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OPTIMIZATION OF THE PROCESS OF INDUSTRIAL WASTEWATER TREATMENT BY DISAGGREGATION OF PHASE-DISPERSED CONTAMINANTS

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Wastewater from various industrial productions is the most difficult task for a designer in the field of developing an effective treatment scheme, since their composition and properties are extremely diverse, and treatment methods are possible, both chemical and physico-chemical, and biological. To select the most effective method for treating a particular type of wastewater, it is necessary to establish in what phase-dispersed states the impurities are. The authors of this article supplemented the existing classification of phase-dispersed states of pollution in wastewater with transition states: ultra-weighted, post-colloidal and atomically dissolved. For the simultaneous separation of contaminants that are in several groups of states according to the above classification, a dispersion phase separator has been developed, which includes several sequentially located purification zones and replaces large-sized and expensive facilities. On the developed installation, computer simulation was carried out in the ANSYS program in order to obtain streamlines and pressure of the fluid flow, velocity vectors in 3D format with their values, and the efficiency of the installation was determined. For the most efficient assessment of the wastewater treatment process in the phase separator, an automated control system has been developed in the OVEN program. Shut-off and control valves were selected, instrumentation was installed, allowing the operator to carry out phased control of the main types of pollution. In order to test the effectiveness of the dispersion separator, experiments were carried out on wastewater of various compositions from several industrial productions. The obtained results make it possible to recommend the phase separator as a facility for preliminary wastewater treatment for a number of industrial enterprises.

Keywords: *industrial wastewater; phase-dispersed states of pollution; disaggregation; phase separator; automated control system; modeling of hydrodynamic parameters*

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ОПТИМИЗАЦИЯ ПРОЦЕССА ОЧИСТКИ ПРОИЗВОДСТВЕННЫХ СТОЧНЫХ ВОД ПУТЕМ ДЕЗАГРЕГАЦИИ ФАЗОВО-ДИСПЕРСНЫХ ЗАГРЯЗНЕНИЙ

А.С. Смоляниченко, Е.В. Яковлева

Сточные воды от различных промышленных производств представляют наиболее сложную задачу для проектировщика в области разработки эффективной схемы очистки, поскольку их состав и свойства крайне разнообразны, а методы очистки возможны как химические и физико-химические, так и биологические. Для подбора наиболее действенного метода очистки конкретного вида сточных вод, необходимо установить, в каких фазово-дисперсных состояниях находятся примеси. Авторами в данной статье дополнена существующая классификация фазово-дисперсных состояний загрязнений в сточных водах переходными состояниями: ультравзвешенное, постколлоидное и атомарно растворенное. Для одновременного выделения загрязнений, находящихся в нескольких группах состояний по приведённой классификации, разработан фазовый сепаратор дисперсий, включающий в себя несколько последовательно расположенных зон очистки и заменяющий крупногабаритные и дорогостоящие сооружения. На разработанной установке проведено компьютерное моделирование в программе ANSYS с целью получения линий тока и давления движения потока жидкости, векторы скоростей в формате 3д с их значениями, а также определен коэффициент полезного использования установки. Для наиболее оперативной оценки процесса очистки сточных вод в фазовом сепараторе разработана автоматизированная система управления в программе Овен. Подобраны запорная и регулировочная арматура, установлены контрольно-измерительные приборы, позволяющие оператору осуществлять поэтапный контроль по основным видам загрязнений. С целью проверки эффективности сепаратора дисперсий проведены эксперименты на сточных водах разных составов от нескольких промышленных производств. Полученные результаты позволяют рекомендовать фазовый сепаратор в качестве сооружения предварительной очистки сточных вод на ряд промышленных предприятий.

Ключевые слова: *производственные сточный воды; фазово-дисперсные состояния загрязнений; дезагрегация; фазовый сепаратор; автоматизированная система управления; моделирование гидродинамических параметров*

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Introduction

Industrial waste water (IWW) is the most dangerous for water bodies. They are much more difficult to treat than municipal wastewater and require complex and expensive treatment facilities. The diversity of the composition and nature of industrial wastewater pollution determines the use of various methods for their purification, both physicochemical and chemical, and biological.

