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Analysis of Wastewater Treatment Facilities for Removal of Suspended Particles

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This paper analyzes wastewater treatment facilities for removal of suspended contaminants. Results confirming dependence of their separation process on a great quantity of natural correlating indicators are listed, and an index characterizing stability of suspensions to a separation process is proposed. The effect of hydraulic and hydrodynamic regimes of streams in the facilities on this process is considered; the example of the construction design including these indices is given. This paper puts forward a hypothesis of a possible development of a unified model of the analysis of the facilities used for separation of suspended contaminants.

Keywords: *Wastewater, suspended contaminants, concentration of suspended particles, natural indicators, specific surface, cramped sedimentation, turbulence, turbulent component.*

1. Introduction

Suspended contaminants of industrial wastewater indicate a wide range of dispersion composition sizes from 1 x 10^{-2} to 1 x 10^{-9} and density from 0.8 to 7 t/m^3, and also the concentrations which sometimes may amount to 20 g/l and over.

The particles of contaminants of different nature are under a permanent interaction in between and can be integrated into agglomerates. This process governs the stability of a dispersion composition of wastewater suspensions (emulsions). Sedimentation tanks, hydraulic cyclones, flotation units, centrifuges and filters are used for their separation. Nowadays, many modifications of these facilities have been elaborated and applied. Each facility where the treatment process takes place is designed following the established procedures. Many procedures do not take into account all the parameters affecting the process, therefore the facilities (apparatuses) constructed under the design do not provide an envisaged outcome. Main parameters which have not been completely considered in the design include natural indicators of contaminants whose interaction shall affect hydraulic regime in a certain facility.

2. Methodology of studying the interaction of suspended particles of contaminants in wastewater suspensions

The interaction of suspended particles in contaminants of different nature was evaluated on artificially prepared suspensions under laboratory conditions. Suspended particles from wastewater arriving from the treatment plants of different types were used for suspensions. In total, 16 suspensions were prepared and studied changing their concentrations within a wide range from 25 to 5000 mg/l. By sophisticated procedures the following indices of suspended contaminants were evaluated for each prepared suspension: density of a solid phase – ρ_s; size of particles – d; equivalent diameter of suspended particles - d_e; form factor - φ; wettability – θ; - loading weight – γ; porosity of released dried mass- m; potential –ζ;, concentration of suspensions – C; specific surface – S_{sp}; for a liquid phase: viscosity- μ, temperature t^0 C, salt content – C_c, density of liquid phase – ρ_l.

Procedures for estimation of selected parameters were obtained from the laboratories of the leading institutes and from technical literature on that subject, and the methods of VNII VODGEO, where that work was realized, were applied. Diameters of the particles were evaluated by instrument ФС 112 and at recalculation of the value of fall velocity it was evaluated from the curves of kinetics of sedimentation E =t (t), following a well known formula of Stokes.

Table 1. Natural indicators of suspended particles selected for the study

Description of suspended particles	$d_э$	θ	φ	ζ	ρ	Ssp	γ	m	E_{10}
Unit of measurements	mm	degree	-	V	g/см^3	cm^2/g	g/см^3	%	%
Sand	0.25	0.52	1.2	+1.8	2.59	149	2.09	19	100
Porcelain clay	0.012	0.2	0.47	-	2.9	5925	1.60	45	70
Clay, veselovskaya	0.008	0.37	0.7	-	2.6	26346	1.13	57	61
Clay, poloshskaya	0.0021	0.26	0.7	+2.8	2.53	11176	0.98	61	66
Clay, nikiforovskaya	0.0042	0.67	0.9	+3.0	2.47	5667	1.82	26	67
Corundum №1	0.005	0.43	0.63	+14.3	3.71	3483	1.77	52	69
Corundum №2	0.0033	0.65	0.68	+9.0	3.77	4713	1.82	52	49
Corundum №3	0.012	0.12	0.77	+24.2	3.87	1290	1.75	55	99
Corundum №4	0.012	0.21	0.7	+18.4	3.94	1290	1.74	56	69
Corundum №5	0.027	0.82	0.4	23.6	3.77	5900	1.82	52	39
Corundum №6	0.027	0.25	0.57	+9.4	3.77	1667	1.77	53	95
Carborun-dum	0.021	0.79	0.63	+6.6	3.08	947	1.60	48	100
Nepheline- sienite	0.045	0.66	0.90	+26.9	2.67	5052	1.29	52	77
Sludge,beast furnace	0.028	0.52	0.87	-13.0	3.21	6230	-	-	90
Sludge, open hearth furnance	0.0003	0.79	0.96	-	3.25	61620	-	-	74
Mixture of sludge from collector и	0.0049	0.3	0.48	-	3.27	3692	-	-	84

