SOME CONSTRUCTIVE METHODS FOR IMPROVING THE OPERATION OF HORIZONTAL SETTLING TANKS

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Abstract: *The main constructive methods for improving the process of settling suspended solids and separating sediment in horizontal settling tanks are considered. Methods for calculating these structures are analyzed both in general terms and for individual characteristic (supply, settling and drain) areas of wastewater flow. Those constructive proposals that can more significantly improve the efficiency of horizontal settling tanks are noted. The proposed modification relates to the part built into the thin-layer sedimentation tank - the flocculator, which ensures the most uniform and laminar flow in the structure.*

Keywords: *horizontal settling tank, structural modifications, suspension particle, flocculator, laminarizing devices*

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Introduction

The advantages of horizontal settling tanks compared to other types are low depth, possibilities of operational improvement through structural modifications, the cleaning effect, both in normal conditions and by using thin-layer elements; the possibility of using one rating device for several sections and a successful combination of the integrated parts of the sand trap or flocculator, etc.

Based on the accepted schemes and considering the maximum laminarizing conditions of the wastewater flow, the preferred design of horizontal settling tanks is selected and an incorporated modified flocculator with thin-layer elements is proposed.

Materials and Methods

The proposed constructive modification of the horizontal settling tank is based on comparative and generalizing methods that, in principle, can improve the operation of the equipment. The most promising methods for calculating these structures are also given.

Main Part

Among the methods used for the technological calculation of settling tanks, the most promising are those that allow more fully to consider the actual conditions of sludge deposition and the relationship between the design parameters. Among these parameters, the most important is the retention time necessary for obtaining the desired clarification effect and the deposition rate of those particles that must be detained in the settling tank. The equation expresses the relation:

$$T = H/(U_0 - \omega), \tag{1}$$

where:

T - the retention time,

H - the accepted working depth of the running part of the settling tank,

U_0 - minimum deposition rate of detained particles in wastewater at rest,

ω - the additional resistance of the suspended particles when water flows through the settling tank [1].

In general, the length of a horizontal settling tank can be found by the formula:

$$L = \left(V \cdot H / \omega_{oc}\right), \quad (2)$$

where:

L - the length of the settling tank, m,

V - fluid flow in the settling tank, m/s,

H - settling tank depth, m,

ω_{oc} - particle deposition rate in the tank, m/s.

In turn, the particle deposition rate can be found by the formula:

$$\omega_{oc} = 1/18\left(d_m \cdot \rho_k \cdot g\right)\mu_{ж} , \quad (3)$$

where:

d_m - the minimum equivalent diameter of the suspended particles, m,

ρ_k - apparent particle density, kg/m^3,

g - free fall acceleration, 9.81 m/s^2,

$\mu_{ж}$ - dynamic viscosity of the liquid, pa·s.

In horizontal settling tanks, it is recommended [2] to determine the vertical component of the flow rate from the equation:

$$\omega = KV_{cp}^{n} , \quad (4)$$

Or from the correlation graphs K and V_{cp}.

The coefficient K has a constant value: $n = 2$ at $V_{cp} < 15$ mm/s and $n = 3$ at $V_{cp} > 15$ mm/s.

The absolute value ω in the range of flow rate equal to 5…10, 10…15, and 15…20 mm/s is 0.05, 0.1 and 0.5 mm/s respectively.

Since the height of the main water layer of the fluid flow in the settling tank is always less than the calculated depth of the structure, the actual flow rate $V_{ф}$ in the settling tank always exceeds those average $V_{ф}$ and their values:

$$V_{cp} = q/\left(B \cdot H\right), \quad (5)$$

which are included in the calculation equations when determining the flow section $A = B \cdot H$ and the length L of the settling tank.

The difference between the values $V_{ф}$ and V_{cp} is especially huge in the beginning and the end of the settling tank. It is just these areas that are zones of chaotic whirlpools and therefore require constructive improvements.

Considering the above characteristics, it can be said that a more detailed calculation of horizontal settling tanks is reduced to determining the dimensions of its flow (operational) and sedimentary parts according to the corresponding calculation schemes (Fig. 1).

It should be noted that, according to [2], the results of calculations of settling tanks carried out according to the scheme of Fig. 1a) differ significantly from the performance indicators of their operation.