To select the most effective treatment facilities for the treatment of a particular type of wastewater, it is necessary to correctly determine the phase-dispersed states of pollutants, since each group of pollutants is released from wastewater in different ways.

The purpose of the ongoing research is to increase the efficiency of industrial wastewater treatment processes to the norms of maximum allowable concentrations of circulating water supply or discharge into the city sewerage system by phase separation of contaminants.

Scientific novelty:

1. The existing classification of phase-dispersed states of wastewater pollution has been supplemented;
2. The theoretical principles of the preliminary separation of contaminants in different aggregate states before the post-treatment facilities formed the basis of technological solutions (phase dispersion separator);
3. Calculated dependences based on a computer model of the movement of fluid flows in the Pyramida N phase separation unit with an acceptable statistical error describe the experimental data on the disaggregation of contaminants in the practice of industrial wastewater treatment.

The most well-known classification of pollution according to the phase-dispersed state of Academician L.A. Kulsky [2], who singled out the following groups of impurities according to their particle size: group 1 ($>10^{-1}$ μm) – particles suspended in water, forming suspensions and emulsions; group 2 (10^{-1} - 10^{-2} μm) – colloid-dissolved impurities and high-molecular organic substances; group 3 (10^{-2} - 10^{-3} μm) – molecularly dissolved substances; group 4 ($<10^{-3}$ μm) – substances that dissociate into ions in water. However, it was found that in natural and waste water there are pollutants that are in intermediate states, and their amount is significant, and the methods of separation from water are fundamentally different, so the authors of the article [1, 3, 14] supplemented the existing classification with three more transitional groups.

The supplemented classification can be presented in the form of a diagram (Fig. 1).

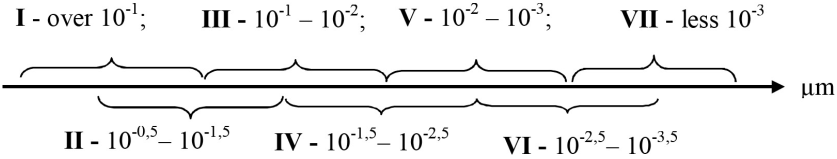


Fig. 1. Diagram of phase-dispersed states of water pollutants

According to this classification (**table 1**):

Table 1.

Supplemented classification of phase-dispersed states of impurities in water

Pollution group	Characteristics of pollution	Pollution designation	State of pollution in water	Methods of isolation (purification)	Note
I group	insoluble substances that precipitate or float at a rate greater than 0.2 mm/s	heavy coarse inclusions and coarse films	weighted	direct separation in gravitational (settling tanks) or centrifugal (cyclones, centrifuges, etc.) field	-
II group	insoluble substances with a sedimentation or ascent rate of less than 0.2 mm/sec, and therefore their direct separation in settling tanks is impractical due to the significant dimensions of these structures	fine particles and emulsions	ultra-weighted	coarsening by flocculation or coagulation, and then isolation during settling. Their complete removal is observed when filtering through a material with a pore size of 0.1 µm.	at a concentration of suspended solids up to 100 mg/l and oil products up to 10 mg/l, the listed contaminants are, as a rule, in an ultra-suspended state

