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Research of the Effect of Particle Size on Optimal Coagulant Dose

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Abstract: *The optimal dose of coagulant has great technological importance and is influenced by many factors. An attempt was made to determine the dependence of the optimal dose of dispersion and the concentration of water impurities. To express the concentration and dispersion of water impurities, a generalized index l / d is proposed. Investigations were carried out on model kaolin suspensions with different dispersion and concentration of impurities.*

Keywords: *optimal dose of coagulant, particle size, dispersion, impurity concentration*

INTRODUCTION

Determining and maintenance of optimal conditions for coagulation of water impurities is one of the important technological problems in the practice of water purification. The optimum is achieved by injecting the required dose of coagulant, which corresponds to the quality of the initial (clarified) water and the desired purification effect. The deviation of the values of the injected dose of the coagulant from the optimal ones, both upward and downward, causes a sharp deterioration in the quality of the clarified water. The optimal dose of the coagulant depends on many factors; however, consideration of all factors is very difficult due to the constant changing water composition. Therefore, the regulation of the coagulant dose according to one or several parameters has become widespread. Analyzing the factors affecting the optimal dose of coagulant, they can be conditionally grouped as follows.

Aquatic environment factor: This factor includes the chemical composition of water (salt composition, pH, etc.) and its physical indicators (temperature, viscosity, etc.).

Impurity factor: This factor refers to the quantitative and qualitative characteristics of the impurities to be removed (concentration, dispersion, density and shape of impurity particles, etc.).

Technological factor: It characterizes the conditions for mixing the reagent with water and separating the coagulated suspension, which depends on the type of coagulation and the type of water treatment apparatus.

The proposed grouping is conditional, as the factors of the individual groups are interrelated. In the practice of water purification, they most often deal with water, the chemical composition of which and its physical parameters change slightly or periodically with a known repeatability, for example, seasonal fluctuations in water temperature. The technological factor associated with the type of coagulation (peri- or orthokinetic) and methods of water treatment remains unchanged. The optimal dose of coagulant for water treatment of a specific object is mainly predetermined by the characteristics of impurities.

Considering that characteristics of concentration and dispersity of water impurities are the most changeable, our investigations were aimed at finding out the dependence of coagulant consumption in water treatment on particle size and concentration. There is a close relationship between the optimum coagulant dose and the concentration of impurities to be removed, which is described by the equation

Dopt = K * C ^ n (1)

where D_{opt}- the optimal dose of coagulant, mg / *l*; c - concentration of removed impurities, mg / l; K and p are empirical coefficients.

Analysis of the research results of many authors, carried out in [1], showed that at C> 100-200 mg / l K takes a value in the range of 1-10, and the exponent n is 0.28-0.65. There is evidence that n can reach 1.0, i.e., the dependence of the optimal dose of the coagulant on the concentration of impurities in this case is expressed by a straight line [2]. According to [1], the values of K and n are influenced by the nature of the used coagulant and the conditions of water treatment.

Exponentialcharacter of the dependence of the optimal dose of the coagulant on the concentration of impurities was determined at electrolytic coagulation [3], discoloration [4], water softening [5] and is explained by a decrease in the charge and exchange capacity of particles at an increase in the concentration of suspensions [6]and the predominance of various types of coagulation [7]. At low concentrations of impurities, coagulation takes place by " wrapping" of particles by products of coagulant hydrolysis, at high concentrations the particles coagulate with protrudingedges[7].The contradictory nature of the judgement suggests that the given dependence for determining the optimal coagulant dose has not found a theoretical basis.

Some studies also provide information on the effect of the dispersal of coagulated particles on the optimal coagulant dose [1,8]. The control parameter here is the diameter of the particles or their surface area. However, even in this case, researchers' opinions are contradictory, for example [1,8], where the dispersity parameter is considered in isolation from other characteristics of impurities. Therefore, the influence of the concentration and dispersity of the impurities on the coagulant dose must be considered as a whole.

Methods: In order to identify the nature of the effect of impurities concentration and dispersion on coagulant dose, special studies were conducted on artificially prepared kaolin containing suspension. Standard samples were prepared according tothe method [9].