For the hydrodynamic conditions of horizontal settling tank operation improvement, it is necessary to create designs for the wastewater inlet and outlet that will ensure their uniform distribution over the width and depth of the settling tank.

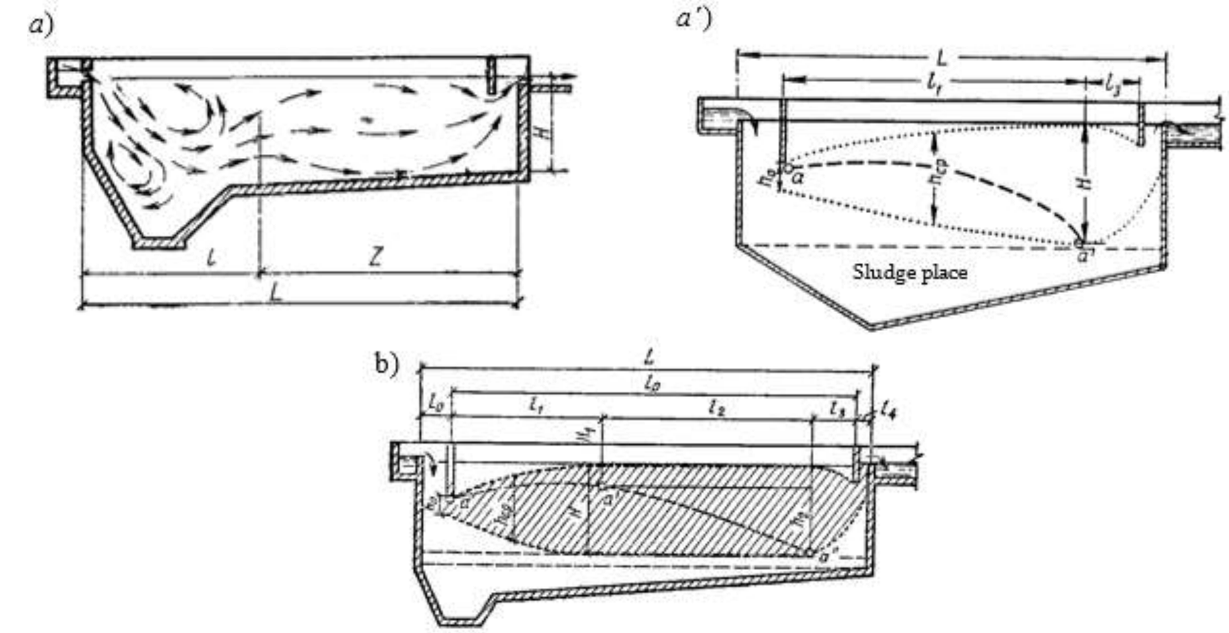


Fig. 1. *Calculation schemes of horizontal settling tanks*
a) - taking into account two [3], b) - taking into account three characteristic sections [4]

Here, the flow distribution is more uniform than in Fig. 1b, since the incoming wastewater is directed to the end wall of the settling tank. At the beginning of the settling tank, the sludge is agitated, and the re-sedimentation of such sludge is much faster and more complete than in the initial settling. As a result, the horizontal settling tanks' characteristic areas must be calculated in accordance with the schemes presented in Figs. 1b and 2.

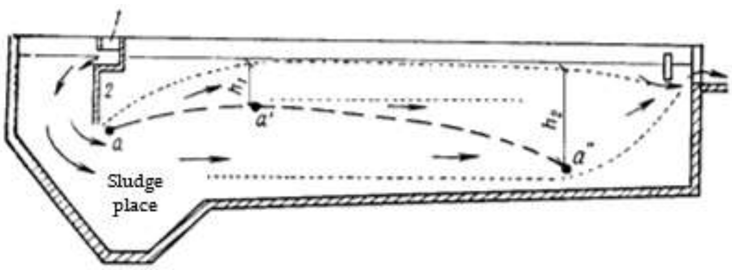


Fig. 2. *Scheme of waste water distribution through spillways*
1 - water supply tray, 2 - training wall

In the inlet section, the flow rate in the settling tank will be

$$V_1 = V_{cp} \cdot H / h_{cp} \ . \quad (6)$$

A particle settling at such a rate will experience a braking force, which will reduce its downfall.

