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Analysis of the accumulation the sedimentary mass in coal-water slurries

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Abstract. The problem of assessing the sedimentation stability of water-coal suspensions, which are a promising type of fuel, possessing the advantages of both liquid fuels and coal, which can be effectively used as a substitute for liquid petroleum fuel (fuel oil), is considered. However, coal-water suspensions have not found wide application at present, which is promoted, in particular, by unresolved issues related to their sedimentation stability: in the production, storage, and transport of suspension, an important qualitative characteristic is its stability over time: the higher it is, the more qualitative is the suspension. The paper proposes a method of solving the problem of predicting the value of particle sedimentation during the sedimentation process, which allows us to calculate the dynamics of sediment accumulation over a certain period of time from the beginning of sedimentation at a given depth of dispersion. The implementation of the calculation method as a systematic approach to determining the dynamics of sediment accumulation is shown on the example of sedimentation analysis data of 50 % water-coal suspension from coal from the Neryungri deposit. It is shown that the proposed method of solving the problem of predicting the size of sedimentation of particles during the sedimentation process allows to calculate the dynamics of sediment accumulation for a certain period of time at a given depth, as well as to determine the minimum sedimentation time, at which the particles of maximum size sediment completely.

1 Introduction

Water-coal fuel is a mixture of finely ground coal and water in proportions ensuring stability of the formed suspension without its stratification for a sufficiently long time. To improve rheological and sedimentation characteristics, various additives are introduced into these suspensions.

The main advantages of water-coal fuel, which has the properties of both liquid fuels and coal, are the possibility of its transportation by pipelines for almost any distance and direct combustion in furnaces without preliminary dehydration by spraying through nozzle devices. Such fuel can be effectively used as a substitute for liquid petroleum fuel (fuel oil).

Studies show [1-7] that water-coal fuel is environmentally cleaner than fuel oil and even

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coal: in terms of the minimum negative impact on the environment, combustion products are inferior only to natural gas fuel. The use of fine substandard coal, slurry products of coal preparation and hydro-mining for the composition of water-coal mixture also increase the environmental prospects of this type of fuel, when direct (without preliminary dewatering) combustion of slurry suspensions in thermal units would solve the problem of their utilisation. Nevertheless, coal slurries have not found wide application, which was promoted, in particular, by unresolved issues related to limited sedimentation stability of the slurry slurry [5-8].

2 Methods and materials

In the existing technologies for preparation of coal-water suspensions, the reduction of dynamic viscosity is achieved by selecting the particle size distribution of the UHS [3-5] or by introducing various types of additives [6-9]. At preparation of water-coal fuel the degree of dispersibility of coal particles (the value inverse to the particle diameter) is an important criterion, on which qualitative characteristics of the obtained suspensions depend, including the sedimentation rate of particles. And the highest sedimentation rate will have particles of maximum size.

Sedimentation stability, which characterises the dynamics of sludge accumulation, is one of the main indicators of coal-water slurry quality. In this paper, the implementation of a systematic approach to determining the dynamics of sludge accumulation in such systems is demonstrated on the basis of experimental data.

With the advent of instruments analysing the sedimentation rate and sieve composition of particles smaller than 500 μm, the traditional task of calculating the particle size distribution of disperse systems has somewhat lost its meaning, since the direct (instrumental) method allows to do it faster and with greater accuracy. At the same time, other tasks [10-15] of practical importance can be solved at the same time, namely:

- prediction of particle sediment accumulation at a certain dispersion depth over time;
- change in the particle size distribution of the dispersion in time along the vertical axis;
- estimation of the change in dispersed matter concentration during the sedimentation process at a "point" and "in a layer";
- differences in sedimentation of "heavy" and "light" particles;
- influence of the change of dispersed substance concentration on the sedimentation process;
- the influence of liquid column pressure (barometric effect) on sedimentation;
- evaluation of the degree of dispersibility of the particle system.

In the production and preparation of suspension, an important issue is its stability over time; the higher it is, the better the quality of the suspension. In this case, it will be of practical interest to solve the problem of predicting the amount of particle precipitation at a given depth of the suspension during the sedimentation process.

