IOP Conference Series: Earth and Environmental Science

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To cite this article: A Akramov *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1112** 012139

Optimum placement of thin-layer elements in a horizontal sedimentation tank purification of drinking water

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Abstract. Experimental studies of the effectiveness of water distribution methods in a thin-layer sump were carried out on model and semi-industrial installations. When designing sedimentation tanks, it is usually recommended to take $\eta = 0.03\text{-}0.07$. According to our data, when $\eta > 0.05$, it is not possible to ensure uniform operation of all slots (holes), which worsens the hydrodynamic conditions in the settling zone. Experiments have also established that double gratings with a relative area of holes of 2n provide almost the same flow distribution as single gratings. In this case, the experimental values of β_1 were 2.6 and 2.7, respectively, i.e. differed by no more than 5%. With this in mind when installing double gratings with reflectors, the relative area holes with a sufficiently efficient flow distribution can be accepted and $\eta = 0.06\text{-}0.1$ instead of $\eta = 0.03\text{-}0.05$ recommended for single grates, which is essential to reduce the risk of clogging them and improve the reliability of sewer sedimentation tanks. The obtained dependences with sufficient accuracy for practice can be used to calculate double gratings and gratings with reflectors at values $\eta=2\eta_1$, where η_1 is the relative area of the slots in a single grating, as well as when calculating partitions with round (square) holes, taking into obtained formulas $b_s = r_{\text{holes}}$, and $n_s = n_{\text{holes.}}$

1. Introduction

In natural water treatment technology, much attention is paid to settling tanks, since the operation of a drinking water treatment plant depends on their efficiency and productivity. In modern conditions, when investments in new construction have practically ceased, the only way to increase the productivity and efficiency of drinking water treatment facilities is their reconstruction and, first of all, the reconstruction of sedimentation tanks, which, with minimal capital investment, can be carried out as soon as possible. In essence, one of the real and promising areas remains the application of the principles of thin-layer settling

In Uzbekistan and abroad, thin-layer sedimentation tanks are used in an ever-increasing volume. Their separating power, especially when separating finely dispersed impurities, is many times higher than the separating power of conventional settling tanks.

For the first time in Russian practice, the calculation of a thin-layer sedimentation tank, based on the elementary theory of sedimentation, was given by V.A. Radtsig [16].

Foreign researchers Camp, Yao, Tanaka, Brunsmann recommended to calculate settling tanks according to the specific surface load, numerically equal to the hydraulic size of the particles retained in the settling tank [95]. A similar procedure for calculating the process of thin-layer settling is given intechnical reference book on wastewater treatment by the French company Degremont [20, 21].

Works [128, 129, 92, 15, 47] are also devoted to the issues of the theory of thin-layer sedimentation tanks and the processes of deposition of pollutant particles in them.

An analysis of literary sources allows us to conclude that one of the main methods for calculating thin-layer sedimentation tanks, which have become widespread abroad, is the method of calculating the specific hydraulic load. In this case, it is usually assumed that the hydraulic size of particles found from the kinetics of suspension settling under static conditions is identical to the rate of their settling (emergence) in thin-layer settling blocks.

In domestic practice, when calculating thin-layer settling blocks, various calculated dependencies are used.

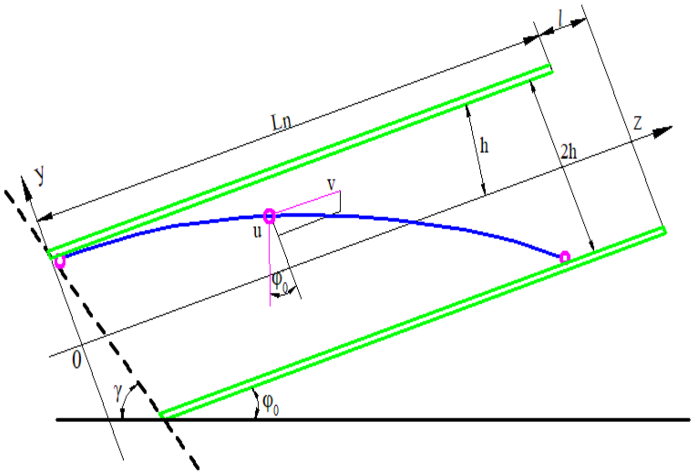

Figure 1. Scheme of sedimentation of a particle in a thin-layer element with an upward movement of liquid.