The length of the inlet section will be equal to

$$l_1 = t_1 \cdot V_1 , \quad (7)$$

where t_1 is the time during which the suspended particle from the initial point α moves to the point a', passing along the vertical path:

$$h_1 = t_1 \cdot (U_0 - \omega). \quad (8)$$

It will take time for this particle to sink into the sludge place of the settling tank (at the point a'')

$$t_2 = \frac{H - h_1}{U_0 - \omega'} , \quad (9)$$

where ω' is the additional resistance for a particle settling in a flow that moves at a rate V_{cp} .

For given t_2, we have

$$l_2 = t_2 \cdot V_{cp} . \quad (10)$$

At the end of the settling tank, the flow rate increases (Fig. 1b), and the settling conditions deteriorate sharply. The section length with an increased rate depends on the settling tank depth and the structure of the discharge device. For the conventional spillways, it is:

$$l_3 = H/tg\alpha , \quad (11)$$

where α is the flow convergence angle at the outlet of the settling tank, equal to 25…30 º.

Thus, the estimated length $(L_{p.})$ of the settling tank is determined as the sum of its main sections:

$$L_{p.} = l_1 + l_2 + l_3 . \quad (12)$$

The first semi-submerged partition is a training wall; it is installed at a distance of l_0 = 0.5 ... 1.0 m from the spillway of the water supply stream; the second serves to keep substances floating in the settling tank and is installed at a distance of l_4 = 0.2 ... 0.3 (0.5) m from the spillway at the end of the settling tank. Thus, the construction length of the horizontal settling tank exceeds the calculated one by about 1.0…1.5m [5,6].

Distribution grids positioned across the settling tank are sometimes used instead of semi-submerged partitions.

Fig. 1a′ refers to cases in which the uniform translational water flow across the entire flow section of the settling tank is achieved only at the outlet, the value is $l_2 = 0$ (in relatively short settling tanks).

Instead of H, its average depth (h_{cp} = 1.5 ... 2.0 m) is taken as the initial estimated depth, since not only the required settling time, but also the usable volume of the structure depends on the settling tank depth, that is the depth which should be taken as the initial value in its calculation. Schemes of uniform wastewater distribution in the settling tank with various training devices are also used (Fig. 3).