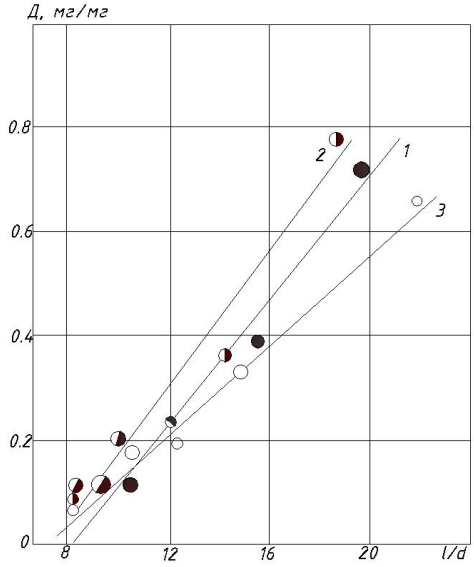
The concentration of impurities in the suspension was measured using a photometric method with automatic recording of the results. The change in dispersion was achieved by multiple sedimentation with a given settling period [10]. The size of kaolin particles in divided fractions was measured by microscopic method [11]. The mode of stirring the reagent in the suspension was intense. An aluminiumsulphate solution with an Al3+ 2000 mg/l concentration was used as a coagulant. The pH value was maintained within optimal limits by adding NaOH. Experiments were carried out at water temperatures of 19-23°C. The kaolin suspension was stabilized with sodium silicate (Na2SiO3).

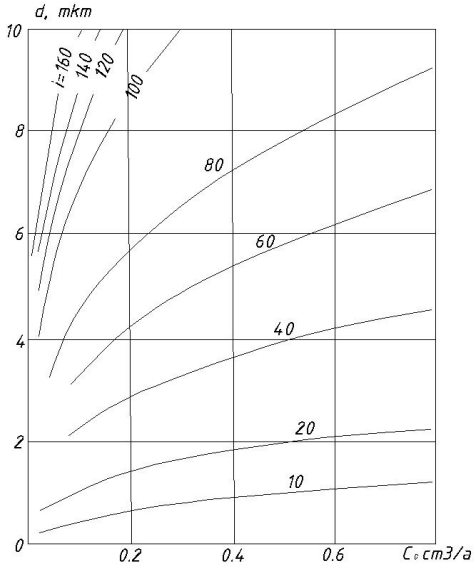
Results and Discussion: The dose of coagulant relevant to the amount of existing substances was taken as the main idicator. By dividing both parts of equation (1), the optimal specific dose of coagulant (hereinafter referred to as specific dose) can be derived as a function of the concentration of existing impurities.

Dud = KCn / C = K / C1-n(2)

where Dud- the specific dose of the coagulant.

Equation (2) shows that at increase of the concentration of impurities in treated water, the specific dose of coagulant decreases. Based on the conditions that the particles are monodisperse and have a spherical shape and the relationship between the concentration of impurities and the size of their particles d is determined by the ratio l/d. Therefore, it has been proposed to characterise the concentration of impurities by a linear parameter, i.e. the distance between the centres of particles l [12, 13].





sion)

Fig 1 Dependence of the optimal doses of coagulant on the parameter: 1-diameter of parts 9.04 μm; 2-2.56 μm; 3-0.7 μm

Fig 2 Isolation of distances between the centers of particles (l) of different particle size(d) at a volume concentration of 2.44 g/cm3.