The most rigorous, theoretically developed and confirmed by numerous experimental data, according to the author, is the theory of thin-layer settling, developed by V.G. Ivanov [104, 37]. Let's consider this theory in more detail.

The magnitude and direction of the velocity of a suspended particle in the sump are determined by the result of the vector addition of two components: the local flow velocity v and the velocity of sedimentation (emergence) of a particle in a stationary liquid u. The ratio of these parameters determines the trajectory of the particle in the process of deposition and, as a result, the cleaning effect.

The flow velocity v and the hydraulic fineness u varying in time and space are generally not constant values. The general scheme of settling of a particle in a thin-layer element is shown in fig. 1.

2. Research methods

Let us analyze the influence of the location of blocks of thin-layer elements on their calculated length of the sump. We will assume that in thin-layer elements a horizontal flow of liquid is provided, the blocks are located at a certain distance x from the distribution devices, made in the form of a slotted (perforated) distribution partition. In this case, the flow of liquid into the settling zone of the settling tank occurs in the form of an outflow of submerged jets into a limited volume. A theoretical solution for such a problem has not yet been obtained [19, 21].

As a result of experimental studies of the flow distribution in settling tanks equipped with slotted partitions, we found [6] that, with an error not exceeding 10%, the velocity in the central part of the jets can be approximated by the equation

$$\frac{v}{v_s} = 0{,}05 + 0{,}95e^{-0{,}21\frac{x}{bs}} \tag{1}$$

where x is the distance from the distribution partition to the section in which the speed is equal to ν;

b_s - slot width (opening radius) in the baffle.

Speed ν_s in openings of the distribution partition is calculated by the formula

$$v_s = \frac{F}{F_s}v_o = \frac{BHv_o}{n_s b_s h_s} = \frac{v_o}{\eta} \tag{2}$$

F_s - the total area of the slots in the partition;
F- clear area of the settling zone;
n_s - the number of slots in the partition;
B - sump width
H - settling zone depth;
h_s - gap-height;

The studies were carried out with η = 0.04 in the range of design speeds v_o from 0.08 to 0.3 sm/ss approximately 0.05 sm /s. values $\frac{v}{v_s}$ by (2.65) for $0 \le \frac{x}{b_s} \le 100$ enough good match With computed on formula I. A. Shepeleva With corrective coefficient B. K. Akhrameeva [2]. Thus, the dependence (1) obtained by us can be considered a satisfactory approximation in the indicated range of known formulas for submerged water jets.

Replacing ν_s through $\frac{v_0}{\eta}$ and introducing the notation $\beta_1 = \frac{v}{v_o}$ based on control (1), we obtain

$$\beta_1 = \frac{1}{\eta}\left[0{,}05 + 0{,}95e^{-0{,}021\frac{x}{b_s}}\right]. \tag{3}$$

When designing sedimentation tanks, it is usually recommended to take η = 0.03-0.07. According to our data, when η > 0.05, it is not possible to ensure uniform operation of all slots (holes), which worsens the hydrodynamic conditions in the settling zone.

When arranging slotted holes with a height $h_u = H$, where H is the depth of the settling zone, we have

$$b_s = \eta\frac{BH}{n_s h_s} = \eta\frac{B}{n_s}, \tag{4}$$

Where $\frac{B}{n_s}$ part of the settling zone width served by one slot.

Experiments [2] confirm the satisfactory coincidence of the maximum velocities of plane-parallel and axisymmetric jets flowing through slotted and round holes at $b_s = r_{holes}$ where r_{holes} is the radius of the round hole. Therefore, when arranging round and square holes, calculations can be performed according to dependencies (1) and (3), substituting the radius of the hole r_{holes} or half the width of the square hole instead of bs.

Let's find the distance to the input sections of thin-layer elements $x = L_1$, at which some given value of the coefficient β_1.