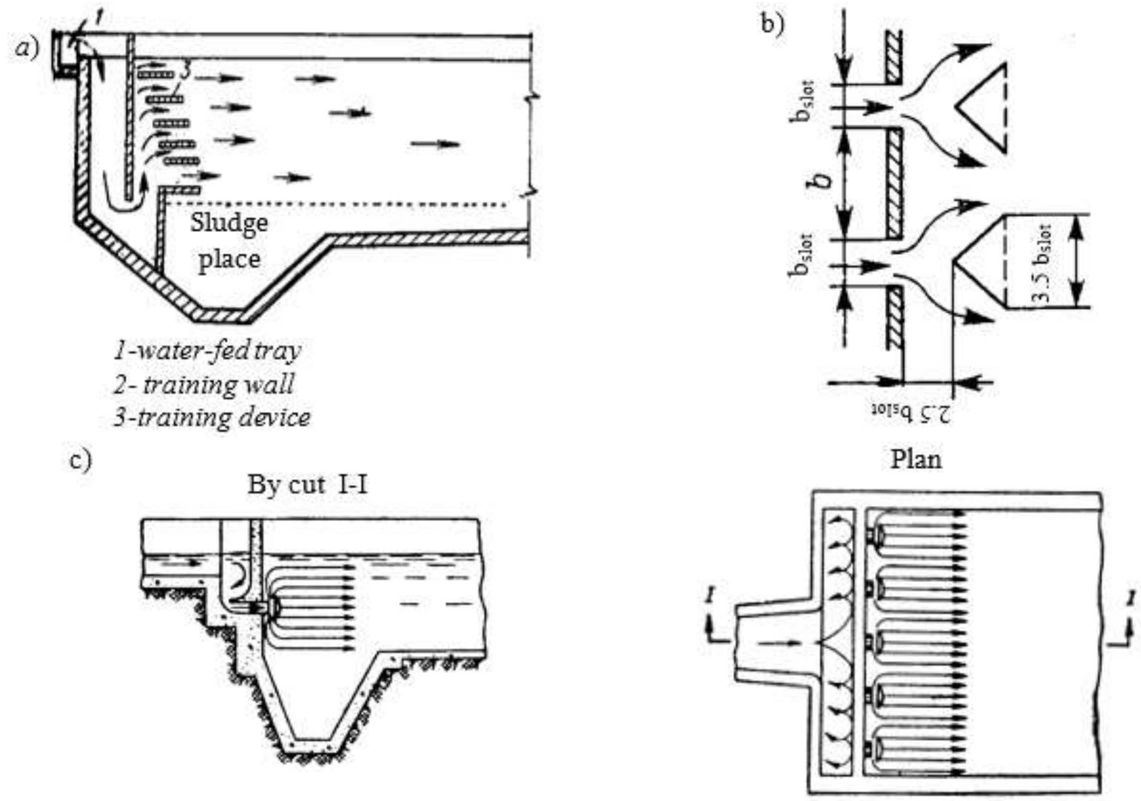


Fig. 3. *Schemes of dispatch devices*

a) - proportional shelf device [2], b) - slotted partition with reflectors [7], c) - disk device [6]

For more complete use of the flowing part volume, several drainage trays are arranged at the end of the settling tank instead of a spillway. Best results are achieved by placing the trays in the last third of the tank length. The working effect of such settling tanks increases by about 5% [2].

Horizontal settling tanks with a vertical flow of settled wastewater are also used in practice (Fig. 4).

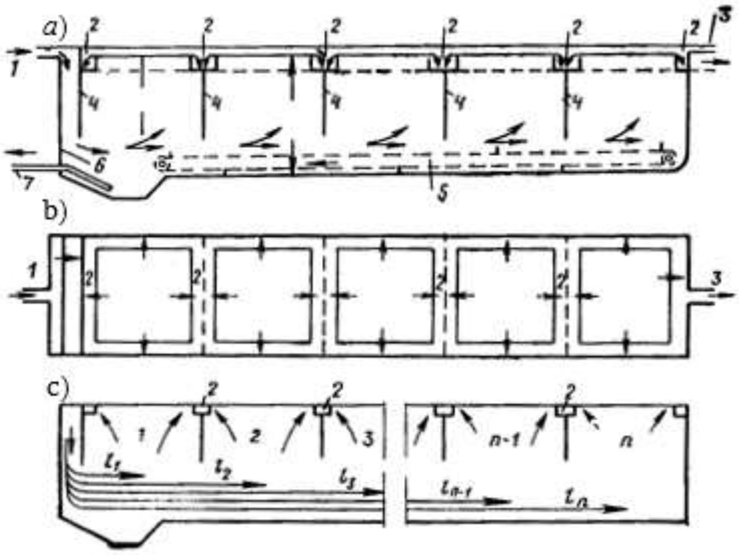


Fig. 4. *Scheme of a horizontal settling tank with vertical partitions*

a) and b) - section and plan, c) - design diagram, 1-water supply channel, 2- drained trays, 3-drainage channel, 4-walls, 5-scrapers for raking sediment, 6-training shield, 7-sludge pipe

This construction type is a constructive modification of settling tanks with dispersed removal of clarified water. However, the productivity of a settling tank with semi-submerged partitions is 30–50% higher than conventional settling tanks. However, their assessment is challenging because of the complex movement of treated wastewater [2].

Constructively, the settling process can also be improved in the settling zone if this zone is divided into thin plates or pipes. Here, settling takes place in the space between the plates, with the height of 20…150mm. Wastewater moves along the plane of the plates inclined by 50…60^0 while solid particles are detained on the plates and roll up into the sludge collectors.

