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USE OF VARIOUS THIN-LAYER SETTLING SCHEMES FOR INDUSTRIAL WASTEWATER TREATMENT

In this paper, the theoretical preconditions in favor of the use of thin-layer settling tanks for industrial wastewater treatment are substantiated by the corresponding laboratory studies. The data from the results of studies of wastewater treatment of the textile, knitwear and silk industries conducted on laboratory thin-layer settling tanks according to the basic schemes of wastewater supply and precipitating sediment are given. As stated by these data, according to the generally accepted criteria for the effectiveness of suspended solids retention for wastewater of the above-mentioned industries, it is more preferable to use thin-layer sedimentation in a cross-sectional scheme.

Keywords: *suspended matter, laminar flow, inter-shelf distance, flow velocity.*

Introduction

The relative simplicity of the settling facilities and the settling process itself, low energy intensity and availability precondition their widespread use at various stages of wastewater treatment and sediment processing. In our case, the sedimentation is used for preliminary industrial wastewater treatment and is carried out in thin-layer settling tanks. Despite the fact that a lot of researchers have studied the issues of thin-layer settling [1…9, etc.], to this day there are no definite recommendations for identifying the optimal scheme for industrial wastewater treatment in a particular sector of the national economy. Therefore, the studies to determine the optimal structural parameters of thin-layer settling tanks and the optimal technological parameters of the settling process are relevant both from the point of view of choosing the appropriate type of structure and its operation scheme, as well as from the possibility of preliminary classification of characteristics of suspended matter (shape and size of particles, density, rate of their sedimentation and the ability to agglomerate, etc.) of wastewater of the industries under study.

Main Part

In order to improve the operation of the settling tanks by constructive methods, Hazen A. developed a theory [1], according to which the division of the general settling zone into a number of elementary zones with a lower depth simultaneously increases the sedimentation area (up to 0.80) according to the data of the works [2…8], and also allows significant increase in the hydraulic load per unit area, thereby providing more effective clarification, the productivity of which increases proportionally to the sedimentation area on average 2 ... 4 times [9]. Thin-layer settling tanks, like the regular ones, have water distribution, settling and catchment zones, as well as a sedimentary zone. The settling zone is divided by parallel shelves (or pipes) and settling is carried out in the space between the shelves with a height of 2 ... 15 *cm*. As a result of reducing the path for the sedimentation of suspended matter, the settling process in thin-layer settling tanks occurs very quickly in 15 ... 30 minutes, the sizes of thin-layer settling tanks are reduced 4 ... 6 times, which makes it possible to construct them even in enclosed spaces [9, 10]. The temperature within the layer is more uniform, the turbulence of flow is minimized, and the hydraulic conditions of settling and separation of sediments are improved.

The hydrodynamic stability of suspended matter is also increased in thin layer settling tanks, and the influence of density and convection flows on the process of settling the suspended matter is minimized. In addition to creeping forces, additional forces of suspension drift on thin-layer elements appear. As a result of dividing the flow by separate elements, the amplitude and frequency of the flow velocity pulsation of the treated wastewater also attenuate, the wetted perimeter significantly increases, and conditions that will contribute to the maximum laminar flow of liquid in thin-layer elements are created*.

It is known that non-pressure flows can be characterized by the ratio of inertial forces to gravity forces, which is the Froude number (Fr):

$$Fr = V^2 / g \cdot h \geq 10^{-5}, \tag{1}$$

where V is the average flow velocity, *m/s*; g is the acceleration of gravity, *m/s*^{2}; h is the average flow depth (in our case, the inter-shelf height), *m*.

Flow stabilization is possible if the energy of water particles movement prevails over the gravity forces. Flow stability is always ensured at $Fr \geq 10^{-5}$. The values of Froude number give us reason to believe that the flow structure in the settling tanks cannot be formally described only by Reynolds numbers (Re):

$$\mathrm{Re} = V \cdot R / \nu \leq 500, \tag{2}$$

where R is the hydraulic radius, *m*; and v is the kinematic coefficient of viscosity, *m*^{2}*/s*.

Equations (1) and (2) are presented for the laminar fluid movements in thin-layer elements, at which the optimal operation mode of thin-layer settling tanks is achieved. Despite the more rigid structure of the tubular elements, which ensures dimensional consistency over the entire length and can operate at higher speeds, they are quicker to fill up with sediments, more difficult to clean and require higher material consumption. Therefore, in the studies carried out, preference was given to shelves, which are mounted from flat or wavy plates convenient in operation.

