Mathematical modeling of wastewater treatment facilities of transport enterprises

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Abstract. Wastewater is purified by mechanical, biological, physicochemical and chemical methods. Mechanical treatment plants are the main stage of treatment and remove most of the harmful substances contained in wastewater. The mechanical treatment facilities include a sand trap, a sump, a hydrocyclone, a grid, etc. Among them, the most common and basic design are sumps, which are divided into types according to design and function. In this article, a new mathematical model for calculating vertical sediments used in local treatment for small enterprises has been improved, and design parameters have been calculated. Theoretical studies of the proposed sump were carried out on the basis of molecular kinetic theory, and its accuracy was verified by the author in experimental tests. In the sump, an expression for the distribution of the concentration of suspended solids in wastewater was found. Thus, a filter structure with a filtration efficiency above 60% was created.

1 Introduction

Today, in developed countries, large-scale organizational and technical measures aimed at the rational use of water and reducing the discharge of insufficiently treated wastewater into water bodies are implemented, and in order to prevent the pollution of water bodies, local wastewater treatment facilities of industrial enterprises are being established. In this regard, in Germany, France, the USA, Japan, Russia and other developed countries, scientific research is carried out in order to clean and discharge industrial waste water into water reservoirs and sewage networks through mechanical, physico-chemical, biological and chemical treatment methods, as well as to direct them to reuse [1-6].

In the field of construction in the world, in the development of a project for the construction of an object, industrial enterprise, service and other organizations, the wastewater discharged from them is cleaned and re-used with the help of local treatment facilities, or the improvement of treatment facilities in order to create environmentally friendly water discharge technology and attention is paid to the implementation of scientific researches [5-12].

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Currently, in our Republic, we need to reduce the pollution of surface and underground water bodies with oil products, surfactants and other harmful substances contained in the wastewater discharged by heavy and light industry, transport and service enterprises, find solutions for the effective use of water resources, and their protection. theoretical and practical results are being achieved [3-5, 13-17].

The high efficiency of clarifier facilities, which are widely used in the treatment of industrial and domestic wastewater, depends on the correct calculation of their constructions and technology. The work carried out in this regard is mainly based on gravitational and diffusion theories [5, 13].

2 Objects and methods of research

Despite the fact that many scientific studies have been carried out to improve the constructions of clarifiers, which are mechanical cleaning facilities used in wastewater treatment, and to create new types, there are many shortcomings in the treatment of wastewater from oil-oil products and surfactants. Due to this, the author proposed a new theory. In this case, the author recommended using the molecular-kinetic theory of distribution of suspended substances in the clarifiers, and made changes to the structure of the clarifier in the vertical view (Fig. 1).

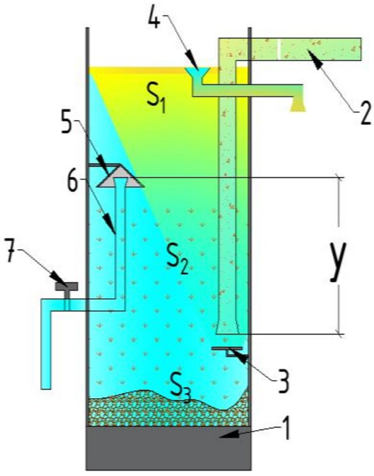

Fig. 1. Concentration distribution of suspended solids in a vertical clarifier: 1- clarifier, 2-canoe discharge pipe to the clarifier; 3-silencer of the movement of liquid coming out of the inlet pipe; 4- oil and oil product storage pipeline; 5- a limiter for the passage of a large proportion of oil and oil products to the filter; 6- a pipe that ensures the discharge of the filtered water to the filter; 7-The valve for adjusting the water discharged from the cooler.

The model of the distribution of the concentration of substances in the wastewater coming to the clarifier - S is described as follows (Fig. 1):

$$S = S_1 + S_2 + S_3 \tag{1}$$

where the concentration of S_1-emulsions ($\rho_з < \rho_{сув}$); S_2-suspended particle concentration ($d_i < d_0$), transferred from the filter to the filter; S_3-suspended particle concentration ($d_i > d_0$) will settle in the clarifier [1-6, 11, 14-17].

The distribution of the concentration of substances in the wastewater in the vertical clarifier was expressed as follows:

$$S_u = S_0\, exp\left\{-\frac{3g(\rho_T-\rho)}{2\rho_T {u_i}^2}\left(\frac{d_i}{d_0}\right)^3 (h-y)\right\} \qquad (2)$$

where: h-flow depth in the quencher; y-particle coordinate is calculated from the flow level; ρ and ρ_t are the density of water and particles, respectively; d_i-particle diameter; S_0 is the initial concentration of particles in the wastewater, in the coordinate y=h.