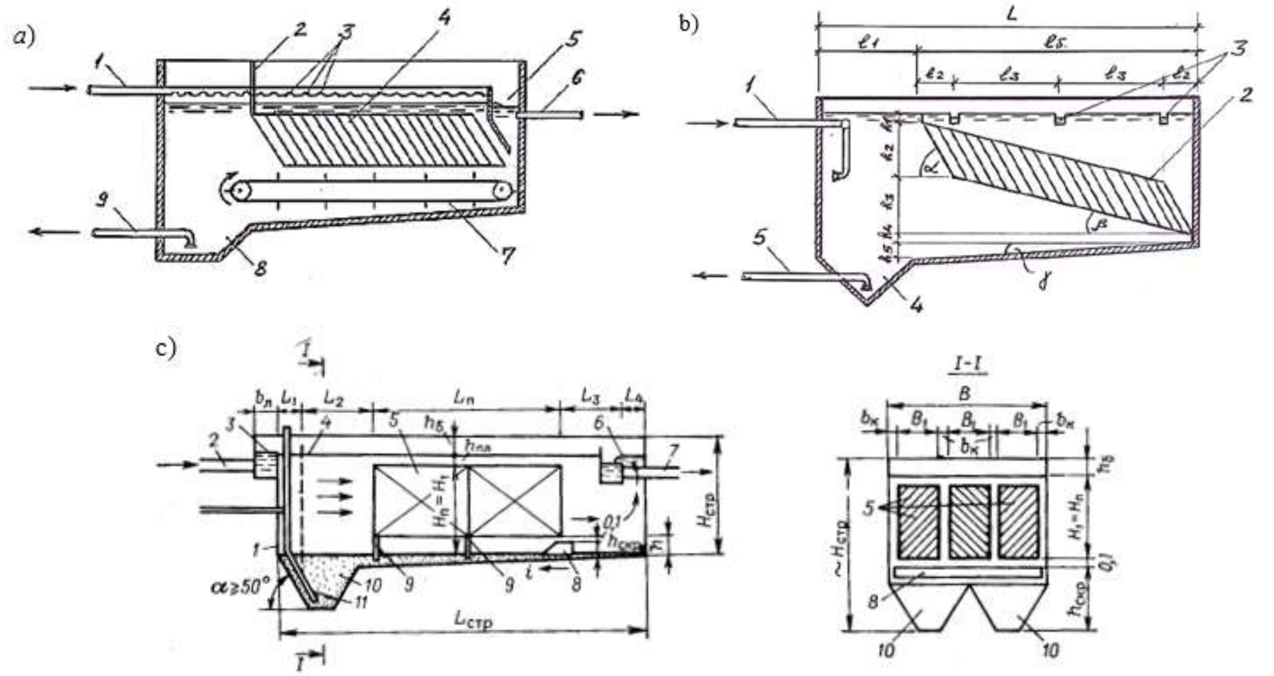
Reducing the settling height decreases the turbulence, characterized by the vertical component of the wastewater flow pulsation, resulting in an increase in volume utilization factor and a decrease in the settling time (up to several minutes). The reconstruction of various types of operating settling tanks uses the thin-layer settling principle. The performance of reconstructed settling tanks can be increased by 2 to 4 times using this technique, which is thought to be the most cost-effective and occasionally the only one that can be used.

Besides the sedimentation process intensification and a significant increase in clarification effect, the benefits of thin-layer sedimentation tanks include operation stability to changes in the fluid temperature, contaminant concentration, and even significant fluctuations in the treated wastewater flow rate[1] [8].

There are three schemes for water flow in a thin layer: direct-flow, countercurrent, and cross-flow. With a cross-flow design, the precipitated sediment moves perpendicular to the movement of wastewater and with direct-flow and countercurrent flow, respectively, toward the wastewater or in the opposite direction.

The characteristic schemes of horizontal thin-layer settling tanks with some design modifications are presented in Fig. 5.

[1] Raschet i proyektirovaniye tonkosloynykh otstoynikov dlya ochistki prirodnykh vod (in Russian). https://vunivere.ru/work52494/page14



a) *1. feed perforated pipeline, 2. support for fastening thin-layer elements, 3. hole, 4. block of thin-layer elements, 5. tray of clarified waste water, 6. outlet pipeline with clarified waste water, 7. scraper mechanism, 8. sink, 9. pipeline for sediment removal*

b) *1. feed pipeline, 2. block of thin-layer elements, 3. trays for removal of clarified waste water, 4. sink, 5. pipeline for sediment removal*

c) *1. frame, 2. supply pipeline, 3. inlet tray with a spillway, 4. distribution device, 5. block of thin-layer elements, 6. collection tray with a spillway, 7. clarified wastewater pipeline, 8. scraper, 9. flexible partitions, 10. sink for sediment, 11. pipeline for sediment removal*

Fig. 5. *Schemes of horizontal thin-layer settling tank operation*
a) - direct-flow [9], b) counter-current [10], c) cross-flow [7]

Horizontal thin-layer settling tanks with a flocculation chamber can also operate according to the above schemes when various reagents are used. Fig. 6 shows such built-in flocculators operating according to countercurrent and cross-flow schemes since it was according to these schemes that the authors of the article got high values for wastewater treatment of the textile, knitwear, and silk industries in early studies [11].

