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Influence of the Properties and Concentration of Pollutants in Wastewater on the Choice of Methods and Technologies of Industrial Water Treatment: A Systematic Review

Evgeniy Neverov*, Alena Gorelkina, Igor Korotkiy, Roman Skhaplok

Abstract

This paper focuses on industrial water treatment, namely modern methods and technologies of pollution removal. The paper discusses the main problems associated with industrial wastewater pollution and describes the most effective purification methods and technologies used in modern industrial processes. Information is provided that allows for a comprehensive and accurate study of modern methods and technologies of industrial water treatment, including a detailed analysis and assessment of the advantages and disadvantages of each of these methods. Authors conducted a literature review for collecting relevant biochemical and molecular approaches to industrial wastewater treatment. Relevant reviews and research papers were selected for detailed analysis. The authors have described each method and provided examples of its application and effectiveness in removing certain types of contaminants. The results of the study indicate that there are many methods and technologies for water purification, but not every method is suitable for all pollution types. The paper contains new data and practical recommendations that can be used by specialists in the field of water treatment to reduce the negative impact on the environment.

Introduction

In the modern world, industry plays a key role in economic development, but it also often becomes a source of pollution of the environment and water resources. The issue of industrial water pollution has become urgent and is under the close attention of researchers around the world. One of the most effective ways to combat water pollution is through water purification. Industrial water treatment is the process of removing contaminants and impurities from the water that is used in industry.

The purpose of this work is to consider modern methods and technologies for removing contaminants in industrial water treatment.

To achieve this goal, the following tasks were set:

- To study the main sources of industrial wastewater pollution.
- To consider the existing methods and technologies of pollution removal in industrial water treatment, their advantages and disadvantages.
- To describe the principles of operation of modern methods and technologies for pollution removal, such as membrane technologies and such methods as flotation, deposition, oxidation, and biological purification.
- To study examples of successful implementation of modern pollution removal methods and technologies in industrial water treatment at industrial facilities.
- To analyze the effectiveness and economic feasibility of using modern pollution removal methods and technologies in industrial water treatment.

Control and regulation of wastewater treatment processes are carried out under regulatory legal acts, including Decree No. 728 of the Government of the Russian Federation dated May 22, 2020 "On Approval of the Rules for Monitoring the Composition and Properties of Wastewater and on Amendments and Invalidation of Certain Acts of the Government of the Russian Federation". These norms define standard indicators for the general properties of the discharged water and the concentration of pollutants. To comply with these rules, all enterprises and organizations must perform an analysis of wastewater that ensures control of treatment processes. To ensure effective analysis, it is necessary to use special equipment and technological complexes [1].

The new rules for the control of the composition and properties of wastewater approved by the last resolution note a significant difference from the previous rules, consisting in the absence of separation of enterprises into categories "with VAT" and "without VAT". Previously, the control was carried out under a special program based on Rules No. 525, which included a list of enterprises for whom standards of permissible discharges into the centralized wastewater disposal system were established. Currently, the composition and properties of wastewater discharged by all enterprises into the sewer system are monitored without division into categories.

The new Rules No. 728 do not require the development and coordination of a program for monitoring the composition and properties of wastewater for enterprises that dump them into the sewage system. This means that there are no VAT requirements for such enterprises. Instead, the mandatory criteria for wastewater compliance are the actual indicators of composition and properties reflected in the Declaration, and/or the standards of composition and properties of wastewater defined by the Rules of Cold Water Supply and Disposal approved by Decree No. 644 of the Government of the Russian Federation dated 29.07.2013.

Thus, new requirements for parallel sampling and visual inspection have been established for the central water supply system (CWSS) customers. The old Rules No. 525 have been completely abolished, as well as the rules for charging fees for the discharge of wastewater and pollutants into the sewage systems of settlements have been abolished. As a result, there have been significant changes in the Rules of Cold Water Supply and Disposal [2,3].

Before studying water treatment methods, the definition of wastewater and various types of wastewater should be considered.

Methods

Literature search and selection criteria

The study methodology is aimed at providing a clear and systematic approach to the collection, analysis, and synthesis of information related to biochemical and molecular approaches to industrial wastewater treatment.