Usually, analysers present the results of analysis in the form of frequency distribution function (fractions $f_i(r_i)$) by size or number of particles, with all particles divided into n fractions $i = 1, 2, 3, \dots, n$ of the minimum radius r_{min} to the maximum r_{max}. By type of histogram $f_i(r_i)$ it can be approximated into any of the known theoretical distribution functions [13].

Based on the classical method of calculation of polydisperse systems of particles of different sizes, proposed by S. Oden, the whole settled per unit area, by the moment t at depth z, particle mass $G(t; z)$ is divided into two parts: the mass of particle fractions that have settled completely and the mass of particulate fractions that have settled partially [12-15]. In this case, the mass of the sludge will be:

$$G(t;z) = c_o z \int_{r_t}^{r_{max}} f(r)dr + c_o \beta t \int_{r_{min}}^{r_t} r^2 f(r)dr \tag{1}$$

where c_o– total particle matter concentration in the initial suspension, kg/m^3; t – sedimentation time, s; z – sedimentation depth, m; r_t – is the size of particles that have travelled along the path z for time t, m; β – coefficient.

Period from sedimentation start ($t = 0$) until a certain time t_{min} is calculated by the formula:

$$t_{min} = \frac{z}{\beta r_{max}^2} \tag{2}$$

During this time, none of the suspension fractions has settled completely and therefore the first summand in equation (1) will be equal to zero. Consequently, for this period equation (1) will have the following form:

$$G(z; 0 \leq t \leq t_{min}) = c_o \beta t \int_{r_{min}}^{r_{max}} r^2 f(r)dr \tag{3}$$

Coefficient β was obtained from the Stokes equation. It is known that the Stokes equation is applicable to determine the finite fall velocity of relatively small particles at Reynolds number $Re < 1$, i.e., at laminar regime of grain flowing by the medium, at which the action of forces from viscosity prevails [12-15]. Thus, for water-coal suspensions containing particles with a diameter of 0-250 µm, for which the Reynolds number $Re < 1$, Stokes' law is applicable.

However, in his equation, Stokes did not take into account the concentration of solids in the suspension, and, therefore, in determining the coefficient β on its basis, overestimated values t_{min} are obtained and calculated from the equation (2). Consequently, in general, the result of determining the dynamics of sludge accumulation will be inaccurate.

To eliminate this disadvantage, let us turn to the well-known methodology used in the calculation of fine ore beneficiation, where the velocity of constrained particle fall is a function of the coefficient *A*, which takes into account the properties of the particle and the properties of the medium:

$$v_{cr} = f(A) \tag{4}$$

$$A = 0.026(\delta - 1)\frac{\theta^3 d^3}{(1-\theta)^2 \nu^2} \tag{5}$$

here δ is solid density, kg/m^3; d – particle diameter, m; ν – kinematic viscosity of the medium, m^2/s; θ – loosening factor, calculated by the formula:

$$\theta = 1 - \frac{V_h}{V_s} = \frac{V_c - V_h}{V_s} = \frac{V_w}{V_s} \tag{6}$$

here V_h , V_w , V_s are the volume of solids in suspension, the volume of water and the volume of the suspension itself, m^3, respectively.

According to the above equations, after finding the coefficient *A* by equation (5) and depending on its value, the function for calculating the final velocity of the constrained fall is selected.

3 Results

After mathematical processing of equation (5) it was found that for water-coal suspension at solid concentration from 50 to 85 % and at particle size $0 < d \leq 250$ µm the calculation of velocity of constricted fall can be carried out by equation:

$$v_{cr} = 2.179(1 - \theta)\nu \frac{A}{d} \tag{7}$$

After substituting equation (5) into equation (7) and substituting v_{cr} on the ratio z/t we get:

$$t_{min} = \frac{4.41(1-\theta)\nu z}{r^2(\delta-1)\theta^3} \tag{8}$$

After substituting equation (8) into equation (2) we have:

$$\beta = \frac{0.142(\delta-1)\theta^3 r^2}{(1-\theta)\nu} \tag{9}$$

When predicting sludge accumulation in coal slurry, calculation by formula (8) is preferable to formula (2) due to the fact that the loosening index is used, reflecting the concentration of coal in the slurry.

4 Discussion

We shall consider the proposed variant of calculation on the example of water-coal slurry prepared from steam coals of Neryungri deposit.

