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

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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.

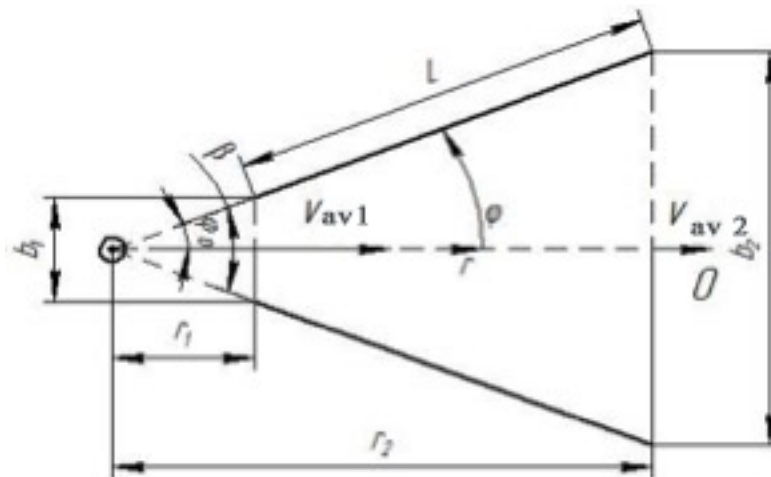


Figure 1. The divergent plates block scheme: β – angle between the plates; b_1 и b_2 – distance between the plates at the input and output from the plates block accordingly; v_{av1} and v_{av2} – r_1 and r_2 distances from the diffuser center accordingly; L – block plate length.

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 α – is a tilt angle to the horizon.

In regard of the water flow velocity at the input and output from the diffuser the following is applicable: at the input to the diffuser [10] the average velocity has to match the velocity in the sedimentation tank (from 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:

$$\frac{v_{av1}}{v_{av2}} = \frac{r_2}{r_1} = \frac{b_2}{b_1}, \text{ consequently } b_2 = \frac{v_{av1} \cdot b_1}{v_{av2}} \quad (1)$$

Then the angle between plates β 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_{match} is calculated, which is required for the hydrodynamic modes matching, by the formula:

$$L_{match} = \frac{b_2 - b_1}{2 \sin \frac{\beta}{2}} \quad (2)$$

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	2°	2°	3°	4°	5°	8°	16°	22°	27°
9	2°	3°	3°	4°	6°	9°	19°	25°	3°
8	3°	3°	4°	5°	7°	10°	21°	28°	30°
7	3°	4°	4°	6°	8°	12°	24°	30°	30°
6	4°	4°	5°	7°	9°	14°	28°	30°	30°
5	4°	5°	6°	8°	11°	17°	30°	30°	30°

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:

$$t_{match} = \frac{r^2 - r_1^2}{2r_1 \cdot v_{av1}} = \frac{L(b_1 + b_2)}{2b_1 \cdot v_{av1}} \quad (3)$$

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:

$$\left\{ \begin{aligned} t_{sed} &= \frac{r_0}{2v_{f0}} \left[\left(1 - \frac{v_{f0}}{u} \left[\frac{\ln \left(\frac{\left(\frac{\pi}{4} + \frac{\alpha}{2} \right)}{\left(\frac{\pi}{4} + \frac{\alpha + \beta}{2} \right)} \right)}{tg \left(\frac{\pi}{4} + \frac{\alpha + \beta}{2} \right)} \right) \right]^2 - 1 \right]; \\ r_{oc} &= \sqrt{2r_0v_{f0}t_{oc} + r_0^2} \end{aligned} \right. \quad (4)$$

Herewith the plate length L_{sed} , required for sedimentation is:

$$L_{sed} = r_{sed} - r_0 \quad (5)$$

Calculation of the main parameters of the divergent plates block is made with the input parameters: $u = 0,7$ mm/sec, $\beta = 5^\circ$, $\alpha = 60^\circ$, $b_1 = 20$ mm, $v_{f0} = 10$ mm/sec, by the formulas (4) and (5). As a result the following data has been acquired: $r_0 = 229$ mm; $t_{oc} = 146$ sec; $L_{oc} = 620$ 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 $L = L_{\text{sed}} = 620$ mm, $\tau = \tau_{\text{sed}} = 146$ 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%.

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