Comparisons were made with the efficiency of sedimentation during one period of time (10 min). The initial concentrations of suspended particles of contaminants used in all experiments comprised C=1000 mg/l. With the computer-aided program the correlation was analyzed, and the correlation of linear and non-linear connections between indices was defined by the types of suspensions. Then, from both values of correlation coefficients and correlation ratio the conclusions as to the importance of interconnections were drawn. The conclusions were examined thereafter during the studies conducted in other projects. For example, at the Alytus integrated house-building factory in the course of joint work with Kaunas Polytechnic Institute (since 1990 it is Kaunas University of Technology) when the wastewater arriving from the works manufacturing the fiber boards was analyzed, That analysis was continued at the Vilnius Concrete Product Plant and other mills.

Since interaction of the particles depends on hydraulics of streams in the facilities and on their turbulence,, the hydraulic efficiency of the analyzed treatment facilities, such as sedimentation tanks, flotation tanks, etc., was evaluated and the parameters of streams were determined. Moreover, there was estimated the moving power of processes of releasing the suspended particles of contaminants in the facilities and apparatuses used, including filters.

On the basis of processing the obtained results, general conclusions concerning regularity of the processes of separating wastewater suspensions were drawn.

3. Study of the effect of suspended particles natural indicators on wastewater treatment efficiency

Analysis and selection of facilities for separation of suspended particles of contaminants are done, as a rule, on fall velocity (U_0) evaluated by kinetics of sedimentation (E=f(t)). These dependences (Fig. 1) are obtained by sedimentation of selected wastewater samples under the static conditions of laboratory experiments. The nature of sedimentation curves depends on many factors: layer height, which in laboratory conditions may differ from that in industrial environment, concentration of suspended contaminants; density, temperature and many other parameters, that cannot be considered in laboratory experiments.

To account for the variation of dispersion compositions of particle contaminants and the recalculation of curves E=f (t), technical literature on the subject recommends coefficients (Kalitsun 1978) and exponents **(**Kalitsun 1978, Kalitsun 2000). It is found out that the suggested recalculation factors depend on the nature of contamination, therefore from time to time they change their values which may affect the accuracy of computations. At the same time, the examination of separation processes (treatment) of wastewater suspension demonstrates that the processes removing suspended contaminants in the facilities, including filters, are similar, but they differ in the moving power of the process and the conditions of its performance. This allows draw the conclusion that there is a chance to develop the unified analysis procedure of wastewater treatment facilities which would enable specialists to select a rational treatment diagram and to optimize the water management system.

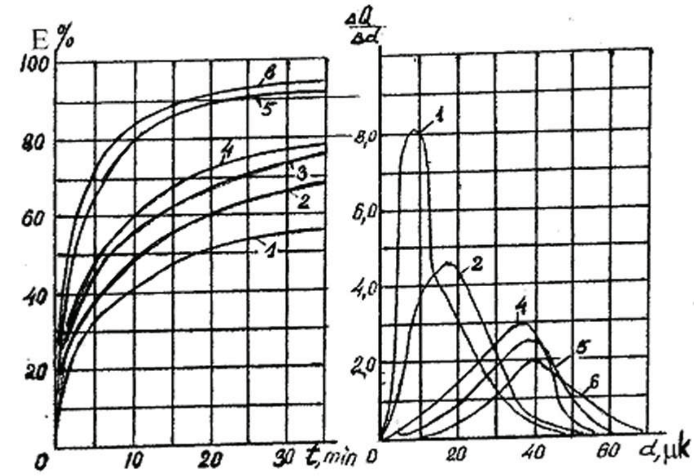

Fig. 1. *Kinetics of sedimentation (a) and distribution by size (b) of solid phase of wastewater contamination of optical and mechanical plants*