Preparation of coal for slurry preparation was carried out by two-stage grinding with subsequent wet sieving into classes. At the first stage the initial coal was crushed on a jaw crusher to the class less than 3 mm, and then grinding was carried out on a planetary mill for 45 s. A grade less than 63 μm was extracted from the resulting coal.

A one-component suspension with a solid phase content of 50% was prepared by mechanically mixing the coal for three minutes with the liquid phase. Distilled water was used as dispersion medium.

The prediction of sludge accumulation can be divided into the following tasks:

1. Approximation of experimental data of sieve analysis function $f_i(r_i)$ by methods of mathematical statistics - some theoretical distribution function.

2. Determining the minimum time t_{min} at which particles of maximum size sediment completely.

3. Determination of sludge mass $G(t;z)$ by formulas (1) or (3) for time t from the beginning of sedimentation.

After sedimentation analysis of the prepared suspension on the scanning photosedimentograph Analisette-20, the particle size distribution was determined. After statistical processing of the experimental data (Fig.1), an equation with a high degree of correlation was obtained ($r = 0.994$):

$$f(r) = 0.544 + 1.048r - 0.06r^2 + 0.0012r^3 - 8{,}9{\cdot}10^{-6}r^4 \tag{10}$$

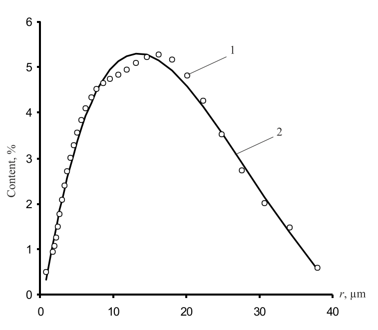

Fig. 1. Experimental data (1) and distribution function $f_i(r_i)$ sieve composition (2) of water-coal slurry prepared from steam coals of the Neryungri deposit

For maximum particle size ($r_{max} = 37.92\ \mu m$) by equation (8) determine the minimum settling time of the largest particles of suspension, which is $t_{min} = 2.79$ h:

$$t_{min} = \frac{4.41 \cdot (1 - 0.574) \cdot 10^{-6} \cdot 0.5}{(37.92 \cdot 10^{-6})^2 \cdot (1.35 - 1) \cdot 0.574^3} = 2.79\ h$$

To predict sludge accumulation in the time interval $0 < t < t_{min}$, we use equation (3), and at $t > t_{min}$ we use equation (1). The dynamics of sludge accumulation of water-coal slurry from coal of Neryungri deposit is shown in Figure 2. At the slurry layer height equal to 0.5 metres, the calculated data of sludge accumulation dynamics are described by the following equation:

$$G(t; 0.5) = \frac{t}{(0.044+0.003t)}\ ;\ (r = 0.995) \quad (11)$$

Using equation (11), it is possible to determine the mass of sludge of a water-coal suspension at a given layer height$(z = 0.5\ m)$.

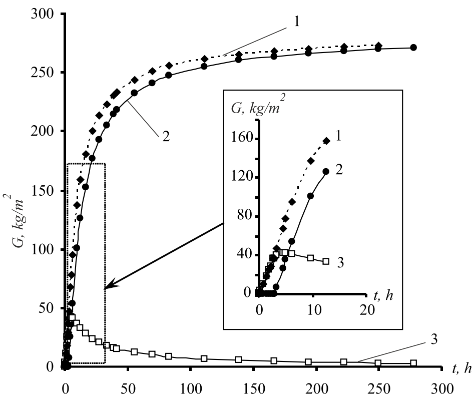

Fig. 2. Dynamics of sludge accumulation in coal slurry: 1 - sludge mass of slurry; 2 - mass of fully sunken fractions; 3 - mass of partially sunken fractions.

5 Conclusion

Thus, the proposed method for solving the problem of predicting the amount of particle sedimentation during the sedimentation process allows to calculate the dynamics of sediment accumulation for the time t from the beginning of sedimentation at a given depth of dispersion, as well as to determine the minimum time t_{min} at which the maximum size particles sediment completely. For example, for the water-coal slurry from Neryungri coal, the minimum sedimentation time of the maximum particle size $r_{max} = 37.92\ \mu m$ at a depth of 0.5 m will be 2.79 h. Using this method, we can also calculate the mass of the coal slurry sediment and simulate the sedimentation process.

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