Table continuation

III group	substances that are not subject to direct settling or settling after flocculation, i.e. they cannot be enlarged using only flocculants	colloidal particles and microemulsions	colloidal	coarsening by coagulation followed by separation in settling tanks. To enhance the effect of enlarging these contaminants, it is recommended to use flocculants after coagulants. Their almost complete removal from water is observed when filtering through a material with a pore size of 0.01 μm.	The concentration of contaminants in the water in a colloidal state can be quite significant.
IV group	macromolecular substances, the molecular size of which can be much larger than the size of colloidal particles, however, these contaminants cannot be enlarged by the coagulation method	pseudocolloids or couplers	postcolloidal	removal by flotation and foam separation (blowing), or destruction during their oxidation with special agents (hypochlorite, O3, etc.).	exhibit properties of both colloid and molecular true solution
Group V	substances that are in a state of true molecular solutions. The particle sizes of these substances are comparable in size or slightly larger (1.5÷5 times) than water molecules (except for the H2 molecule)	true molecular solutions	molecularly dissolved	separation by using sorption materials (the sorption capacity of these materials is used with maximum effect)	dissolved molecular gases can be effectively replaced by atmospheric gases during the process of intensive blowing of the water layer with compressed air (blowing or foam fractionation (separation).

End of table

VI group	substances in the state of atomic solutions are usually unstable and tend to form either molecules or ions, for example: $Na + H2O \rightarrow NaOH + H$ (atom); H (atom) $+ H$ (atom) $\rightarrow H2\uparrow$; $NaOH \rightarrow Na^+ + OH^-$.	atomic solutions	atomically dissolved	free impurities from group VI in the source water, as a rule, are absent	atomically dissolved gases oxygen (O-atom) and hydrogen (H-atom) are more chemically active than their molecules (O2 and H2) and react much more intensively with oxidation and reduction with other substances contained in water
VII group	impurities whose molecules are in water in a dissociated state	true ionic solutions	ion-dissolved	separation from water on a reverse osmosis membrane, designed specifically to separate electrically charged particles (ions), due to the special property of its surface, which allows electrically neutral molecules to pass through and retains electrically charged ions	the ions contained in the water are replaced by other ions present in the ion-exchange resin during the treatment of water on ion-exchange filters.

The distribution of the main impurities contained in water, according to the phase-dispersed states, can be represented in the form of a diagram (Fig. 2).

For the simultaneous separation of contaminants that are in I - IV groups according to the phase-dispersed state, it is recommended to use phase separators of dispersions.

Separators made in China, USA, Germany, Italy, Great Britain are known, differing in design, operating principles (centrifugal, coalescing, lamellar, gravitational, magnetic) and purpose for wastewater treatment of different composition and properties [11, 12, 15-17, 20].

