Multistage model of flotation process for water purification

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Abstract. The paperdeals with the features of multistage model's application of the flotation process that was devoted by the author. In his paper, the author described the applicability of ion flotation for wastewater treatment using the flotation machines. The author showed the approach associated with the use of a multi-stage process model is effective for determining the floating time. The author gives the theoretical and experimental data of the flotation process and their comparison. The paper shows that the proposed model reasonable describes the process of flotation water purification, in particular from metal ions. In this case, the kinetics of the formation of flotation complexes and the concentration of metal ions in the foam layer are also quite understandable.

1. Introduction

Modeling of various technological processes allows not only to more deeply study the phenomena underlying these processes, but also to increase their efficiency [1–9]. The development of modeling is also important for water purification technology, in particular using flotation [10–20]. Previously used models of the flotation process did not consider the particular gas bubble flotation complex as the main object, which did not allow an objective presentation of the elementary flotation act and the process as a whole.

2. Basic proposals and ideas

B.S. Ksenofontov developed a multistep flotation model, taking into account the main features of the process, including the formation of a flotation complex [18]. The main stages of the flotation process according to this model are shown in the figure. 1.

B.S. Ksenofontov determined the values of the flotation process's constants for the constant K1 [18].

The constant K_1 in a variety of ways flotation:

$$K_1 = \frac{1}{t_0} P_{CN}$$

where

P_{CN} – probability of flotation complex formation bubble – a particle over a period of time t_0.

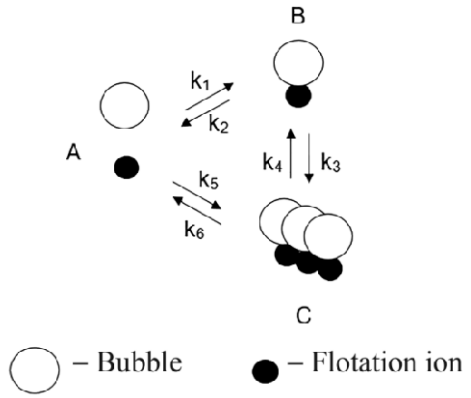

Figure 1. Diagram of multistage flotation model:
A, B, C – system condition, Ki – kinetic constant.

It is generally accepted that during the flotation process of clarifying fine suspension or wastewater treatment, the constant K_1 can be determined from the ratio:

$$K_1 = \frac{1.5qE}{k_0 \overline{D}}$$

where
q – speed of barbotage;
E – the capture efficiency of particles by a floating gas bubble during flotation, which characterizes the probability of a bubble contacting with a particle (a dimensionless quantity);
$\overline{D}$ – average bubble diameter in the flotation cell;
k_0 – bubblepolydispersity factor. The most of all the value of this constant is taken 10-3.

The probability of destruction of the formed flotation complexes is characterized by a constant, which can be approximately determined by the formula

$$K_2 = A\ C_ф\ Ga M^2\ C^{-1}ПП$$

where
A – nondimensional coefficient;
$C_ф$ – particulate bubble flotation concentration;
Ga – velocity gradient in the aeration zone, determined by the ratio of the difference of the speeds to the difference of the distance between the points in question;
M – ratio of particle diameter to bubble diameter;
Спп – bubble concentration in the under bubble column.

Displacements of flotation complexes particulate bubble from a liquid to a bubble column are characterized by a constant

$$K_3 = \frac{\upsilon_{под}}{h}$$

where
$\upsilon_{под}$ – lifting speed of the flotation complex;
h – distance from the zone of suspended water to the bubble column (depth of the flotobox).

The constant K_4, characterizing the loss of flotation complexes from the bubble column, provided it is immediately removed, is determined by the following approximate formula

$$K_4 = F\ Gп\ Cп\ d^3ср$$

where
F – constant of proportionality;
Gп – rate of shear in under bubble column;
Cп – concentration of bubbles in the bubble column;
dcp – bubbles average diameter in bubble column.

The constant K_5, determining the precipitation of solid particles from the foam layer to the aeration zone:

$$K_5 = \frac{\upsilon_{oc}}{h}$$

where
υ_{oc} – sedimentation rate of solid particles falling out of the bubble column (as a rule, can be calculated using Stokes formula).

