Effect of technological parameters on clarification low-concentration suspension by dissolved air flotation

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Abstract. In this work, the technological parameters that can significantly effect on a quality of clarification low-concentration suspension by dissolved air flotation were considered. These parameters are: particle size, air bubble size, water rise velocity and air concentration in water. The size of solid particles influences on the probability of their collision with bubbles. The water rises velocity change time of contact between solid particles and bubbles in the working area, which also effects on the probability. Increasing the air concentration in a tank improves the quality of water clarification, because more bubbles are formed there. These factors will be taken into account in further studies to find the optimal dimensions of flotation tank for better cleaning low-concentration suspension.

1. Introduction

The high level of development of the city is determined by the possibility of supplying water with high drinking quality. Unfortunately, for Ukraine there is a big problem to supply water with such quality to customers. Due to the uneven distribution of surface water sources in the country it is difficult to supply water to the consumer in the required quantity [1]. Reservoirs or storage ponds, which collect water, were built in order to achieve the necessary volume of water for citizens and industry [2]. The disadvantage of these facilities is the deterioration of hydrochemical parameters of surface water. In many cases, the quality of source water is inappropriate [3]. This is due to discharge of insufficiently treated wastewater or surface runoff, which contains contaminants, into surface water.

In our country, a traditional technological scheme of clarification a low-concentration suspension is a two-stage scheme (settling tank-filter), or a scheme with contact illuminators [4]. Advantages of contact illuminators are that water with reagents (coagulants) almost instantly come into contact with the loading of the illuminator and these facilities are easy to use. The disadvantages are low rate of filtration and the deterioration of the formation flakes in the cold season, which leads to a decrease in the efficiency of water clarification. Therefore, it is necessary to intensify the methods of clarification low-concentration suspension, or to introduce new methods and devices that could effectively clarify water to the quality [5, 6]. One of such method is dissolved air flotation. This technology allows due to the different physicochemical properties of the phases to isolate suspended solids from the low-concentration suspension. The physical and chemical properties of air bubbles help to remove suspended solids, algae, metal hydroxide deposits and natural organic matter from the water [7-9]. Using facilities with dissolved air flotation process will reduce the area of treatment plants [10]. Unfortunately, the influence of technological parameters on the efficiency of the removal suspended particles by size 10^{-6} - 10^{-3} m remains poorly understood.
The aim of this work is to study the technological parameters which can affect on dissolved air flotation process for clarifying low-concentration suspension and to research the possibility of their control.

2. Material and Methods
We have improved the mathematical model to research influence of the technological parameters on flotation process. It is based on the following equations and dependencies [11]:

1. Transfer concentration of suspended solids by the water stream equation:

\[
\frac{\partial C}{\partial t} + W \frac{\partial C}{\partial z} = D_c \frac{\partial^2 C}{\partial z^2} - bKC,
\]  

(1)

The equation of mass transfer that determine the distribution of concentration of suspended solids on the height of the working part in flotation tank:

\[
\frac{\partial C(z, t)}{\partial t} + W \frac{\partial C(z, t)}{\partial z} = D_c \frac{\partial^2 C(z, t)}{\partial z^2} - J(z, t),
\]  

(2)

where t is the time, s; z is the vertical coordinate, m; W is the water rise velocity, m/s; C(z, t) is the suspended solid concentration in water, kg/m³; D_c is the diffusion coefficient of the concentration of suspended solids, m²/s; J(z, t) is the flow of suspended solid concentration from the liquid phase into the gaseous phase, kg/(m³·s).

According to the ideas about the kinetics of the flotation process, the flow J is proportional to the concentration to bubble (air) concentration and the suspended solid concentration in the water:

\[ J(z, t) = b(z, t)KC(z, t), \]  

(3)

where b is the volumetric concentration of bubbles in water; K is the flotation process constant [11].

2. The concentration transfer equation is:

\[
\frac{\partial b(z, t)}{\partial t} + \frac{\partial ((W + u_{bub}(z, t))b(z, t))}{\partial z} = D_b \frac{\partial^2 b(z, t)}{\partial z^2},
\]  

(4)

where \( u_{bub}(z, t) \) is the bubble rise velocity in stationary water, m/s. The initial bubble velocity can be found by the Stokes equation; \( D_b \) is the diffusion coefficient of bubble concentration, m³/s.