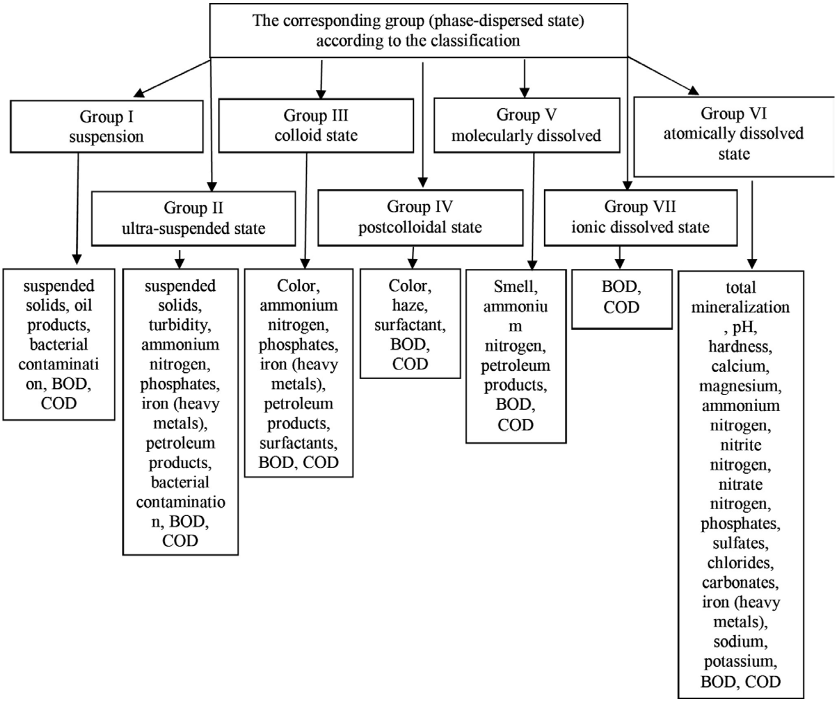


Fig. 2. Distribution of the main impurities by phase-dispersed states

The disadvantages of these separators are their high cost, complex design, energy costs, large occupied areas of buildings, and their design does not provide for the removal of contaminants with a dispersion degree of 10^{-2}-10^{-3} microns: molecularly dissolved gases and volatile impurities. However, for the simultaneous purification of water pollutants in different phase-dispersed states, it is necessary to determine the maximum time for the removal of one or another type of pollution, which will dictate the process as a whole. With three-phase pollution systems, according to hydrodynamic indicators, the removal of gases must be carried out at the first stage of purification.

Within the framework of import substitution, the issue of creating domestic equipment that is not inferior in efficiency to foreign ones, but has economic superiority, has become particularly relevant.

We have proposed a phase separator (Fig. 3), which is a compact design in the form of vertically arranged components. This phase separator consists of two vertical columns, which are a flocculation and flow stabilization body and a body with a dedicated zone of a weighed filter, connected by a thin-layer settling chamber.

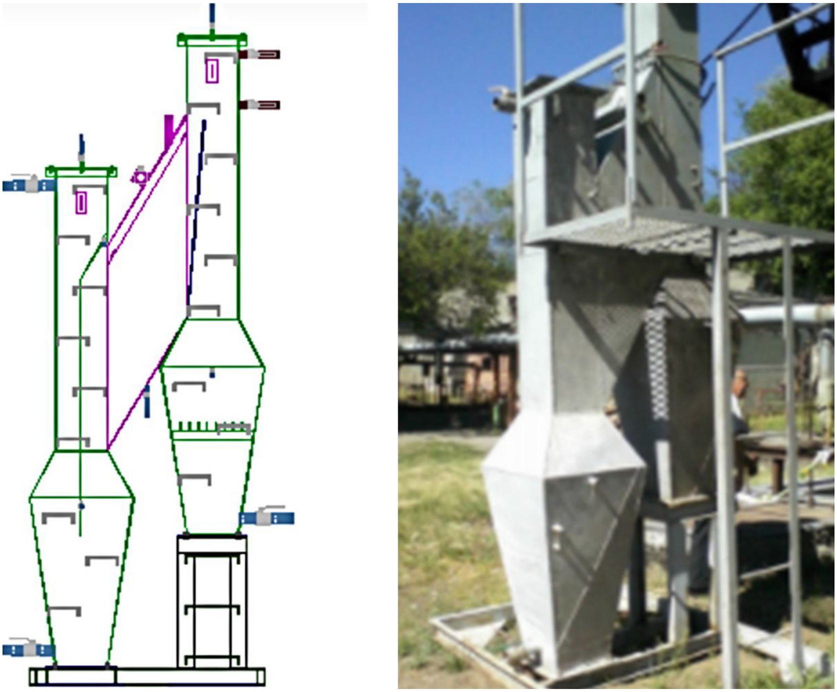


Fig. 3. Phase separator of dispersions

Thus, in one facility, a number of successive processes of industrial wastewater treatment take place: purification from coarse impurities through a grate in the first building, coagulation as a result of introducing a reagent into the pipeline for supplying initial wastewater for treatment, flocculation, thin-layer settling, filtering through a layer of formed sediment. It also provides for the removal of floating impurities, oil film and oil products and the removal of gas through the corresponding pipelines in the separator housings.

Materials and Methods

To calculate the hydrodynamic parameters of the liquid flow in the installation, computer simulation was carried out in the ANSYS program [4, 5, 7-10, 18, 19], which makes it possible to obtain streamlines and pressure lines, velocity vectors in 3D format with their values.

Models of fluid flow through the installation were built for laminar and turbulent regimes (Fig. 4, 5).