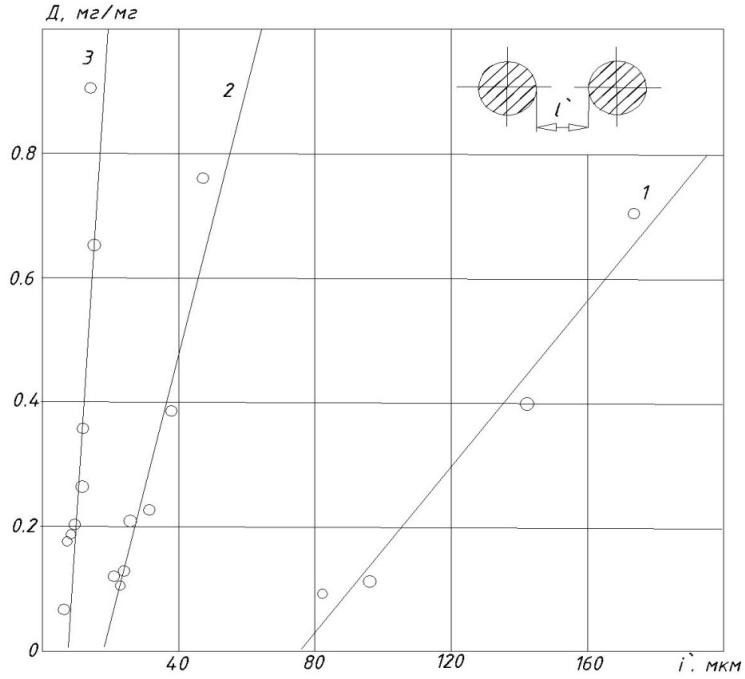


Fig 3 Dependence of the specific dose of the coagulant on the distance between the centers of the particles, μm

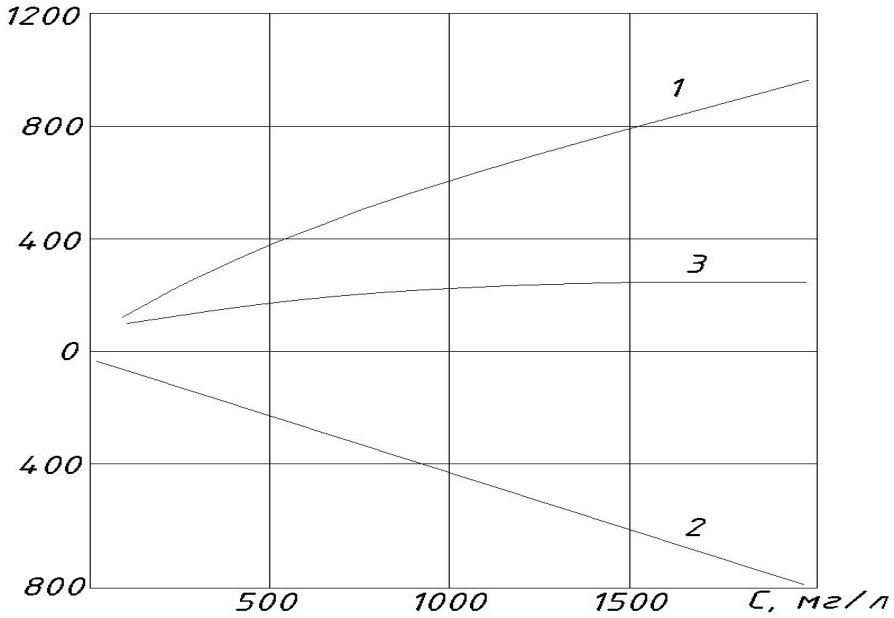


Fig 4 Change in theoretical (1) and actual (2) doses of coagulant and value (3) depending on the concentration of impurities, particle size 9.04 μm.

Expressing the parameter in terms of the known characteristics of impurities, we obtain the equation

$l / d = \left[\!\left[(6c / \pi\rho)\right]\!\right]^{(-1/3)}$ (3)

where *l*- the distance between the centers of particles, μm; d - particle diameter, μm; p - dispersed phase density, kg / m3.

In order to study in detail the dependence of the optimal dose of the coagulant on the parameter l / d, a series of experiments on the coagulation of mineral impurities with aluminum sulfate was carried out. The coagulated flakes were separated by free volume sedimentation. The studies were carried out on a kaolin suspension with an average particle size of 9.04; 2.56 and 0.70 microns. The research results show that the dependence of the specific dose of the coagulant on the parameter l / d is expressed by crossing lines (Fig. 1). According to this graph, it is difficult to establish the effect of the dispersion of impurities on the dose of the coagulant. The straight-line dependences of the specific dose of the coagulant on the parameter a, obtained in [12-15], can apparently be explained by the fact that in each individual case a system was investigated with a relatively stable value of the dispersion of impurities. The *l / d* value changed mainly with varying impurity concentration. This is confirmed by the absence in the right-hand side of Eq. (2) of a parameter characterizing the dispersion of impurities, i.e., the parameter *l / d* depends only on the concentration and density of the dispersed phase and can be control, provided the average size of the removed impurities is constant.