Extensive research (Ponomarev 1993) into sedimentation processes of several artificially prepared suspensions was done. Sludge from various industrial plants such as optical and mechanical factories, foundries, metallurgical works, engineering plants, asbestos cement plants, as well as several kinds of clays, sludge of concrete product plants and concentrating mills were used to prepare suspensions. The object of this research has been to evaluate the relationship between sedimentation processes and natural parameters of suspended particles and water

The influence and interrelation of selected parameters are evaluated from curves E = f (t). Handling of the obtained results has demonstrated that in linear and quadratic fields all the listed parameters are dependent on each other (Fig. 2). Moreover, there are parameters by which it might be possible to determine the order of the values of other indices. Once again the hypothesis is approved for giving a good chance of providing the unified analysis procedure of wastewater treatment facilities.

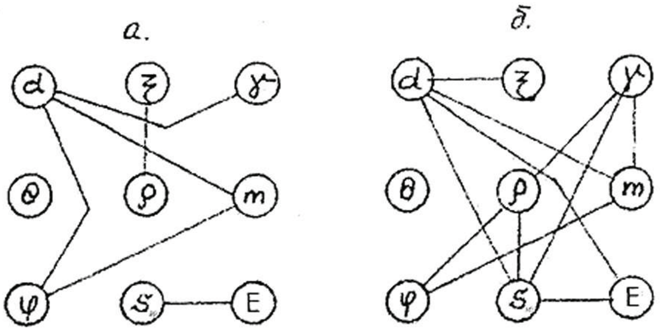

Fig.2. *Graphs of correlation between natural indices of suspended contaminants in a) linear and b) quadratic dependences*

Further, research on sedimentation has been done under static conditions studying the variation of the height of a sedimentation layer over the range of 50-2000 mm and the concentration of suspended particles of 25-5000 mg/l (Ponomarev 1993).

It is found out that at a low concentration (Fig. 1, curves 5 and 1) down to C=50 mg/l the particles appear in free sedimentation and when they do not produce any effect on each other, they do not agglomerate. The graphs indicate that curves E=f (t) are merging into one curve (Fig. 1a). Conclusion may be drawn that a real granulometric composition of the dispersion system should be estimated by the method of sedimentation at low concentrations, but not at high ones as it is recommended in some procedures used.

Then, curves E=f (t) start to differ in between, as the content of suspended particles**,** practically one of granulometric compositions, increases. As this takes place, the curves of considerable concentrations are placed above. It suggests that the content of particles of large fractions increases due to reduction in the small ones, i.e. the agglomeration of suspended contaminants takes place (Fig.1b). It should be also stated that with an increase in the concentration the cramped sedimentation occurs.