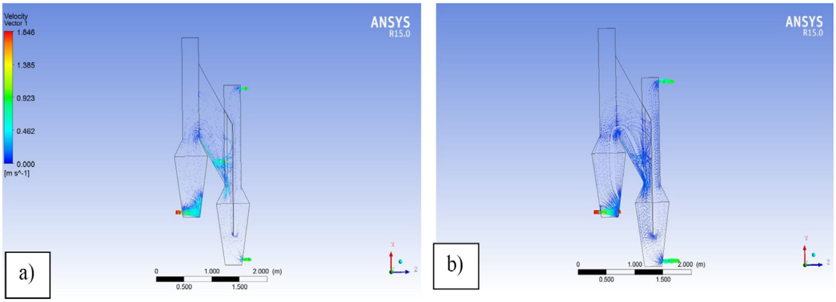


Fig. 4. Velocity vectors of liquid movement in the phase separator

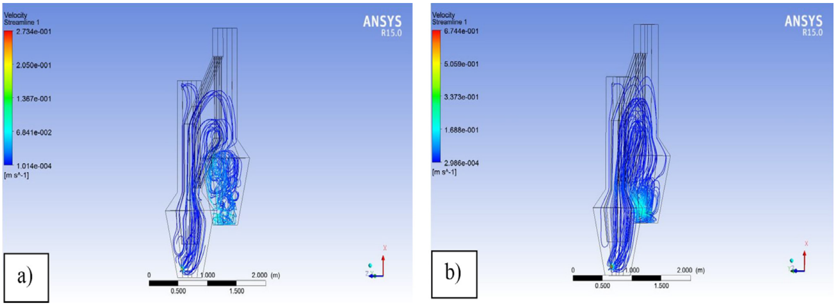


Fig. 5. Distribution of streamlines in the phase separator: a) laminar regime of fluid movement (Q=0.0005 m^3/s); b) turbulent mode of fluid movement (Q= 0.0015 m^3/s)

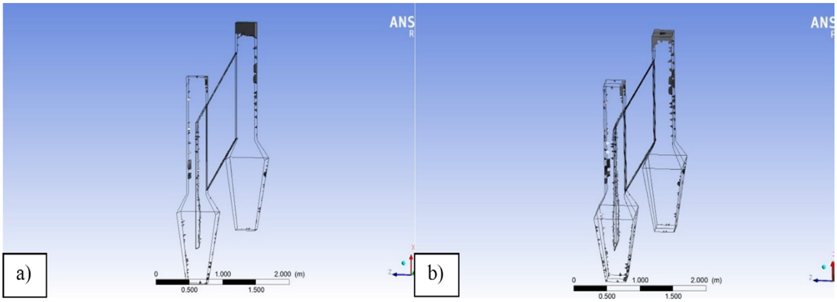


Fig. 6. Distribution of stagnant zones under a) laminar and b) turbulent modes of fluid movement in a phase separation unit

The volume of stagnant zones in laminar and turbulent modes was determined: 0.00892699 m^3 and 0.00411956 m^3 (Fig. 6) with a total installation volume of 1.15 m^3. As a result, the coefficient of volumetric utilization in laminar and turbulent modes was calculated, which is equal to 0.96 and 0.99, respectively.

Results

To implement the trouble-free operation of the phase separator, visualization of the technological process, completeness and objectivity of the displayed parameters at each stage of wastewater treatment, an automated control system (ACS) has been developed [6, 13].

The automation system is designed for automatic control of wastewater supply, removal of sludge, oil products and floating substances separated during the cleaning process, automatic washing of thin-layer modules after a specified time interval, as well as indication of the process and physical and chemical parameters on the operator panel.

Structurally, the automation system is built on the basis of PLC 200-04 CS (“Oven”). All pipelines are controlled by controlled valves, which ensures smooth opening and closing to avoid water hammer. The status of all cranes is controlled by the automated control system and displayed on the operator panel. The installation locations of the cranes are shown in fig. 7 and listed in table 2.