The change in the water rise as a result of compression of the flow by bubbles is taken into account:

\[ W(z, t) = \frac{Q}{F} \left[ 1 - \frac{\pi}{4} \left( \frac{6b}{\pi} \right) \frac{2}{3} \right]^{-1}. \]  

(5)

3. Suspended particle concentration on bubbles is determined by the mass transfer equation:

\[
\frac{\partial S(z, t)}{\partial t} + \frac{\partial ((W + u_{bub}(z, t))S(z, t))}{\partial z} = KC(z, t)
\]  

(6)

Using this improved mathematical model for the clarification low-concentration suspension by dissolved air flotation, we have studied the effect of the main parameters on the facility.

As the main technological parameters, which influenced on the process, we accepted:
- size of suspended solid (r);
- size of bubble (d_{bub});
- average of water rise velocity (W);
- air concentration in source water (b_0).

We decided to take the quality of cleaning as a criterion of efficiency. It is calculated as the ratio of the suspended solid concentration in purified \( C_1 \) and source water \( C_0 \).
Figure 1 and Figure 2 are presented examples of calculations the quality of cleaning for average sizes of solid particles and bubbles. These parameters we varied in ranges: \( r = 1-5 \ \mu m \); \( d_{bub} = 10-30 \ \mu m \). The calculations are performed with the following fixed parameters: average water rise velocity \( W = 5 \ \text{mm/s} \), the volumetric concentration of bubbles in source water \( b_0 = 0.1 \text{ m}^3/\text{m}^3 \). The working height of flotation tank is 3 m.

![Graph](image)

**Figure 1.** Dependence of the quality of clarifying on the bubble size with a particle size from 1 to 5 \( \mu m \)

![Graph](image)

**Figure 2.** Dependence of the quality of clarifying on the bubble size

The data, which presented in Figure 1, show that with decreasing particle size of the contaminant, the quality of cleaning deteriorates sharply. As the size of the suspended solid decreases, the probability of encountering the bubble and the solid phase fraction decreases, as well as its capture by the bubble. The radius of the suspended solid depends on the capture coefficient and, accordingly, the flotation process constant.
When diameter of the bubble decreases, then the cleaning process improves. A larger number of bubbles is formed from one unit of the volume of dissolved air. The probability of their encounter with the suspended solid particles increases and the constant of the flotation process increases.

The Figure 3 presents an example of calculating the dependence of the quality of cleaning on the average water rise velocity in the working area and the average diameter of the bubbles. If the cross-sectional area of the floater does not change in height, the flow rate will be the same. The water rise velocity we varied in the range of 2-7 mm/s.

Figure 3. Dependence of the quality of cleaning on water rise velocity

When the rise velocity decreases, then the quality of cleaning increases too. The time, when bubbles are in the working zone, increases, and the probability of attachment bubbles with particles increases. The dependence between the quality of cleaning and the rise velocity, for bubbles with a diameter of 20 μm in the range of the parameter W, is almost linear (line 2, Figure 3). For larger bubbles with low water rise velocity the cleaning quality improves (line 3, Figure 3), and for smaller bubbles it slows down (line 1, Figure 3).

The Figure 4 shows an example of calculating the dependence of the quality of cleaning on air concentration in source water and average bubble size (d_bub). The value of air concentration varied in the range of 0.03-0.12.

Figure 4. Dependence of the quality of cleaning on air concentration in source water and bubble size
These data show that if air concentration increase in source water, then the cleaning quality improves dramatically. In this case, a larger number of bubbles are formed. The process of mass transfer of suspended solids from the liquid phase to the gaseous phase goes more intensively.

The slowdown in the growth of cleaning quality at large values of $b_0$, especially for small bubbles, can be explained that the air concentration and the number of bubbles increase, but the hydrodynamics of the flow change slightly.

The Figure 5 is presented the dependence between water rise velocity in tank, where flow is squeezed by bubbles, ($W_{sq}$) and water rise velocity without bubbles in tank ($W_0$).

![Figure 5](image)

**Figure 5.** Dependence between water rise velocity with bubbles ($W_{sq}$) and without bubbles in tank ($W_0$)

In this case, the compression of the flow with bubbles increases, the water rise velocity increases and the probability of contact with the solid particles decreases.

3. Conclusion
In this work, the technological parameters of clarification low-concentration suspension by dissolved air flotation were considered. We have analysed dependences and decided that technological parameters have a significant impact on the flotation process. In the process of designing new dissolved air facilities, it is possible to control and change: water rise velocity and air concentration in the source water. During operation, it is necessary to change the water rise velocity and air concentration too. Reducing the rise velocity requires more flotation tanks. This is increase area of water treatment plant. To increase the air concentration possible when water is saturated with more gas under greater pressure, but this requires higher energy consumption.

Our next step will be to research the impact of design parameters on the flotation process and develop a design of flotation tank, which would provide positive impact of these parameters on the quality of cleaning without increasing capital and operating costs.

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