We conducted a literature review for collecting relevant biochemical and molecular approaches to industrial wastewater treatment. The search was conducted in databases such as PubMed, Scopus, and Web of Science using relevant keywords, including "industrial wastewater treatment", "biochemical methods", "molecular biology", and "biodegradation". The search was limited to papers published in English over the past 10 years. Relevant reviews and research papers were selected for detailed analysis.

Data on the effectiveness, limitations, and potential applications of various methods were collected and

analyzed. The collected data were tabulated and summarized to identify trends, similarities, and differences between different approaches.

Discussion

Wastewater types

Effluents (wastewater) are waters that enter the natural environment from various sources, such as industrial facilities and settlements, through sewage systems or naturally. The characteristics of these solutions depend on the features of the technological process in which they were formed, and, as a rule, harm the environment with which they interact [4].

Based on their composition, wastewater can be divided into three categories (Figure 1).

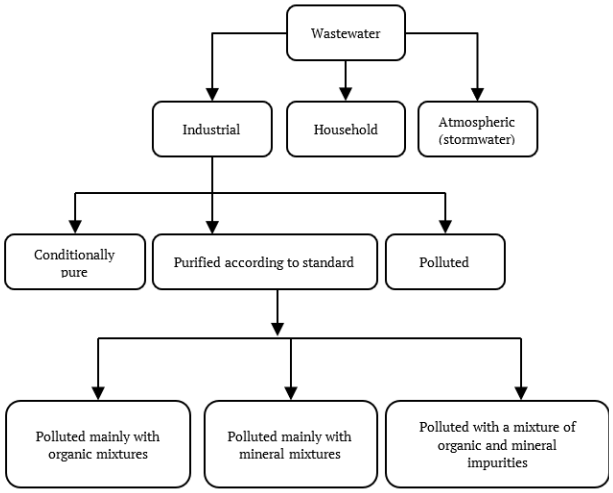

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Figure 1: Wastewater types

Wastewater generated in the production process is one of the most common types of wastewater. It may enter the sewage system of an enterprise unevenly depending on the technological processes and have different levels of pollution. Wastewater can be conditionally pure, purified according to standards, or heavily polluted, depending on whether it has undergone purification procedures and what level of pollution was initially present. The composition of industrial wastewater may include organic and mineral impurities. Depending on the type of pollution, the degree of pollution, and the specifics of the production process, various wastewater treatment methods can be used. These methods may include mechanical, physicochemical, chemical, and biological purification processes [5-8].

Household wastewater is one of the types of wastewater that is characterized by a relatively uniform flow. It is considered highly polluted and contains organic substances of plant and animal origin, as well as waste products and detergents. By the type of pollution, household wastewater contains mechanical and biological impurities. Various methods can be used to treat this type of wastewater, including mechanical, biological, physicochemical, and other technologies.

Atmospheric wastewater, or stormwater, is heterogeneous in its characteristics. Its flow to the treatment facilities is uneven and depends on the amount of precipitation. As a rule, such wastewater has a conditionally pure composition but may contain various contaminants, including minerals and petroleum products. Stormwater treatment methods include mechanical, physico-mechanical, and chemical methods. Mechanical methods are used to remove solid particles and other mechanical impurities. Physico-mechanical methods include filtration, coagulation, and flocculation, which allow the removal of various chemical impurities. Chemical methods, such as oxidation, are used to remove contaminants, such as petroleum products [5].