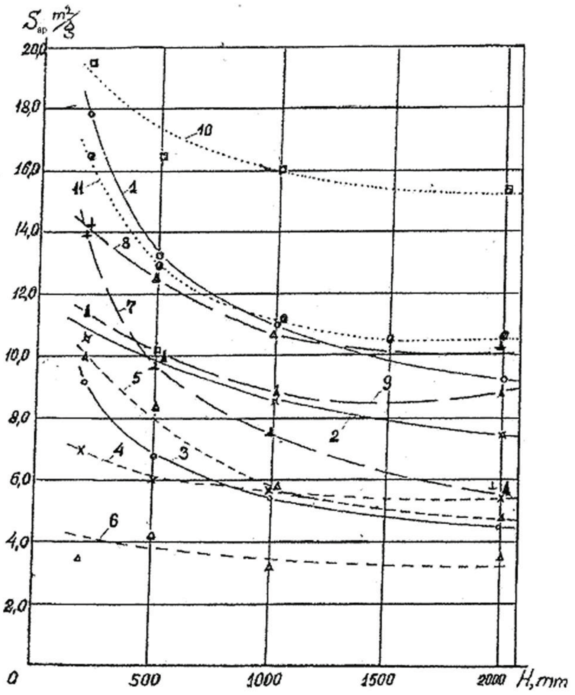

Fig.3. Dependence of specific surface Ssp on sedimentation height: optical and mechanical factory- 1, 2, 3 – C0 = 86, 337, 980 mg/1; asbestos cement plant - 4, 5, 6 - C0 = 302, 465, 953 mg/1; concentrating mill- 7, 8, 9 - C0 = 262, 589, 1819 mg/l; clay-10,11 - C0 – 106, 423 mg/1.

The results of the inspection of water management in a number of plants have demonstrated that with high concentrations of suspended particles over 5000 mg/l for some suspensions the process of cramped sedimentation transforms into that of suspended contaminant compaction. Curves E=f (t), in this case, are below the curves conforming to the lower concentrations. Thus, the conclusion may be drawn that if there is a problem of treating the wastewater containing high concentrations of suspended contaminant particles, it is advisable to dilute the arriving water with the same water subjected to treatment. Moreover, in the last case lower humidity of produced sludge should be expected.

Agglomeration of suspended contaminant particles at variation of sedimentation parameters can be characterized, as a whole, by the variation of its specific surface S_{sp} evaluated from curves E=f (t) under different conditions of the process and concentration (Figs 3, 4). The relation between S_{sp}^{50} evaluated at the concentration of 50 mg/l and S^{c}_{sp} , defined at the initial concentration (C), is recommended to be taken as agglomeration coefficient J.

$$J = S_{sp}^{50} / S^{c}_{sp} \quad (1)$$

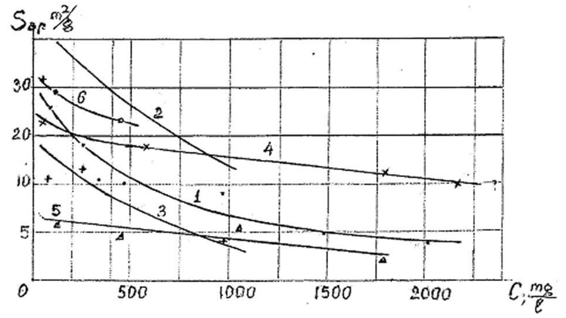

Fig. 4. Dependence of specific surface Ssp of suspended contaminants on their concentration in: 1- optical and mechanical factory; 2 - ventilation effluents of foundry; 3-run-off from asbestos cement plant; 4-wastewater of concentrating mill; 5- concrete product plant; 6 – clay.

Stability of a dispersion system of contaminants to separation can be estimated by coefficient J. Figure 5 illustrates the experimentally obtained curves of relationship between J and concentration C and the height of sedimentation layer H for several types of wastewater of different nature and dispersion compositions. A direct dependence of function J= f (C,H) was experimentally found. This bears witness that there is a chance of predicting the stability of a contamination system and the necessity of using chemicals for changing the size of a dispersion phase. It is calculated that agglomeration intensity of the systems whose particles are similar in size is not high. This conforms to value $J \leq 1.1$, while wastewater containing mechanical contaminants, whose composition is of different size $J \approx 3$ and over, possesses a considerable ability to agglomerate.

4. Estimation of turbulence of hydraulic streams in the facilities.

It has been known that in the facilities an elevated effect of wastewater suspensions (Kalitsun 2000) on the process of separation is produced by both the hydraulic regime of streams generated under the influence of velocity diagrams of the main stream and by the convection and increased density streams occurring due to irregular distribution of concentration of contaminants and temperatures in the scope of facilities.

On purpose to take into account the turbulence effect on precipitating particles,, special literature on the subject recommends to insert into the design formula indicator ω – a turbulent component, counteracting the separation process with the sign (-). Various studies have demonstrated that hydrodynamic regime can be produced in the facility, wherein turbulent mixture springs up and produces a positive effect on agglomeration ability of the dispersion system, when the separation process is accelerated, i.e. indicator ω shall have sign (+). The obtained results point to the fact that, when developing the facilities, the provision should be made for the possibility to control the hydraulic regime there, when a turbulent regime could be continuously transferred into a laminar one. Such a conclusion has been previously drawn by American scientist Camp T.R (1953).