From equation (3) we get

$$e^{0{,}021\frac{x}{b_S}=\frac{0{,}95}{\beta_1 n - 0{,}05}} \tag{5}$$

Whence, after taking the logarithm and substituting the value b_s, we find

$$L_1 = 47.6\eta\frac{B}{n_s}ln\left(\frac{0.95}{\beta_1\eta - 0.05}\right) \tag{6}$$

Formula (6) is valid for $\beta_1 n > 0{,}05$

As follows from the dependence graph $\frac{L}{B}n_s = f(\beta_1, n)$ (Fig. 1), the non-uniformity of the flow distribution at the inlet to thin-layer elements β_1 at the beginning intensively decreases with an increase in the relative length $\frac{L}{B}n_s$, and then, as $\frac{L}{B}n_s$, changes very slowly, asymptotically approaching $\beta_1 = 1$ as

$\frac{L}{B}n_s \rightarrow \infty$ Thus, the greater the distance L_1 , the less uneven distribution of the flow at the inlet to thin-layer elements β_1 .

3. Results and discussion

A further change in the uneven distribution of the flow β within thin-layer elements, as we have established earlier [16], occurs according to the dependence

$$\beta = \frac{v_{\text{cp}}}{v_0} = \beta_2 + 0{,}061(\beta_1 - \beta_2)\frac{e^{-X}}{X} = \beta_2 + \frac{0{,}061(\beta_1-\beta_2)}{Xe^{x}} \tag{7}$$

Where v_c is the depth-averaged velocity in the calculated section of a thin-layer element;

β_1 - uneven distribution of flow at the inlet to thin-layer elements$\beta_1 = \frac{v_{middle\ entrance}}{v_0}$

β_2 - the same, at the exit of thin-layer elements$\beta_2 = \frac{v_{middle\ entrance}}{v_0}$

$$X = 0{,}8\left(\frac{x}{hRe}\right) + 0{,}06$$

According to experimental data

$$\beta_1 = \beta_2^{\frac{0{,}25}{\beta_1}+0{,}1034}$$

The required length of blocks of thin-layer elements L_p is found on the basis of dependence (7) by integrating the differential equation of motion of a particle in a thin-layer element. As a result of additional processing of the data obtained by us, for the block length L_p. a general analytical dependence is derived, which has the form

$$L_{п} = (1 + 0{,}11\beta_1 A^{0{,}22\beta_1^{0{,}63}})L_o \tag{8}$$

Where $A = \frac{2hRe}{L_{п}} = 2(\frac{L_{п}}{hRe})^{-1}$is a dimensionless complex;

L_O - estimated length of a block of thin-layer elements with a uniform flow distribution in their inlet section

$$\beta_1 = \beta_2 = 1 \text{ и } \psi = 1$$

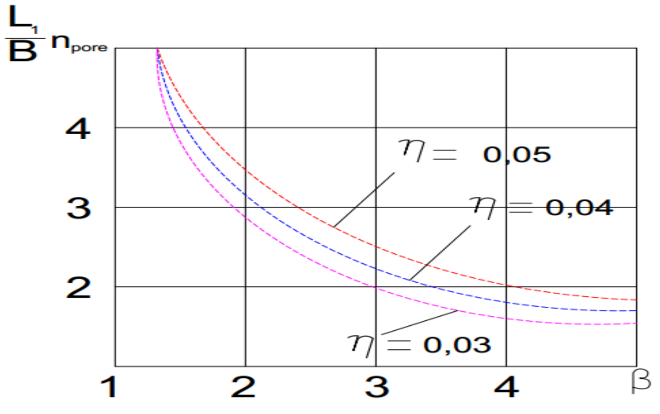

Figure-2. Dependence graphics$\frac{L}{B}n_s = f(\beta_1, n)$

The minimum estimated length of the sump L_{min} , other things being equal, will correspond to the minimum of the function

$$L = L_1 + L_n = f(\beta_1)$$

The study of this function to an extremum shows that when

$$\frac{\partial L}{\partial \beta_1} = \frac{\partial L_1}{\partial \beta_1} + \frac{\partial L_n}{\partial \beta_1} = 0$$

there is a minimum of the function.