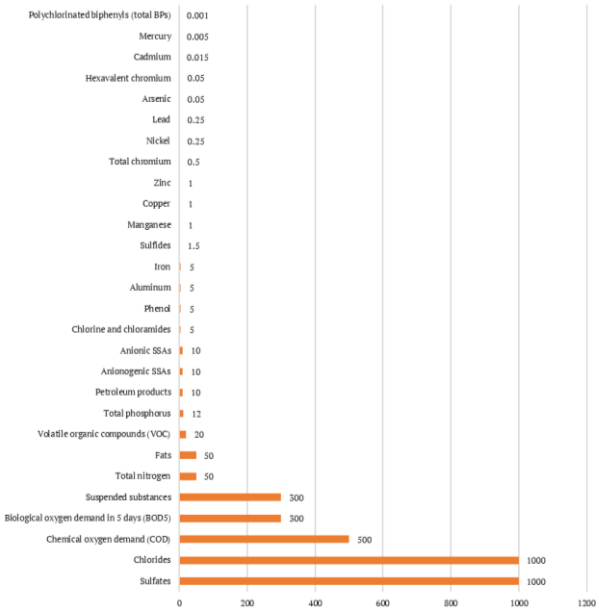
The effect on the amount, composition, and concentration of contaminants in the water is determined by several factors, including the type of industrial activity, the nature of technological processes, the composition of raw materials used, the type of products produced, the properties of the source water, and the modes of production processes. The assessment of these factors can help in determining the most effective methods of wastewater treatment and will allow enterprises to comply with pollution standards and maintain environmental sustainability [9]. In the wastewater of various industries, the concentration of contaminants can vary significantly, and it can also vary within the enterprise both in different divisions and individual technological processes. The range of contaminant concentrations can range from a few milligrams to tens of grams per liter of water. Complex multi-component mixtures that are difficult to remove are formed in industrial water. As an illustrative example, we can present a table with the composition of discharges from various enterprises (Table 1). Decree No. 644 of the Government of the Russian Federation dated 29.07.2013 determined the maximum permissible concentrations (MPC) of harmful substances for wastewater coming out of industrial enterprises, the excess of which is prohibited.

The discharge of liquid industrial waste is prohibited if it contains substances for which the MPCs have not been established. In addition, it is prohibited to exceed the established standards for the volume of wastewater discharge and its discharge in places not provided for this, as well as in adjacent territories of treatment facilities. In case of exceeding the MPC of contaminants in wastewater discharged by the enterprise, its work may be suspended for a period of up to 90 days [11].

Classification of wastewater from various enterprises	
Metallurgical industry	Mineral impurities, dust, dirt, sand, slag, oils, heavy metals, acids
Pulp and paper industry	Fiber, selenium, chlorine, sulfur dioxide, turpentine
Machine-building industry	Petroleum products, phenols, suspended solids
Oil refining industry	Petroleum products, sulfates, suspended solids, chlorides
Poultry farms and meat processing plants	Nitrogen, phosphorus, potassium, viruses, and bacteria
Fishing industry	Fats, vegetable oils, proteins, minerals
Oil industry	Hydrogen sulfide, paraffin, ammonia, mercaptans, sulfides, phenols, petroleum products, mineral salts, ammonium nitrogen
Plastic production	Phenols, plasticizers
Mining and processing industry	Heavy metals, acids, organic solvents
Coal industry	Suspended solids (coal dust and particles of related rocks), petroleum products in the form of mineral oils
Textile industry	Mineral and organic impurities, reagents, detergents, fibers, and suspended solids
Canned food production	Suspended solids, ammonium nitrogen chlorides, sulfates, ether-soluble substances, phosphorus
Sugar and starch production	Nitrogen, potassium, calcium, and phosphorus
Dairy industry	Milk whey

Source: Complied by authors based on the [10]
Table 1: Classification of industrial wastewater released from various enterprises.

If an enterprise is forced to discharge polluted water, then individual norms of maximum permissible discharge (MPD) are established for it, based on the quality of water in the source of discharge and considering the volume of discharge (Figure 2).



Source: Compiled by authors based on the [11]
Figure 2: Maximal permissible values of the standard indicators of the general wastewater features and contaminant concentrations in wastewater, mg/dm^3.

Household wastewater is a result of people's activities in the household sphere, including the use of water for hygienic purposes, washing dishes, washing clothes, cleaning rooms, and other household needs. Another source of such discharge is a sewer drain. Household wastewater contains various pollutants, such as organic and inorganic substances, microorganisms, suspended and dissolved particles, and also some impurities, such as oils and fats, pesticides, and other chemical compounds that require special treatment before they are released into the environment. The discharge of household wastewater without preliminary treatment can lead to pollution of natural reservoirs and soil, which has negative consequences for human health and the environment as a whole [12,13].