The probability of transition of particles of a solid phase from a liquid to a bubble column is characterized by a constant:

$$K_6 = \psi \frac{\partial}{\partial x}\left\{\frac{1}{2\sqrt{\pi\psi t}}\left[\exp\left(-\frac{(x-h)^2}{4\psi t}\right) - \exp\left(-\frac{(x+h)^2}{4\psi t}\right)\right]\right\}$$

where
t – time;
x – current distance from the boundary of the bubble column;
ψ – diffusion coefficient of solid particles in a liquid.

As an example, it seems appropriate to consider a multistage model of ion flotation, which can be shown as a sequence of the following system states (figure 2):

-condition A – collegial and collector ions and gas bubbles exist autonomously;

- condition B – the formation of a sublate as a result of the interaction of the collector and the colligend;

- condition C – flotation complex gas bubble collector;

- condition D – the formation of the flotation complex ion collegiate-collector-gas bubble;

- condition E – the formation of a bubble column containing ions of a colligend and a collector and gas bubbles;

- condition F – formation of foam containing colligend ions and a collector without gas bubbles (sublate concentrate).

The mathematical description of the flotation process that showed in figure 2 can be described by the following system of equations:

$$\begin{cases} \frac{dC_A}{dt} = -k_1C_A + k_2C_B - k_3C_A + k_4C_C - k_{15}C_A + k_{16}C_F; \\ \frac{dC_B}{dt} = k_1C_A - k_2C_B - k_5C_B + k_6C_D - k_{13}C_B + k_{14}C_F; \\ \frac{dC_C}{dt} = k_3C_A - k_4C_C - k_7C_C + k_8C_D; \\ \frac{dC_D}{dt} = k_5C_B - k_6C_D + k_7C_C - k_8C_D - k_9C_D + k_{10}C_E; \\ \frac{dC_E}{dt} = k_9C_D - k_{10}C_E - k_{11}C_E + k_{12}C_F; \\ \frac{dC_F}{dt} = k_{11}C_E - k_{12}C_F + k_{13}C_B - k_{14}C_F + k_{15}C_A - k_{16}C_F. \end{cases} \quad (1)$$

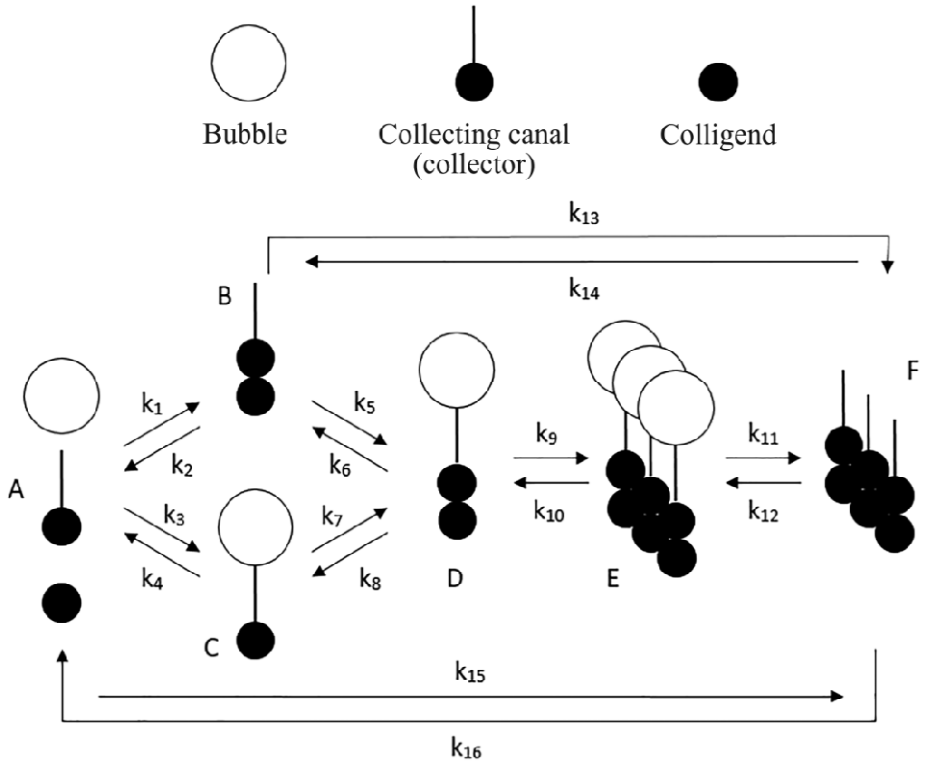

Figure 2. Diagram of multistage model of ion flotation.