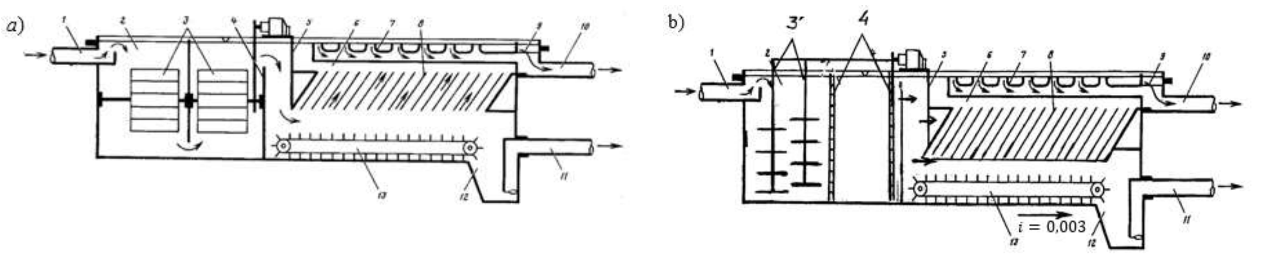


Fig. 6. *Schemes of built-in flocculators*
a) countercurrent [2], b) cross
1. waste water supply, 2. chamber of flocculator, 3. mixers on the horizontal and vertical axes, respectively, 4. drowned spillway, 5. deflector, 6. horizontal settling tank, 7. drain trays, 8. thin-layer plates, 9. side collecting channel, 10. drainage of treated sewage), 11. hydraulic sludge removal system, 12. mud pit, 13. sludge scraper *for precipitate removal*

[2] B.N. Frog, A.P. Levchenko, Vodopodgotovka. Moscow State University, Moscow, 1996

The proposed modified flocculator operates according to a cross scheme (Fig. 6b), in which, instead of a flooded spillway and a training semi-submerged partition, there are paired distribution (perforated) walls, which provide maximum laminarization of the wastewater flow. According to preliminary calculations, the distance between distribution partitions (considering the numerical model developed in [12]) can be taken to be (1/12 – 1/10), but not over 3-4m.

In Fig. 7 a thin-layer settling tank is presented with three sludge pits, working according to a cross scheme.

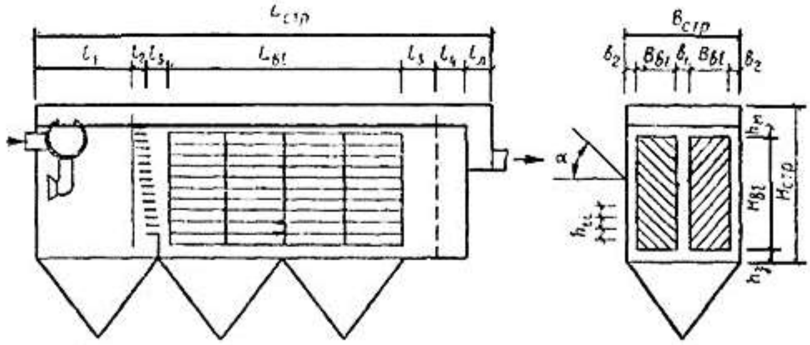


Fig. 7. *The design of a thin-layer settling tank with a cross scheme*

Proposals

On the whole, constructive proposals for the efficient operation of horizontal thin-layer sedimentation tanks are:

1. to ensure an even distribution of the wastewater flow between all thin-layer elements,
2. the uniform mixing of the flow with reagents, which is carried out in the proposed version using vertical mixers arranged in a checkerboard pattern (three in the first row, two in the second) with opposite rotations of the blades,
3. to forecast the distribution zone expansion along the settling tank (about 20 degrees in plan) in order to prevent vortex flow.

Conclusion

After analyzing the structural proposals of horizontal settling tanks using reagents with a built-in flocculation chamber, the structure presented in Fig.6 is the most optimal.

For general (reagent-free) settling, we keep to the structure presented in Fig. 7. In this case, the following advantages are provided:

1. a sufficient zone is formed for sediment stirring-up (Fig. 2),
2. a perforated partition and a horizontal training device at the beginning of the settling tank provide the most uniform wastewater flow,
3. the processes of clarification of the runoff and sedimentation are improved with the help of a perforated partition at the end of the settling tank and several sediment catch sinks.

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