of mass parts of fractions with diameters lesser and greater than d_m. Numerical handling of results of experimental research of rheological characteristics of structured suspensions obtained from materials with different bimodal particle-size distribution allows recommendation of follow dependences for calculation of initial shear stress and effective viscosity of structured suspensions [9]:

$$\tau_0 = \begin{cases} 0{,}4061 \cdot \Gamma^{1{,}7471} & C < 65 \\ \dfrac{7{,}2856}{\Gamma^{0{,}9267}} & C \ge 65 \end{cases}; \qquad \eta = 0{,}2921 \cdot \Gamma^{0{,}40261}; \qquad \Gamma = \frac{P_{-0{,}06}}{P_{+0{,}06}}, \tag{5}$$

where Γ – parameter, which characterizes bimodality of particle-size distribution of solid phase of structured suspensions; $P_{-0,06}$ – part of structured suspension solid phase particles with the size less than 0,06 mm; $P_{+0,06}$ – part of structured suspension solid phase particles with the size greater than 0,06 mm; C – suspension mass concentration, %.

Comparison of data given in tables 1, 3 and 6 indicates weak lowering of porosity when forming bimodal particle-size distribution of solid phase. The value of K_d is changing from 3 to 4,5 whereas the values from 5.71 to 8.55 are necessary for essential lowering of porosity. But such values of K_d are considered as unachievable from the point of view of self-oscillating conception of materials destruction.

Taking into account expression (5) Bengham-Shvedov law for considered structured suspensions may be written in such form:

$$\tau = 0{,}2921\left(A + \dot{\varepsilon}\right)\Gamma^{0{,}40261}; \qquad A = \begin{cases} 1{,}39\Gamma^{1{,}34} & C < 65 \\ \dfrac{24{,}94}{\Gamma^{1{,}33}} & C \geq 65 \end{cases}, \tag{6}$$

where τ – tangential stress; $\dot{\varepsilon}$ – strain rate.

Conclusions

1**.** The bimodal particle-size distribution of solid phase of structured suspension prepared using operations of crushing and grinding is forming in accordance with self-oscillating conception of material failure.

2. Bimodality degree impacts on characteristic dimension of internal defects of crystal lattice and on the size of crushed particles and of grinding bodies. The most probable mode of control of particle-size distribution of solid phase of structured suspension is changing of grinding bodies' size and of drum rotating frequency.

3. It is impossible to reach low values of porosity during preparation of structured suspension with bimodal particle-size distribution of solid phase using only operations of crushing and grinding. These operations must be supplemented with operations of sieving and classification.

4. The aggregative stability of structured suspension is determined not only by bimodality of particle-size distribution of solid phase, but also by value of surface potential of solid particles and by magnitude of energy barrier of repulsion. This energy barrier appears when potential of double electric layer on the surface of solid particle is near to 50 mV.

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СПОСОБИ АКУМУЛЯЦІЇ ЕНЕРГІЇ НЕТРАДИЦІЙНИХ ДЖЕРЕЛ

Вступ. При добовій і сезонній нерівномірності вироблення електроенергії значна економія традиційних енергоносіїв може бути досягнута шляхом акумуляції енергії, вироблюваної в періоди її мінімального споживання. Особливо важливо мати системи, що запасають енергію, при експлуатації установок з нерегулярним виробленням протягом доби або триваліших періодів - вітрових, сонячних. Проблема не вирішується із застосуванням електроакумуляторів - вони дуже коштовні, громіздкі і мають малу ємність. Гідроакумулюючі станції, дозволяють повернути в енергосистему в години пік до 70% енергії, накопиченої в години мінімуму споживання, проте їх будівництво доцільне в місцевостях з гористим рельєфом, де поруч розташовані зручні ділянки для верхнього і нижнього водойм.

Теплова енергія може акумулюватися речовинами, які при нагріві міняють свій агрегатний стан, структуру або хімічний склад, споживаючи або виділяючи при цьому теплоту. Наприклад, кристалічний сульфат натрію, якщо до нього при температурі 32,3°С підводиться теплота, втрачає воду, що входить до складу кристалів:

$$Na_2SO_4.10H_2O \rightarrow Na_2S0_4 + 10H_20.$$

Цей процес дегідратації супроводжується поглинанням великої кількості теплоти, яка може знову виділитися при зворотній реакції.

При застосуванні акумуляторів в енергосистемах на основі відновлюваних джерел енергії виконуються такі основні функції:

– забезпечення безперебійного енергопостачання споживачам за рахунок накопичення надмірної енергії та подальшого її використання в період відсутності або недостачі;
– забезпечення оптимального режиму роботи джерел енергії та споживачів за рахунок згладжування коливань в енергомережі;
– підвищення потенціалу енергії до необхідного при накопиченні низькопотенціальної енергії;
– перетворення енергії одного виду в інший відповідно до потреб споживача.

Як акумулятори енергії відновлюваних джерел можна використати:

– електрохімічні акумулятори;
– теплові акумулятори;
– акумулятори на основі зворотних фазових переходів;
– акумулятори на основі зворотних хімічних реакцій;
– акумулятори, що працюють при переробці палива за рахунок його збагачування;
– акумулятори, що працюють на основі водню.

Метою роботи є аналіз можливостей акумулювання енергії в енергосистемах на основі відновлюваних джерел енергії.

Матеріали досліджень. Використання електрохімічних акумуляторів є доцільним у комплексі із сонячними та вітровими установками різної потужності. Вони необхідні в установках невеликої потуж-