In order to obtain a parameter that simultaneously takes into account the concentration, dispersion and density of impurities, the equation has been transformed (3)

$l` = d\left[\!\left[(6c / \pi\rho)\right]\!\right]^{(-1/3)} - d = d\left[\left[\!\left[(6 / \pi c\_0)\right]\!\right]^{(-1/3)} - 1\right]$ (4)

where *l`* is the distance between the surfaces of the particles, μm; C0 = s / p is the volume concentration of the dispersed phase.

The graphic representation of this function (4) shows that in highly dispersed systems (d<1 μm), the distance between the centers of particles decreases insignificantly with an increase of the volume

concentration of the dispersed phase from 0.2 to 0.8 cm3 / L, from 13.7 to 8, 7 μm, in low-disperse systems (*d*> 10 μm), on the contrary, slight changes in concentration correspond to sharp changes between the centers of particles (Fig. 2).

The dependence of the specific dose of the coagulant on l` at a fixed dispersion of the impurities that are the subject of removal in the first approximation can be taken as linear (Fig. 3). In general, the dependence of the specific dose of the coagulant on l` is described by the equation

$D = A * l` - B$(5)

where A and B - are empirical coefficients.

Mathematical processing of the research results made it possible to determine the empirical coefficients included in expression (5) for suspensions with the investigated dispersion of impurities:

particlediameter,μm	A	B
9,04	0,00666	0,4934
2,56	0,02245	0,3930
0,70	0,08610	0,5423

The research results show that with an increase in the dispersion of impurities, the angle of inclination of the found rectilinear dependences to the abscissa axis increases (Fig. 3), i.e., the value of A increases. The segment cut off on the abscissa by the function D = $\oint(l`)$, in all probability, expresses the critical distance between the centers of particles at which the dispersed phase can spontaneously aggregate. Fig. 3, it can be seen that in low-disperse systems spontaneous aggregation can occur at large distances than in highly dispersed systems (Fig. 3). In this case, the critical concentrations in highly dispersed systems are lower than in low dispersed systems, which is consistent with generally known conclusions [8].
The value of B during coagulation of suspensions with a fineness of 0.70–9.04 microns is on average 0.4762–0.066, i.e., it changes insignificantly. We represent the dose of coagulant in mg / l, which is identified by multiplying both sides of equation (5) by the value of the concentration of impurities and, as a result, we obtain:

$Dopt = A * l` * C - B * C$ (6)

As you know, the rate of formation of poorly soluble products of hydrolysis of coagulants in the presence of an extraneous solid phase is accelerated and is a function of the specific surface area of solid particles and the value of the relative saturation of the solution [2]. Consequently, the expression B * C in (6) can be considered as a value (Ds.) That reduces the flow rate of the coagulant by increasing the number of particles of the solid phase. In this case, the product (A * l` * C) can be considered as the theoretical dose of the coagulant (Dtheor), and the Dopt - the actual dose. Thus, the actual dose of the coagulant is equal to the theoretical dose, reduced by an amount proportional to the amount of suspended solids.

Dopt = Dteor- Ds (7)

Analysis of the equations (6) and (7) shows, that at low suspended phase concentrations actual coagulant dosage is close to theoretical one. Increase of concentration of the disperse phase leads to the increase of theoretically calculated coagulant consumption, but the actual consumption increases with smaller rate, which is connected with growth of the number of nucleation centres (fig. 4). In our opinion, factor B reflects the influence of the media factor and the type of the used coagulant.

Conclusions. Thus, the specific consumption of the coagulant, determined by the equation (5), is associated with the phase-dispersed characteristic - suspension - the size of impurity particles (A) and their concentration (l`), the environmental factor and the type of the used coagulant (B).

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