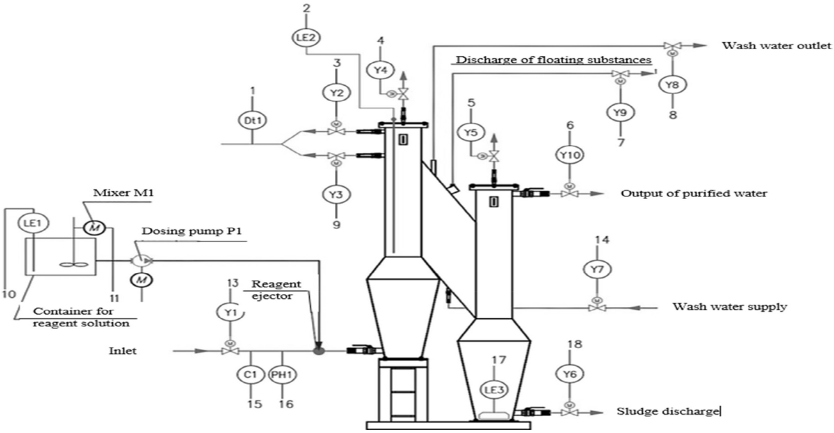


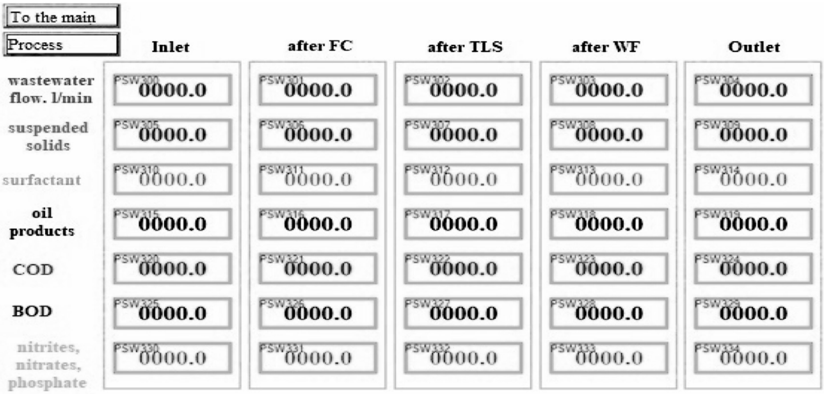
Fig. 7. Functional diagram of the automation of the dispersion phase separator: Y1…Y10 Valve BAV-S304-2P-T-015 with actuator ELA-DT-30-230VAC-P; LE1 Level sensor DU.3-1; LE2 Level sensor PDU-I.1000.10 (Aries); LE3 Sludge level sensor SUF-5; C1 Flow meter VLF-U(I)15(3/4)-1.5-110; PH1 Sludge level sensor SUF-5; Dt1 Oil sensor CF360 sc + SC200; M1 Stirrer in reagent bottle; P1 Dispenser EVO APG 500

Table 2.

Installation locations of controlled valves on the pipelines of the phase separator

		1 Concentration of oil products	2 Liquid level in column 1	3 Removal of oil products in pressure mode	4 Gas removal from column 1	5 Gas removal from column 2	6 Removal of purified water	7 Discharge of floating substances	8 Wash water outlet	9 Removal of oil products in non-pressure mode	10 Reagent tank level	11 Agitator in reagent tank	12 Reagent dispenser	13 Inlet gate valve	14 Water supply for washing	15 Input stream counter	16 Ph measurement	17 Sludge level sensor	18 Sludge discharge
Automation cabinet	485	*																	
	AI		*														*		
	AO												*						
	DI			*2	*2	*2	*2	*2			*2			*2	*2	*		*	*2
	DO			*2	*2	*2	*2	*2				*	*	*2	*2		*		*2

Connection to the system of devices for monitoring the physical and chemical parameters of the process at the following points is provided: inlet pipeline, outlet pipeline, after the flocculation chamber (FC), after the thin-layer settling zone (TLS), after clarification in the weighed filter (WF). On the operator panel, a separate page is provided for this (Fig. 8). All devices are connected to the system via RS-485 interface.



