Analysis of hydraulic modes of operation of the divergent plates block of the flotation-sedimentation tank

To cite this article: B Ksenofontov et al 2019 IOP Conf. Ser. Mater. Sci. Eng. 492 012024

View the article online for updates and enhancements.
Analysis of hydraulic modes of operation of the divergent plates block of the flotation-sedimentation tank

B Ksenofontov¹², E Senik¹ and M Ivanov¹

¹ Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation
² E-mail: ksenofontov@bmstu.ru

Abstract. This article shows the results of hydraulic characteristics analysis of operating modes of divergent plates of the thin-layer clarification block of the flotation-sedimentation tank for wastewater treatment. A method for calculating the velocity gradient and the geometric parameters of the block of divergent plates is proposed and tested by a computer modeling in this article, and besides the distance between the plates varies from 12.5 mm to 141 mm. The particles are assumed to be spherical in shape; its modeling is carried out by using the Lagrangian multiphase model. By the results of modeling it has been discovered, that with the set parameters of the plates block, the time for particles to reach the highest point of the sedimentation trajectory is 140 seconds. Moreover, the plate length, required for particles sedimentation, turns out to be 590 mm. Whereas the sedimentation time and the plate length, calculated by the suggested method, are almost the same with the results acquired by modeling. In connection with that the suggested formulas appliance becomes possible for calculation of the sedimentation time and the plate length.

1. Introduction
The most complete wastewater treatment from both hydrophobic and hydrophilic particles is achieved by the flotation-sedimentation process. The most important condition of highly efficient treatment, and for the other such methods too, is optimization and matching of the main technological parameters [1-19], and in this particular case the velocities of the treated water flow at on the flotation and sedimentation stages [1]. For that purpose we have developed the thin-layer clarification blocks in the form of a set of divergent plates (or blocks of divergent plates) [2]. Apart from that in dependence of its application the divergent plates block may be applied for other purposes:
- hydrodynamic modes matching in the flotation and sedimentation tanks;
- contaminating particles sedimentation on the lower plate of an element of the divergent plates block (by “an element of the divergent plates block ” it is meant the two plates next to each other) [3];
- safety provision for the flakes of contaminating particles.

At the same time, destruction of the flakes of contaminating particles is characterized by the velocity gradient [3], an important parameter for the particles sedimentation is the plate length. And for hydrodynamic modes matching in the flotation and sedimentation tanks the geometrical parameters of
the divergent plates block are essential (the angle between the plates). Moreover for the device operating volume calculation the residence time of treated water at the divergent plates block is needed [5].

2. Modeling of the hydraulic modes of a divergent plates block
A method to calculate the velocity gradient and the geometric parameters of the block of divergent plates is suggested and tested by computer modeling [6].

The divergent plates block scheme is shown in the figure 1.

**Figure 1.** The divergent plates block scheme: $\beta$ – angle between the plates; $b_1$ and $b_2$ – distance between the plates at the input and output from the plates block accordingly; $v_{av1}$ and $v_{av2}$ – $r_1$ and $r_2$ distances from the diffusor center accordingly; $L$ – block plate length.

In accordance with [4, 5, 6] in thin-layer clarification blocks, which are composed of parallel plates, it is recommended to take the operation depth of the sedimentation zone $h_{ti}$ in the range from 25 to 200 mm, so consequently distance between the plates at the input of the divergent plates block $b_1 = h_{ti} \cdot \cos \alpha$, where $\alpha$ – is a tilt angle to the horizon.

In regard of the water flow velocity at the input and output from the diffusor the following is applicable: at the input to the diffusor [10] the average velocity has to match the velocity in the sedimentation tank (form 5 to 10 mm/sec), and at the output - in the flotation tank (no more than 5 mm/sec).

Symmetrical and all-over divergent flow has to be developed in the plates block element for the safety of contaminating particles flakes [10]. Wherein the developing flow type strongly depends on the angle between the plates. Maximum angles between the plates of the divergent plates block, at which symmetrical and all-over divergent flow are developed, for various velocities of the water flow in the sedimentation tank and distances between the plates are shown in table 1.

In such a manner, if the angles of divergence are smaller than those mentioned in the table 1, only symmetrical and all-over divergent flow will occur in the divergent plates block.