For shelf settling tanks $\mathrm{Re} \approx h$ and dependence (2) takes the form

$$\mathrm{Re} = V \cdot h / \nu \leq 500. \tag{3}$$

The maximum available velocity of fluid movement in thin-layer elements, based on condition (2) and at $\mathrm{Re} \leq 500$ should be:

$$V_{макс} \leq 500 \cdot \nu / h. \tag{4}$$

The study was carried out on two laboratory units of rectangular and circular cross-sections designed and mounted by the author of the paper, for application of flat plates made of galvanized sheet and plastic, providing easy sliding and removal of sediment from the surface.

The laboratory unit of thin-layer rectangular cross-section is a plexiglass prism open from the top with dimensions of $100 \times 200 \times 500$ *mm*. From above this prism is immersed in rectangular prismatic frame, in which sets of shelving elements made of a galvanized sheet (0.8 *mm* thick) and from plastics (1.0 and 1.2 *mm* thick) were applied. Galvanized sheets assembled in a rectangular prismatic frame are shown in Fig. 1, and sets of plastic plates are shown beside. Plate sets made of these materials are designed for studies of settling of suspended matter from wastewater at an angle of 55 ... 65° relative to the bottom of the laboratory settling tank. There is also a rectangular prismatic frame made of plastic with flat elements of galvanized sheet assembled at an angle of 45…55° relative to the bottom of the laboratory settling tank.

Installation of a thin-layer rectangular settling tank is shown in Fig. 2.

The feed rate is controlled by a valve located on the pipe just in front of the inlet to the thin-layer settling tank. A branch pipe with a valve for periodic sediment discharge and emptying of the thin-layered settling tank into a bucket is located on the right side next to the sewage pipe. Occasionally, the experiments were performed

* https://stowater.com/katalog-oborudovaniya/otstojnik-tonkoslojnyij.html
https://prom-water.ru/catalog/ochistka_stochnyh_vod/otstojniki/

with a perforated panel (shown in the image below on the left side before the measuring cylinder), which was placed vertically near the frame of the shelf elements in order to maximize the laminarization of the wastewater supply. The clarified wastewater is drawn off from the surface through a 15 *mm* hose. Three other hoses having clamps at the end with a diameter of respectively 12; 8 and 5 *mm*, immersed in liquid, are designed for taking samples from different heights of the laboratory settling tank.