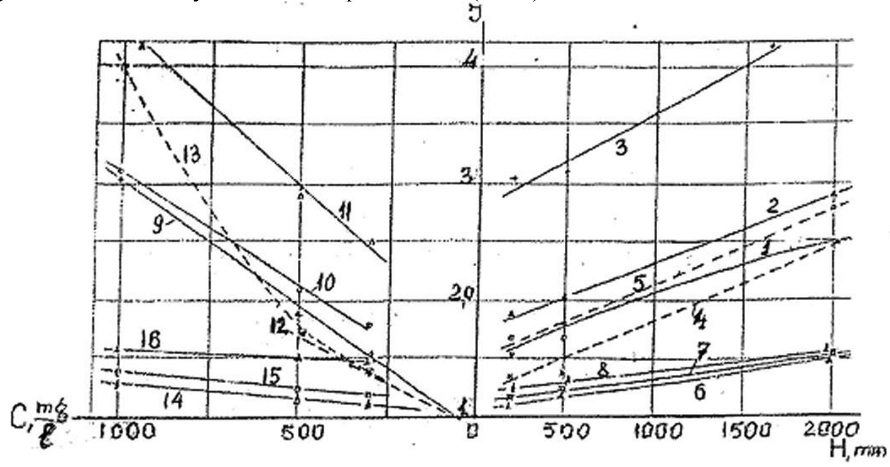

Fig.5. Dependence of agglomeration intensity – J on: a) sedimentation height: optical and mechanical factory-1, 2, 3 – C0 = 300, 500, 1000 mg/l; asbestos cement plant - 4, 5 - C0= 300, 500 mg/1; concentrating mill - C0= 300, 500, 1000 mg/1; b) concentration: optical and mechanical factory - 9,10,11- H0 = 200, 500,1000 mm; asbestos cement plant – 12,13 H0 = 200, 500 mm; concentrating mill -14, 15,16 - H0 = 200, 500, 1000 mm.

Special literature recommends to evaluate hydrodynamic regime in the facilities by parameter Re or by coefficient of turbulent diffusion Pe and also by longitudinal diffusion coefficient D/V1 (Rozenberg 1970). The last two parameters are determined from the response curves derived when evaluating hydraulic regime in the facility by the method of introducing the solutions of flares and by sampling water at the outlet according to time (Rozenberg 1970):

$$Re = V P / \nu \quad (2)$$

$$Pe = 8 / (1 + 8\sigma^2)^{1/2} - 1 \quad (3)$$

$$D/Vl = f (C_i t_i) \quad (4)$$

where:

V – stream velocity, m/sec;

1 – length of the stream path in the facility, m;

P- - typical linear dimension of the facility, m;

ν – dynamic viscosity, $m^2 sec^{-1}$;

σ – diffusion factor, equal to

$$\sigma^2 = \{(\Sigma t_i^2 C_i / \Sigma C_i) / t_{av}^2 \} – 1 \quad (5)$$

where:

C_i – concentration of the indicator (color) at the facility outlet after a lapse of time, evaluated by colorimeter;

t_{av} - average duration of the stream staying in the facility evaluated as

$$t_{av} = \Sigma t_i C_i / \Sigma C_i \text{ min.} \quad (6)$$

Research into the turbulence effect on separation processes of the artificially made suspensions containing concentrations of 300-1000 mg/l was carried out under the laboratory conditions on a fragment of a thin-layered block of the sedimentation tank on a scale of 1:1. The supplied flow rate was varying from 0.2 to 1.85 m^3/h conforming to the specific hydraulic loads of 0.25 - 2.3 m^3/h per one square meter. Hydraulic regime was evaluated from a response curve obtained with an impulse injection of the color at the inlet of the block fragment. The samples leaving water were selected at the spillway. Facing the model at some distance from the inlet of water and prior to the spillway, perforated partitions, practically producing laminar regime in between, were installed, the coefficient of the use of the facility volume being 85-90%.