It is possible to determine the installation height of the wastewater transfer pipe filtered to the filter according to the concentration distribution of the substances (d_i=d_0):

$$y_0 = \frac{1}{A} ln \frac{S_A}{S_0} \qquad (3)$$

where S_A is the concentration of suspended solids in the solvent; S_0- initial concentration of suspended substances; A-turbulent diffusion coefficient.

The expression of the molecular-kinetic theory, based on the equality of the suspended and non-resting substances, i.e., their densities, was given the following expression after mathematical operations and changes:

$$ {u_i}^2 = \frac{{d_0}^3}{{d^3}_i} u^2 \qquad (4)$$

where: d_0-diameter of suspended particles moving with continuous wastewater in the clarifier (particles trapped in the filter), u-speed of solid particles; u-the vertical velocity of the solid particles, which is the same as the velocity of the wastewater.

Denoting the vertical (from bottom to top) movement speed of wastewater in the clarifier with U, the hydraulic size-sedimentation speed of settling suspended solids was equaled to W:

$$U=W \qquad (5)$$

According to the theoretically determined expression (3), it was determined how high it is necessary to install the discharge pipe to the filter from the bottom of the filter.

Table 1. Dependence of the hydraulic particle size of the suspension on its diameter

d_t, m	$V_t, m/s$	Re	C	$W, m/s$	d_0, m
0.00025	0.0049	8.715	2.754	0.00134	0.00048
0.00010				0.00021	
0.00040				0.00343	
0.00120				0.03087	
0.00015				0.00048	
0.00100				0.02144	

3 Results and their discussion

In the course of the research, 80 car wash enterprises in the city of Tashkent, which have been in continuous operation for at least 3 years, were studied. It was found that 35 of the studied car washes mainly use horizontal type dryers, and 45 use vertical type dryers. The measurement of the accuracy of the theoretically found formulas was carried out in the device of the tester created in the "HYDRAULICS" laboratory of the Department of "Engineering Communications and Systems" of the Tashkent State Transport University. Experimental tests were conducted on real industrial wastewater from car washes.

In order to increase the filtering efficiency in the clarifier, research was conducted by changing the height "y" between the inlet and outlet pipes, and the diameters of particles settled in them were determined (Table 1).

Based on theoretical studies and laboratory experiments, the optimal value of the height "y" between the inlet and outlet pipes of waste water in the clarifier was determined (Fig.2).

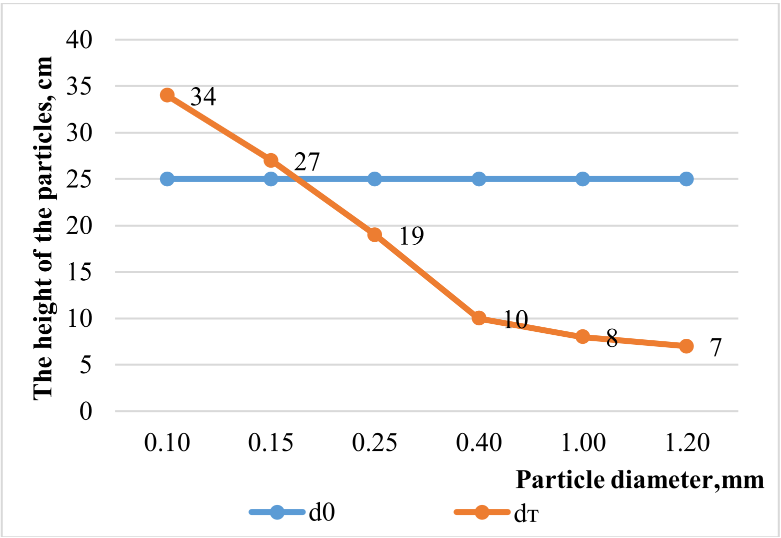

Fig. 2. Distribution of particles of different diameters according to the depth of the filter

The rate of sedimentation of dispersed particles of different fractions in the clarifier was calculated (Fig. 3).

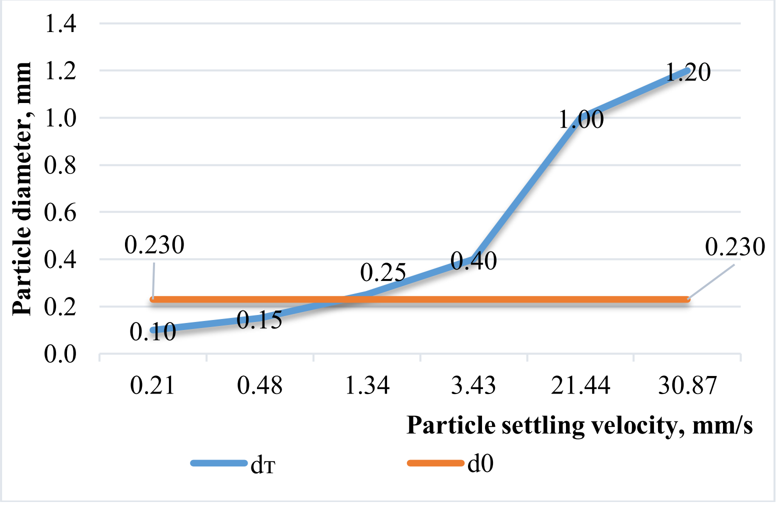

Fig. 3. The rate of sedimentation of particles of different fractions in the clarifier