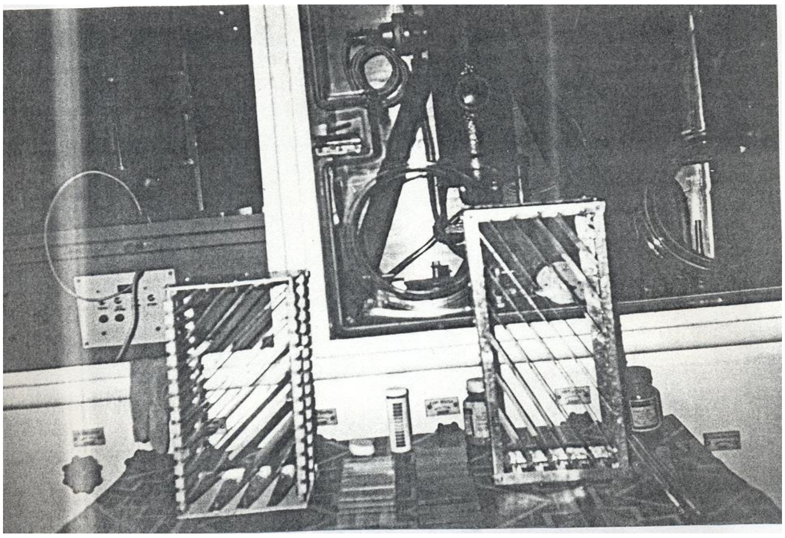


Fig. 1. *Prismatic frames with thin-layer elements*

In the cross - flow scheme study, the wastewater is supplied through a 12 *mm* lateral central connecting pipe with a plug, which is connected to a transparent hose of the same diameter (the longest in the image). Wastewater is also supplied through a 50 *mm* metal pipe displayed on the foreground, with a 10 *mm* connecting pipe mounted to it. At the end of the connecting pipe, a connected piece of a submerged hose of the same diameter directs the wastewater stream to the left lateral side of the unit. In both cases, the stream under study will flow from the top of a container with a volume of 42.5 liters with dimensions of $500\times340\times250$ *mm*. The frame of the circular section unit is a steel cylinder with an inner diameter of 140 *mm* and a height of 500 *mm*. At a height of 360 *mm* on the left side, there is a branch pipe with a clamp at the end of the hose, through which it is also possible to supply the treated wastewater thus conducting part of the experiments of thin-layer settling in a cross-scheme. But in general, this unit is designed to carry out experiments of thin-layer settling tanks in a countercurrent scheme. To do this, the treated wastewater is supplied by a hose (10 *mm*) from a cylindrical container located on the top, with a volume of 42.5 liters (diameter 300 *mm* and height 600 *mm*) through the central bottom pipe branch to the laboratory settling tank.

Fig. 2. *Laboratory unit of a thin-layer settling tank (rectangular section)*

The clarified wastewater is discharged from the top through a 10 *mm* hose on the right side, from where periodically a sample is taken to determine the effectiveness of the treatment according to the main indicators. The located upper central branch pipe with a hose and a clamp can also be used for supplying treated wastewater. In this case, if the lower central pipe is disconnected, the laboratory unit will work according to a direct flow scheme of wastewater and sediment removal. The recurrent sediment is removed through the brown hose with a clamp, the beginning of which is located 30 *mm* above the level of the unit bottom. The dynamics of the sediment accumulation and the whole process of wastewater clarification can be monitored through a cutout transparent window with a diameter of 55 *mm*.

Fig. 3 shows two sets of oval shelf elements made of galvanized sheets and plastic. Each set of flat elements has been mounted at angles from 45 ° to 65 ° (as in the case of the rectangular prism) with a gap in order to avoid obstacles to the settling process itself. At the same time, this distance contributed in part to the laminarization of the flow in the thin-layer elements as a distribution zone. Thin-layer oval elements were installed into the unit, starting from a level just above the transparent window to a level of 5 *cm* below the clarified wastewater at a distance of 2 ... 10 *cm* between themselves.

From above, the height of the entire thin-layer settling tank can be extended by a flanged connection, thereby providing more accurate technical data on the sedimentation of suspended matter. Fig. 3b shows the general appearance of a thin-layer settling tank extended by additional 550 *mm*.

The basic schemes of reciprocal movement of wastewater and released sediment are the following: cross-sectional scheme - when the selected sediment moves perpendicularly to the movement of the fluid flow; countercurrent scheme – the discharged sediment is removed in the direction opposite to the movement of the fluid flow; direct-flow scheme - direction of the sediment movement coincides with the direction of water flow. In fact, two laboratory units could be used for cross-sectional studies (prism unit) and for direct or countercurrent scheme (cylindrical unit) of thin-layer settling.

All experiments were carried out at optimal values of the wastewater flow velocity of ($V = 5...10$ *mm/s*) and the inclination angle of the plate elements ($\alpha = 55^o$) obtained by the author in advance for the observable wastewater. The inter-shelf distance was taken $h = 2...10$ *cm*, at which, according to conditions of (1) and (3) (or (4)), a laminar flow in thin-layer elements was theoretically ensured.

a

b

Fig. 3. *Laboratory unit for thin-layer settling*

a - circular cross-section; b - elongated version of circular cross-section

In general, thin-layer settling tanks are effective in extracting finely dispersed impurities from wastewater, which is typical for wastewater from silk, textile and knitwear industries. The data from the cross sectional scheme studies are shown in Table. 1, while the data from direct and countercurrent scheme studies are shown in Table. 2, where the maximum treatment efficiency values are presented.

Table 1. Indicators of wastewater treatment after thin – layer settling by direct-flow scheme and countercurrent scheme

Main characteristics	Industrial wastewater					
	textile			knitwear		
	before treatment	after thin-layer settling/ effect, %		before treatment	after thin-layer settling/ effect, %	
		direct flow scheme	countercurrent scheme		direct flow scheme	countercurrent scheme
suspended matter, *mg/l*	120…180	54..81 / 55	48..72 / 60	32…320	14..140 / 56	13..130 / 62
COD, *mg/l*	450…900	337..674 / 25	315..630 / 30	880…2600	642…1898 / 27	581…1716 / 34
BOD, *mgO₂/l*	160…340	125..265 / 22	120..255 / 25	200…500	152..380 / 24	146..365 / 27
pH	8.5…10.0	9.1	9.2	6.5…9.0	7.8	7.9

According to the Table. 1, it can be confirmed that the effectiveness of suspended solids retention is from 5 to 7% higher in the countercurrent scheme compared to the direct-flow sedimentation scheme. This is due to the fact that favorable conditions are created for suspended solids settling in shorter trajectories when the wastewater moves up in inclined plates from the bottom.