Household wastewater is considered highly polluted because it contains a large number of microorganisms (more than a hundred different types). This type of pollution is usually associated with animal or plant waste. Due to the presence of pathogenic microorganisms that can cause diseases, household wastewater is dangerous from an epidemiological point of view. In this regard, its neutralization and removal are monitored. To ensure the safety of the disposal of household wastewater, there are regulatory indicators that are controlled by microbiological and parasitological analyses of wastewater. There are methodological guidelines (MU)2.1.5.800-99 "Organization of state sanitary and epidemiological supervision of wastewater disinfection. Methodological guidelines", which contain several standards aimed at ensuring safety in the treatment and disposal of household wastewater. Atmospheric wastewater or stormwater is water that is collected as a result of precipitation, such as rain, snow, or hail. It may contain contaminants that accumulate on the earth's surface, such as petroleum products, salts, metals, and other toxic substances [14]. From stormwater, dangerous streams can form, which can cause serious damage to the environment, as well as people and animals.

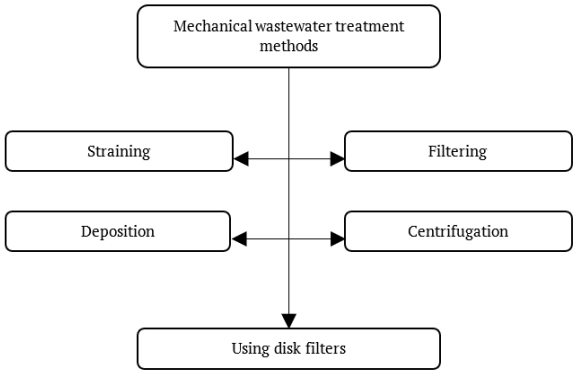
To solve this problem, it is necessary to properly collect, clean and dispose of atmospheric wastewater. It is usually collected in storm sewers and then sent to sewage treatment plants to remove contaminants. This may include the use of filters, aeration, and other purification methods that help remove impurities from the water and reduce its harmful effects on the environment.

The pollution of surface runoff is influenced by the following factors [15]:

- Traffic intensity,
- Frequency of street cleaning,
- The level of organization of public services and amenities,
- Population density,
- Type of surface cover,
- Presence of industrial enterprises,

- The amount of emissions into the atmosphere.

After studying the characteristics and variations of wastewater, we will consider the methods used for its purification. As a rule, the first stage of wastewater treatment is mechanical treatment, which is carried out to remove coarse contaminant particles larger than 0.1 mm. However, mechanical purification can be used as an independent method if the purified water is involved in technological production processes or does not have a harmful effect when discharged into reservoirs [16]. The classification of mechanical purification methods is based on various physical properties and the level of concentration of contaminant particles. These methods are aimed at removing insoluble particles that can settle or are suspended. However, mechanical purification is one of the primitive methods and may not be effective enough to completely purify wastewater from all contaminants [17]. There is a classification of mechanical purification methods by type (Figure 3). Straining, filtering, and deposition procedures are simpler mechanical purification methods, while the use of disk filters and centrifugation are more complex methods. The features of the described methods are given in Table 2. Mechanical purification cannot always provide sufficient purification quality, especially in cases with a high level of contamination. In such cases, the chemical and physicochemical methods purification methods shown in Figure 4 are used.

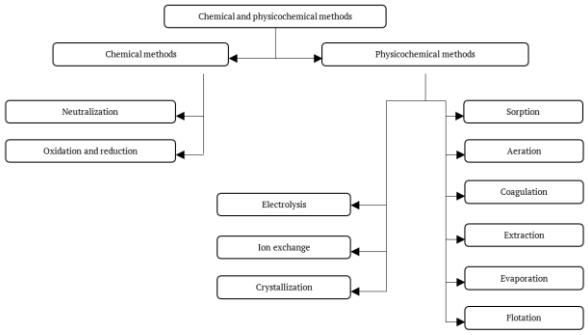


Source: complied by authors based on the [15].
Figure 3: Methods of mechanical wastewater treatment.

Sorption is the process of absorption of one substance in the surface layer of another substance called a sorbent. The sorbent can be solid, liquid, or gaseous, and the sorbate can be any substance dissolved in a gaseous, liquid, or solid medium. The sorption process occurs due to the attraction of sorbate molecules to the surface of the sorbent. This attraction can be caused by various mechanisms, such as Van der Waals forces, ion-dipole interaction, the interaction of hydrophobic groups, chemical bonds, and others. During sorption, the sorbate is absorbed on the surface of the sorbent and can form a layer or film on its surface. After saturation of the sorbent, the sorption process may stop, which makes it unsuitable for further use [19].