	Inlet	after FC	after TLS	after WF	Outlet
wastewater flow. l/min	PSW300 0000.0	PSW301 0000.0	PSW302 0000.0	PSW303 0000.0	PSW304 0000.0
suspended solids	PSW305 0000.0	PSW306 0000.0	PSW307 0000.0	PSW308 0000.0	PSW309 0000.0
surfactant	PSW310 0000.0	PSW311 0000.0	PSW312 0000.0	PSW313 0000.0	PSW314 0000.0
oil products	PSW315 0000.0	PSW316 0000.0	PSW317 0000.0	PSW318 0000.0	PSW319 0000.0
COD	PSW320 0000.0	PSW321 0000.0	PSW322 0000.0	PSW323 0000.0	PSW324 0000.0
BOD	PSW325 0000.0	PSW326 0000.0	PSW327 0000.0	PSW328 0000.0	PSW329 0000.0
nitrites, nitrates, phosphate	PSW330 0000.0	PSW331 0000.0	PSW332 0000.0	PSW333 0000.0	PSW334 0000.0

Fig. 8. The page for monitoring physical and chemical parameters on the operator panel

The efficiency of the separation of contaminants in different phase-dispersed states on the developed separator was tested on the industrial wastewater of some industrial enterprises: a machine-building plant, a milk plant and an agricultural machinery car wash station (Table 2).

Table 2.

Efficiency of wastewater treatment at the dispersion phase separator

Pollution indicators	Types of treated wastewater		
	Machine building plant	Dairy plant	Car wash station
suspended solids	65%	88%	75%
BOD5	60%	60%	50%
COD	60%	60%	50%
Fats	-	35%	-
Phosphates	-	50%	95%
Oil products	71%	-	90%
Ammonia nitrogen	-	-	86%
surfactant	60%	70%	65%
Metals (Fe^{3+}, Zn^{2+}, Cu^{2+}, Al^{3+})	40%	-	-

Discussion

The data obtained with the help of computer simulation are very close to the experimental data, which leads to the conclusion that it is possible to use computer simulation using the ANSYS program to determine the volume utilization factor in design.

With the help of the developed automated control system for the operation of the phase separator, all pipelines are controlled by smoothly opening and closing taps to avoid water hammer, pH is monitored and automatically adjusted by adding alkali with an installed dispenser, the volume and rate of input flow is controlled by a pulse counter, continuous monitoring is performed sludge level by optical sensor. Also, after a specified time, floating substances and oil products are automatically discharged through the corresponding pipelines of the installation. In order to be able to adjust the wastewater treatment mode by the technologist, the main pollutants are monitored in the plant: suspended solids, oil products, surfactants, COD, BOD, nitrites, nitrates, phosphates at the main stages of wastewater treatment in the separator.

After analyzing the results obtained for the treatment of industrial wastewater at the dispersion phase separator, it can be concluded that the developed plant can be used industrially and the plant can be recommended for implementation at wastewater treatment plants as a pre-treatment of IWW at the stage of new construction or reconstruction / re-technologicalization of existing treatment facilities.

Conclusions

To develop a technological scheme for the treatment of industrial wastewater, the need to determine treatment methods using an extended classification of phase-dispersed states of pollutants has been identified.

As part of solving the problems of research on the intensification of industrial wastewater treatment, a phase separator of dispersions is proposed. The efficiency of wastewater treatment of some industrial enterprises at the developed installation has been confirmed.

The possibility of using computer simulation in the ANSYS program for the calculation of the hydrodynamic parameters of the liquid flow in the dispersion phase separator (velocity, pressure and volume utilization factor) is revealed.

An automated control system for the process of industrial wastewater treatment at the dispersion phase separator has been developed in order to ensure its trouble-free operation, visualization of the technological process, completeness and objectivity of the displayed parameters at each stage of wastewater treatment.

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