Table 2. Indicators of industrial wastewater treatment after thin-layer settling in a cross-section scheme

Main characteristics	Industrial wastewater					
	textile		knitwear		silk	
	before treatment	after thin-layer settling / effect, %	before treatment	after thin-layer settling / effect, %	before treatment	after thin-layer settling / effect, %
Suspended matter, mg/l	150	67 / 58	290	104 / 64	260	96 / 63
COD, mg/l	610	439 / 28	1100	726 / 34	850	578 / 32
BOD, mgO₂/l	220	165 / 25	340	148 / 27	365	266 / 27
pH	8.6…9.8	9.2	6.8…9.1	7.9	7.6…9.0	8.2

Comparison of the data in Table. 1 and Table 2 shows that wastewater treatment in the aforementioned industries by thin-layer sedimentation is preferable to be performed using a cross-sectional scheme, in which the effectiveness of the retention of suspended solids is on average increased by additional 1 ... 2%.

Outcomes

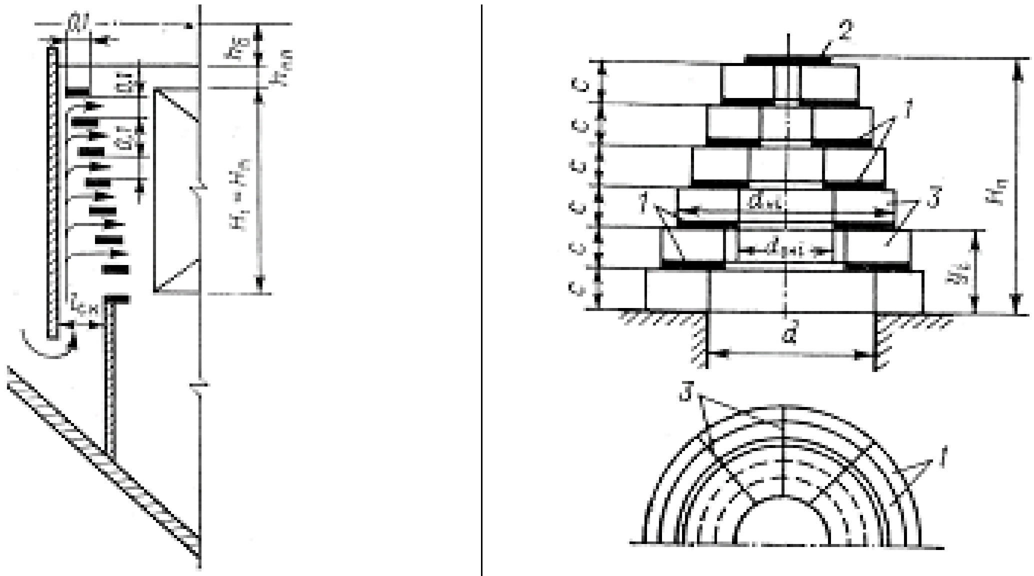
From the above-mentioned it follows that:

1. The treatment of wastewater from textile, knitwear and silk industries by thin-layer settling is almost the same, and high efficiency is provided by cross-section flow and countercurrent flow schemes,
2. The tendency of higher effectiveness of retention of suspended substances at their proportionally high initial values was confirmed for all three thin-layer settling schemes.

Conclusion

The cross-section flow scheme primarily implies the realization of the process in horizontal, thin-layer settling tanks with a detailed calculation of the distribution zone length of the structure.

It should be noted that the effectiveness of thin-layer sedimentation depends not only on the adopted scheme but also on other structural parameters [11, 12]. In particular, it is also important that the flow is distributed evenly among all thin layer elements. For this purpose appropriate proportional distribution should be provided in the laboratory units, similar to Fig. 4 and additional studies should be conducted for wastewater of the industries under study.



a b

Fig. 4. *Proportional distribution devices*

a - in a cross-section scheme; b - in a countercurrent scheme based on the principle of flow differentiation; 1 - disc annular; 2 - the same, solid; 3 - radial directing baffles

Among the technological parameters, we may note the need to use various reagents for the discoloration and retention of surfactants of the wastewaters under study, as well as the possibility of some increase in the flow velocity [13, 14] in order to identify the optimal combination of values between duration and efficiency of settling for suspended substances.

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