Mechanical purification method	Method characteristics
Straining	Effluents are filtered through grids (usually made of metal) with a predetermined cell size to retain mechanical particles (e.g., stones, plastic bottles) and biological residues (such as branches or leaves) of the appropriate cell size.
Filtering	The water purification process involves passing through partitions filled with backfill or porous material that stop the dispersed phase.
Deposition	This method is based on the use of gravitational force, which leads to the deposition of polluting particles at the bottom of the settling tank or reservoir. In this case, the top layer of purified water is poured into the next chamber, leaving the contaminants in the first chamber. This process is repeated in subsequent chambers, which makes it possible to achieve a higher degree of wastewater treatment.
Disk filters	These are small devices that include several polymer disks placed in cylindrical housing.
Centrifugation (hydrocyclones)	The method is based on the principle of separation of solid particles in a liquid stream that rotates at high speed.

Source: Compiled by authors based on the [18]
Table 2: Characteristics of mechanical wastewater treatment methods.



Source: Compiled by authors
Figure 4: Chemical and physicochemical methods of wastewater treatment.

Extraction is a method of mechanical purification based on the solubility of certain pollutants in a liquid that does not mix with wastewater. To carry out the extraction, a liquid such as hexane is added to the wastewater, which picks up impurities. The removal of this liquid from wastewater leads to a decrease in the contamination of effluents. This method is effective for removing phenols and fatty acids [19]. The aeration method is a purification process where contaminants are oxidized to transfer volatile components such as hydrogen sulfide and other sulfides, as well as surfactants (SAs), into a gaseous phase for their subsequent removal from wastewater. In the flotation method, wastewater is purified by saturating it with the smallest air bubbles, which attach to polluting particles

such as petroleum products, fats, and fibers, and rise to the surface where they can be removed.

Coagulation is a method of wastewater treatment based on the use of coagulants (iron sulfate, iron hydrosulfate, iron chloride, aluminum sulfate, sodium aluminate), which lead to the formation of gel-like flakes of iron and aluminum hydroxides. These flakes bind to colloidal suspended particles in the wastewater, which then settle to the bottom. To speed up the coagulation process, flocculants such as polyacrylamide or activated silicic acid are used, which increase the size of the flakes and make them more durable. Active sludge can be used to remove organic impurities; this process is called bio coagulation.

The ion exchange method is also used, which is based on the interaction of ions in wastewater with ions located on the surface of ionite (a solid material). This process removes valuable impurities, including metal ions (zinc, chromium, copper, lead, mercury), phosphoric and arsenic compounds, surfactants, and radioactive substances [20]. In the evaporation method, the impurities are extracted by co-entrainment with circulating steam. The contaminated steam is then mixed with an alkali solution to further isolate the contaminants. This method is used to remove volatile substances. Crystallization is a purification method based on the formation of crystalline phases from solutions, melts, or gases. For this process, a change in the temperature of polluted water is used, which creates supersaturated solutions of pollutants, which then pass into crystals [21,22].

Electrolysis is a method of water purification based on the use of electrochemical processes. It involves passing an electric current through contaminated water, in which organic substances are oxidized at the anode, and acids, alkalis, and metals are reduced at the cathode. In the process of electrolysis, the electrolytic decomposition of water into oxygen and hydrogen occurs, which also contributes to water purification. This method is effective for removing various contaminants, including heavy metals, organic substances, and radioactive substances. However, its use requires high voltage and power [23]. Chemical water purification consists of the use of reagents that form chemical compounds with pollutants in water or bind them into insoluble complexes, which makes them safe for the environment. Such processes occur quickly and evenly in the volume of liquid, which makes this method of water purification effective. Chemical water purification is important in enterprises where water is reused and it is necessary to neutralize industrial effluents [24].

Chemical treatment types

The neutralization method involves regulating the acid-base balance by conducting a neutralization reaction between acid and alkali with the formation of salts. This makes it possible to optimize the process to achieve the required level of acidity and alkalinity in the solution [25].