Thus, if the block of divergent plates functions only for the hydrodynamic modes matching, then the distance between the plates of the thin-layer clarification block from the flotation tank side $b_2$, in accordance with the sequence from the continuity equation [11, 12, 13, 14], will be:

$$\frac{v_{av1}}{v_{av2}} = \frac{r_2}{r_1} = \frac{b_2}{b_1}, \text{consequently } b_2 = \frac{v_{av1} \cdot b_1}{v_{av2}}$$

Then the angle between plates $\beta$ has to be chosen, and at the set parameters it should not be greater than the values in the Table 1. After that the plate length $L_{\text{match}}$ is calculated, which is required for the hydrodynamic modes matching, by the formula:
Table 1. Maximum angles between the plates of the block of divergent plates at various distances between the plates and the velocities of water flow at the input of the divergent plates block.

| Velocities of the water flow in the sedimentation tank, mm/sec | Distance between the plates (from the sedimentation tank side), mm |
|---------------------------------------------------------------|---------------------------------------------------------------|
| 140                                                          | 120                                                          | 100 | 80  | 60  | 40  | 20  | 15  | 12.5 |
| 10                                                           | 2º                                                          | 2º  | 3º  | 4º  | 5º  | 8º  | 16º | 22º  | 27º  |
| 9                                                            | 2º                                                          | 3º  | 3º  | 4º  | 6º  | 9º  | 19º | 25º  | 30º  |
| 8                                                            | 3º                                                          | 3º  | 4º  | 5º  | 7º  | 10º | 21º | 28º  | 30º  |
| 7                                                            | 3º                                                          | 4º  | 4º  | 6º  | 8º  | 12º | 24º | 30º  | 30º  |
| 6                                                            | 4º                                                          | 4º  | 5º  | 7º  | 9º  | 14º | 28º | 30º  | 30º  |
| 5                                                            | 4º                                                          | 5º  | 6º  | 8º  | 11º | 17º | 30º | 30º  | 30º  |

To calculate the operating volume of the whole device, it is necessary to know the residence time of water at the block element [10] as well:

\[
L_{\text{match}} = \frac{b_2 - b_1}{2\sin\frac{\beta}{2}} \tag{2}
\]

If the plates block, apart from the hydrodynamic modes matching at the sedimentation and flotation tanks, has to provide the sedimentation of the particles with the specific hydraulic thickness, then the plate length matters, besides the sedimentation time is important too:

\[
\begin{align*}
L_{\text{sed}} &= r_0 \left[ \frac{1}{u \cdot v_{f0}} \left[ \ln \left( \frac{\tan \left( \frac{\pi}{4} + \frac{\alpha + \beta}{2} \right)}{\tan \left( \frac{\pi}{4} + \frac{\alpha}{2} \right)} \right) \right]^2 - 1 \right] \\
&= \sqrt{2r_0 v_{f0} t_{\text{osc}} + r_0^2} \\
\end{align*}
\]

Herewith the plate length \(L_{\text{sed}}\), required for sedimentation is:

\[
L_{\text{sed}} = r_{\text{osc}} - r_0 \tag{5}
\]

Calculation of the main parameters of the divergent plates block is made with the input parameters: \(u = 0.7\ \text{mm/sec, } \beta = 5^\circ, \alpha = 60^\circ, b_1 = 20\ \text{mm, } v_{f0} = 10\ \text{mm/sec}\), by the formulas (4) and (5). As a result the following data has been acquired: \(r_0 = 229\ \text{mm}; t_{\text{osc}} = 146\ \text{sec}; L_{\text{osc}} = 620\ \text{mm}\).

3. The results and consideration

To verify the acquired data computer modeling of the particles motion in the element of the divergent plates block has been performed [11]. The particles were assumed to be spherical in shape, modeling has been carried by using of the Lagrangian multiphase model [17, 18].

By the results of modeling it has been discovered, that with the set parameters of the plates block, the time for particles to reach the highest point of the sedimentation trajectory is 140 seconds. Moreover, the plate length, required for particles sedimentation, turned out to be 590 mm.
Wherein the sedimentation time and the plate length, calculated by the suggested method are almost the same with the results acquired by modeling. In connection with that using of the suggested formulas becomes possible for calculating of the sedimentation time and the plate length.

If the plates block serves for both the hydrodynamic modes matching and for water clarification, then the greatest calculated value is used. I.e. if \( L_{\text{match}} > L_{\text{sed}} \), then \( L = L_{\text{match}} \), \( \tau = \tau_{\text{match}} \); if \( L_{\text{match}} < L_{\text{sed}} \), then \( L = L_{\text{sed}} \), \( \tau = \tau_{\text{sed}} \).