Dispersion composition was controlled by the curves of kinetics of sedimentation E=f (t).

n the first zone between the inlet of streams and the first perforated partition, where the turbulent mixing is observed, the agglomeration and subsequent separation of suspended particles are found to take place. In this case, large (d≈ 30 μк and over) and small particles (smaller than 10 μк) interact and the ensuing agglomeration occurs. As the rate was changing within the specified limits, parameter Re was varying within the limits of 2700 – 18900, Pe = 91-24 and D/V1=0.131 – 0.202. Comparison with the obtained technological results of the separation process has demonstrated that these characteristics cannot be used for technological simulation of treatment facilities and can be used only for classification of the hydrodynamic regime in them.

Simultaneously, when developing the unified procedure of the analysis of facilities and apparatuses used in separation of suspended contaminants, their dispersion composition, density, concentration, their surface properties must be taken into consideration, as well as the properties of a liquid phase, and the indicator of streams dynamics, in the capacity of which a longitudinal diffusion factor (Rozenberg 1970) can be taken.

5. Testing under working conditions

A positive effect of artificially generated hydraulic regime of streams in the facilities on the efficiency of processes for separating suspended contaminants should be considered in the design process. The design of hermetic sedimentation tank SPS (Fig. 6) (Patent of RF № 2206369) developed in the company STROYENGINEERING SM Ltd with participation of the author and used for treatment of wastewater from oil products may furnish an example. At the inlet of this tank the hydraulic mixing passing into the zone of laminar settling is produced. Sedimentation tank SPS - 300/2.5 with the capacity of 300 m^3/h provides a high degree of water treatment in the recirculation system of the oil refinery. The hermetic mode allows supply water to the cooling towers under the residual head. In this case, the volume of the pumping station of the recirculation system is reduced at the cost of elimination of the whole group of pumps.

Sedimentation tanks SPS-300 and SPS-500 are located above the ground. For this reason stored oil products are removed when the gate valve on the branch pipe of the upper manhole is open and under its cover oil is collected; and in this case the content of water should be low (to 5%).

The sludge under pressure is also removed via the bottom branch pipe. At regular intervals, after the discharge of sedimentation tanks, the system of hydraulic wash-out providing the complete removal of sludge is engaged. The processes of oil products and sludge removal are automated.

Extended time (~ 10 years) of the settling tank operation has demonstrated its reliability and simple operation in addition to no contamination of the environment

Hermetic sedimentation tanks can be used in the treatment systems of various types of wastewater.

Fig. 6. Hermetic sedimentation tanks in the system of circulating water supply of the oil refinery

6. Conclusions

At present there is a lack of experimental data for development of the unified model for analysis, therefore when designing new facilities under laboratory conditions it is suggested to evaluate kinetics of sedimentation E= f (t) with the considered wastewater at the height of 200 and 400 mm. Then, the curves derived by mathematical dependences and the analysis of specific surfaces S_{sp}, including concentration of 50 mg/l obtained by artificial dilution of the initial water with the filtered one, should be approximated.

Parameter J should be calculated and plotted against the concentration and height of sedimentation J=f (C, H). Based on these data the curve for the height of sedimentation of the selected facility E=f (t) is to be plotted and the parameters for its analysis are obtained.

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Nuotekų valymo įrenginių, skirtų suspenduotosioms dalelėms pašalinti, analizė

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(gauta 2012 m. kovo mėn., priimta spaudai 2012 m. rugsėjo mėn.)

Straipsnyje tiriama pakibusių dalelių nuotekose valymo įranga. Gauti rezultatai rodo suspenduotųjų dalelių atskyrimo priklausomybę nuo jų srauto, taip pat teigiamą koreliacinę priklausomybę tarp dalelių kiekio ir jų atskyrimo. Išanalizavus hidraulinio ir hidrodinaminio efekto srautus, galima daryti prielaidas, jog galima analizuoti ir plėtoti efektyvesnį pakibusių dalelių atskyrimą nuotekų valymo įrenginiuose.