The proposed system must satisfy at least two conditions, namely, at the initial moment of time; the concentration of the colligend at the first stage is equal to the initial concentration in the solution and at any moment of time the sum of the concentrations of the colligend at all stages is equal to its initial concentration.

3. Calculations and discussion of results

Usually the proposed system is solved with using the numerical methods. For practical cases, as shown by the author's calculations, it is possible to use simplified calculations according to the scheme shown in figure 3.

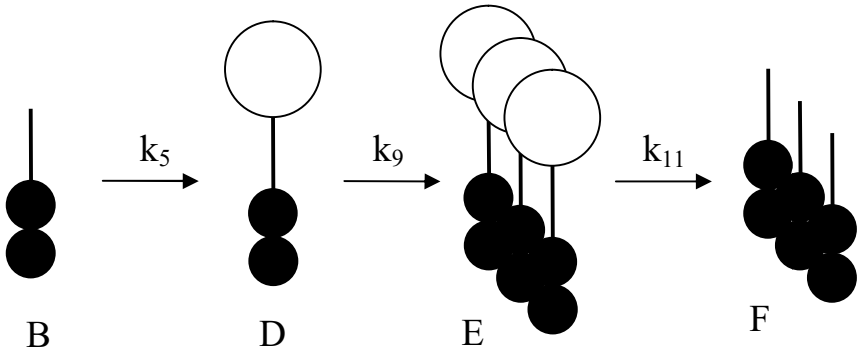

Figure 3. Simplified diagram of the ion flotation process in a flotation machine with a conditioning chamber.

Considering that the collector, which in some cases can be used, activated sludge [21-22], fully reacted with a colligend in the mixing reactor, and then the system of equations (1) will take the form:

$$\begin{cases} \frac{dC_B}{dt} = -k_5 C_B; \\ \frac{dC_D}{dt} = k_5 C_B - k_9 C_D; \\ \frac{dC_E}{dt} = k_9 C_D - k_{11} C_E; \\ \frac{dC_F}{dt} = k_{11} C_E. \end{cases} \quad (2)$$

Solving the system of equations (2), we take the following initial data on the example of the extraction of nickel from waste water:

$C_0 = 0.9$ mg/l – concentration of the extracted substance in the initial solution;

$k_5 = 0.005$ c^{-1};

$k_9 = 0.15$ c^{-1};

$k_{11} = 0.001$ c^{-1}.

to $t = 0$ $C_B = C_0$; $C_D = C_E = C_F = 0$.

The efficiency of extraction of individual metals from wastewater, obtained by calculation and determined experimentally, is showed in table 1. Comparison of calculated and experimental values shows a small discrepancy, not exceeding about 7%, which allows you to use the calculated data to assess the effectiveness of wastewater treatment, including from metals, using ion flotation.

Table 1. Extraction of individual metals from waste water using ion flotation.

No	Metal	Concentration of metal in waste water,Mg/l	Flotation time,min	Estimated cleaning efficiency,%	Experimentally determined cleaning efficiency, %
1	Chrome (generic)	2.2	15.5	97.7	91.4
2	Pb (plumb)	4.4	15.5	96.9	89.6
3	Ni (nickel)	3.5	15.5	98.4	92.7
4	W (wolfram)	2.9	15.5	97.8	93.3
5	Co (cobalt)	4.1	15.5	96.5	89.6

It should also be noted that this possibility allows to determine the concentration of the extracted substance at each of the considered stages of the process at any time point without conducting expensive experiments, which is especially important when designing a sewage treatment system. In addition, it is possible to find a time-limiting stage, affecting the flow of which can reduce the total time of the process of extracting contaminants, including metal ions. In this case, the intensification of the flotation process can be achieved by using reagents.

4. Conclusion

Analysis of the solutions obtained and calculation examples show that the proposed model rather accurately describes the process of flotation water purification, in particular from metal ions. At the same time, the kinetics of the formation of flotation complexes and the concentration of metal ions in the foam layer are also quite understandable.

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