After performing the operation of differentiation of the functions L_1 y and L_p , defined by equations (6) and (8), and transformations, we obtain

$$0{,}11A^{0{,}22\beta_1{}^{0{,}63}}\left(1+0{,}1386\beta_1{}^{0{,}63}1nA\right)L_0-\frac{47{,}6\eta^2 B}{n_s(\beta_1\eta-0{,}05)}=0. \qquad (9)$$

The roots of equation (9) give the optimal values $\beta_1=\beta_{1opt}$ corresponding to the optimal length of the settling zone of a thin-layer settling tank. The solution of equation (9) presents certain difficulties and was obtained on a computer.

The solution results can be approximated by the equation

$$\beta_{1opt}=f\left(\frac{B}{L_0 n_s},\eta,A\right).$$

A particular solution of equation (9) for A = 1 gives

$$\beta_{1opt}=433n\left(\frac{B}{n_s L_0}\right)+\frac{0{,}05}{\eta}.$$

Usually η =0.03-0.05; $\frac{B}{n_s L_0}+1{,}1$.

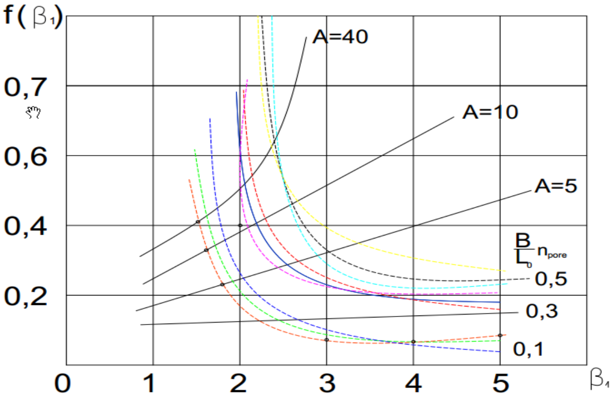

Figure 3. Nomogram for determining the optimal value of β_{1opt} on $A=\frac{2hRe}{L_п}$ and $\frac{B}{L_0 n_s}$

The results of solving the equation, characterizing the range of change of the optimal values of β_{1opt} at practically existing ratios of the main elements of horizontal thin-layer sedimentation tanks, are shown in Fig. 2 in the form of a nomogram. On the vertical axis on Figure 2 shows the values f(β_1) = $\frac{\partial L_1}{L_0\partial\beta}$ and f(β_1) = $\frac{\partial L_1}{L_0\partial\beta}$= The points of intersection of the curves correspond to the values $\beta_1=\beta_{1opt}$.

At optimal values $\beta_1=\beta_{1opt}$ according to dependences (6) and (8) the values of L_1 and L_p are determined, providing the minimum length of a thin-layer horizontal settler.

4. Conclusion

The derivation of the formula for determining L_1 is based on the dependencies obtained in the absence of thin-layer blocks of elements in the settling zone, so it needs experimental verification. From this purpose on a large-scale model of a thin-layer horizontal sump, the maximum flow rates were measured and determined experimental values of the coefficient β_1, at $\frac{L_1}{B}n_s$= 4.5-5.8 and η = 0.03-0.07 for single gratings with slot width **b** equal to 5.10 and 20 mm and double gratings. The B values ranged from 2.7 to 2.9 for single gratings and 2.6 for a double lattice, which is close to the values of β_1 found from the dependence (6) obtained for the settling zone not occupied by thin-layer elements.

Experiments have also established that double gratings with a relative area of holes of 2n provide almost the same flow distribution as single gratings. In this case, the experimental values of β_1 were 2.6 and 2.7, respectively, i.e. differed by no more than 5%. With this in mind when installing double gratings with reflectors, the relative area holes with a sufficiently efficient flow distribution can be accepted and η = 0.06-0.1 instead of η = 0.03-0.05 recommended for single grates, which is essential to reduce the risk of clogging them and improve the reliability of sewer sedimentation tanks. The obtained dependences with sufficient accuracy for practice can be used to calculate double gratings and gratings with reflectors at values $\eta=2\eta_1$, where η_1 is the relative area of the slots in a single grating, as well as when calculating partitions with round (square) holes, taking into obtained formulas $b_s = r_{\text{holes}}$, and $n_s = n_{\text{holes}}$.

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