Based on hydraulic, mathematical and physical formulas, the parameters of the proposed local treatment plant vertical clarifier model were calculated (Table 2). The chemical composition of purified water was analyzed in the created model (Table 3). Based on the calculations performed in the experiments and the analysis of the chemical composition of the treated water, the dimensions of the structural parameters for the nature of the local treatment facility were recommended (Table 4).

Table 2. Local treatment plant model calculation values

H_t, m	$H_{t.work}$, m	D_t, m	W_t, l	$W_{o.s.r.}$, l	$H_{p.r.}$, m	$D_{p.r.}$, m	$W_{p.r.}$, l
0.5	0.45	0.25	22	80	0.5	0.25	24.5

Continuation of table № 2

T, s	Q, l/s	H_p, m	W_p, l	$H_{t.qol.}$, m	$W_{t.qol}$, l	W_t, l	Э, %
2400	0.033	0.03	1.47	0.20	9.8	68.73	60

Table 3. Initial and post-treatment chemical composition of industrial wastewater fed to a vertical clarifier model

Designation	pH_0	$C_{m.m.}$	C_p
Unit of measure		mg/l	mg/l
Initial composition of water	7.5	870	9.5
Composition of water after softener	7	345	3.5

Table 4. Recommended dimensions for the type of local treatment plant

H_t, m	$H_{t.work}$, m	D_t, m	W_t, l	$H_{p.r.}$, m	$D_{p.r.}$, m	$W_{p.r.}$, l
4	3.6	2	11264	3.6	2	11264

Continuation of table № 4

T, s	Q, l/s	H_p, m	W_p, l	$H_{t.qol.}$, m	$W_{t.qol}$, l	W_t, l	Э, %
2400	0.033	0.24	1.47	0.20	9.8	68.73	60

Explanation of the sizes included in the above tables: H_t - height of the cooler; $H_{t.\ work}$ - working height of the cooler; D_t is the diameter of the strainer; W_t is the volume of the solvent; $W_{o.s.r.}$ – waste water reservoir; $H_{p.r.}$ - the height of the tank and the oil-oil collector; $D_{p.r}$ - the diameter of the cylinder and oil-oil collector; $W_{p.r}$ - the volume of the tank and oil-oil collector; T – time of experiment; Q - waste water consumption during the experiment; H_p is the height of waste water collected in the oil-oil collector during the experiment; W_p is the volume of wastewater collected in the oil-oil collector during the experiment; $H_{t.qol}$ - the height of wastewater remaining in the clarifier after the experiment; $W_{t.qol.}$ - volume of waste water remaining in the clarifier after the experiment; W_t is the volume of water taken during the experiment; E is the filtering efficiency of the vertical filter.

The filtering efficiency of the vertical filter in the model is determined as follows [7-9]:

$$C = 100\% \cdot \frac{C_1 - C_2}{C_1} = 100\% \cdot \frac{870 - 345}{870} = 60.34\%$$

Usually, the efficiency of the clarifier in sewage treatment plants is 40-60%. The fact that the efficiency of the vertical strainer in the model is 60.34% shows that the structural parameters of the model are found correctly and the experiment was successfully carried out.

4 Conclusions

In order to prevent problems arising during the construction, operation, and reconstruction of wastewater treatment facilities of settlements and industrial enterprises, in order to improve their cleaning efficiency, first of all, by creating their models, performing experiments and calculations on them, making forecasts for their nature, economic success with deeper water purification can be achieved. Based on mathematical modeling, a mock-up was created through physical modeling of the structural parameters of the quencher, and the results of experiments carried out in laboratory conditions represented the correctness of the research.

Through the vertical filter model created in the article and calculations, it is possible to develop an economical and efficient filter model for industry and small settlements. In addition, it will be possible to create a catalog of sprinklers designed for different water consumption through one model, and to ensure that construction works proceed in a fast pace.

By changing the linear scale of modeling K_1=8, it was possible to create silencers with different structural parameters, and by changing the time modeling scale K_2=1, silencers whose work activity was accelerated or, on the contrary, slowed down to the required level.

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