In the present case, \( L_{\text{match}} < L_{\text{sed}} \), then \( L = L_{\text{sed}} = 620 \text{ mm}, \tau = \tau_{\text{sed}} = 146 \text{ sec.} \)

Overall, the suggested method allows to calculate the main parameters of the divergent plates block, which in turn makes it possible to apply this method for calculating of the floatation-sedimentation tanks and define the optimum conditions to increase efficiency of the purification by 20-30%.

Published under licence in Materials Science and Engineering by IOP Publishing Ltd. [c] by [author]. Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

References
[1] Isaev S A, Leont’ev A I, Mil’man O O, Sudakov A G, Usachov A E and Gul’tsova M E 2018 Intensification of Heat Exchange in Laminar Vortex Air Flow in a Narrow Channel with a Row of Inclined Oval Trenches Journal of Engineering Physics and Thermophysics 91(4) pp 963–974
[2] Ksenofontov B S and Petrova E V 2013 Flotation-sedimentation tank: patent 132434 Russian Federation Reg 20 09 2013
[3] Blott S J and Pye K 2001 GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth surface processes and Landforms 26(11) pp 1237–1248.
[4] Ivanov M V and Ksenofontov B S 2014 Intensification of flotation treatment by exposure to vibration Water Science and Technology 69(7) pp 1434–39
[5] Clara M, Kreuzinger N, Strenn B, Gans O and Kroiss H 2005 The solids retention time — a suitable design parameter to evaluate the capacity of wastewater treatment plants to remove micropollutants Water research 39(1) pp 97–106
[6] Womersley J R 1955 Method for the calculation of velocity, rate of flow and viscous drag in arteries when the pressure gradient is known The Journal of physiology 127(3) pp 553–563
[7] SNiP 2.04.03-85 1986 Canalization. External Supply Lines and Constructions
[8] A reference book to SNiP 2.04.03-85 Construction Design for waste water treatment 1990 Moscow Stroyizdat Publ
[9] Arefyev K Y, Prokhorov A N and Saveliev A S 2018 Study of the breakup of liquid droplets in the vortex wake behind pylon at high airspeeds Thermophysics and Aeromechanics 25(1) pp 55–66
[10] Kim M I, Kim O S, Lee D H and Kim S D 2007 Numerical and experimental investigations of gas–liquid dispersion in an ejector Chemical Engineering Science 62(24) pp 7133–39
[11] Moghaddam S S, Moghaddam M A and Arami M 2010 Coagulation/flocculation process for dye removal using sludge from water treatment plant: optimization through response surface methodology Journal of hazardous materials 175(1-3) pp 651–657
[12] Landau L D and Lifshits E M 1986 Theoretical physics: Manual In 10 vol Vol VIIHydrodynamics 3rd edition, revised Moscow Nauka Publ Chief editorial Physics-mathematics literature 736 p
[13] Slezkin N A 1955 Dynamics of viscous incompressible liquid Moscow State Publishing Company of technical-theoretical literature 521 p
[14] Targ S M 1955 The main concerns of the Laminar Flows theory Moscow State Publishing Company of technical-theoretical literature 420 p
[15] McDonald M G and Harbaugh A W 1988 A modular three-dimensional finite-difference ground-water flow model Vol 6 p. A1 Reston, VA: US Geological Survey
[16] Ksenofontov B S and Ivanov M V 2013 A novel multistage kinetic modeling of flotation for wastewater treatment Water Science and Technology 68(4) pp 807–812
[17] Kulik V V, Parkin A N and Navasardyan E S 2016 Numerical Modeling Procedure for Micromachined Cryogenic Cooler Elements Using ANSYS Fluent Software and Viscous Flow in a Small-Diameter Channel with Heat Transfer as an Example Chemical and Petroleum Engineering 52(7-8) pp 531–538
[18] Marocco L and Inzoli F 2009 Multiphase Euler–Lagrange CFD simulation applied to wet flue gas desulphurisation technology International Journal of Multiphase Flow 35(2) pp 185–194
[19] Yeganeh A, Gotoh H and Sakai T 2000 Applicability of Euler-Lagrange coupling multiphase-flow model to bed-load transport under high bottom shear Journal of Hydraulic Research 38(5) pp 389–398