Oxidation is the mechanism of changing the chemical structure of the target substances due to the action of the oxidizing properties of chlorine and its compounds. As a result of oxidation, toxic organic substances change and turn into less harmful ones. Besides, pathogenic microorganisms are destroyed.

The reduction method involves the transformation of oxidized forms of toxic substances into a molecular state, which allows their further processing using various methods of water purification, such as coagulation, flotation, deposition, and binding on filters. This is achieved by introducing substances capable of reducing toxic elements into more neutral forms with less toxicity and easier removal from wastewater.

In recent decades, more and more attention has been paid to biological methods of water purification, which are based on the use of living organisms, such as microorganisms and plants, for the disposal of pollutants in water. These methods are widely used in various fields, from wastewater treatment to ecosystem restoration in natural reservoirs.

For classification of bio-purification structures (stations), they are divided into two main categories [26]:

- Natural or specially created conditions of biological stations. Purification is slow due to the availability of oxygen in the water and additional sources of nutrition for microorganisms, such as the water of biological ponds and soil.
- Treatment facilities that are controlled artificially to purify water (for example, aero tanks and biological filters). In such installations, special conditions are created that accelerate the process of biological purification.

Characteristics of wastewater discharge in the oil refining industry

Oily wastewater can become a serious source of long-term pollution of water systems. The hydrocarbons and organic acids contained in oil form a film on the water surface that interferes with the gas exchange between water and the atmosphere, which can lead to oxygen deficiency and the death of aquatic organisms [18,27].

To regulate the quality and composition of wastewater occurring at oil refining facilities, there are regulatory documents that establish MPCs of

petroleum products, as well as mineral and organic compounds [28,29]. Oil refineries use complex wastewater treatment, which involves the extraction of not only petroleum products. The various stages are presented in Table 3.

Purification stage	Method group	Removed contaminants	Methods/ equipment
1	Mechanical purification	Coarse impurities and oil films	Oil traps, sand traps, hydrocyclones Additional settling tanks
2	Physicochemical purification	Colloidal and dissolved compounds	Flotation, adsorption, coagulation, and flocculation
3	Biochemical purification	Dissolved organic compounds	Aerotanks and settling tanks
4	Disinfection	Pathogenic organisms	Ozonation, ultraviolet disinfection

Source: Compiled by authors

Table 3: Characteristics of mechanical wastewater treatment methods

Characteristics of wastewater discharge in the production of textile materials

Effluents produced at textile enterprises contain a significant amount of pollutants, such as dyes, reagents, impurities, heavy metal compounds, synthetic SAs (SSAs), fibers, and other harmful organic compounds. These pollutants can harm the environment and human health. Therefore, wastewater treatment from such contaminants is an important task for textile enterprises [30,31].

Textile enterprises use methods of mechanical, chemical, and biological purification to remove contaminants from wastewater. Depending on the nature of the production, mechanical and chemical purification can be used for both primary and final purification before discharge into water bodies.

Flotation treatment with preliminary chemical treatment of wastewater is used in the purification process. This makes it possible to isolate 90-95% of suspended solids, reduce biochemical oxygen consumption (BOC) by 20-50% and reduce the color of water by 50% or more [31].

Characteristics of wastewater from laundries and car washes

Laundries and car washes produce a large amount of wastewater that contains surfactants, including anionic SAs (ASAs) and SSAs (washing agents, detergents, bleaches), suspended solids (including emulsified dirt), hardness salts, dyes, petroleum products, mechanical particles, and fabric fibers. The concentration of contaminants in wastewater exceeds two to three times the level of pollution in urban sewage. Mixing wastewater from laundries and car washes with urban sewage leads to the appearance of persistent foaming, which complicates the work of sewage treatment plants and reduces the degree of purification of household wastewater. Technologies for purification of the effluents of car washes and laundries are selected considering the specifics of pollutants [18].

Characteristics of the wastewater treatment process on livestock and poultry farms

Agriculture uses about 30% of water resources for the supply of farms, irrigation of land, and other needs. However, agricultural wastewater contains dangerous chemical components in the amount of up to 10 g/l, as well as soil particles [32,33].

The composition of such wastewater includes both inorganic components and organic substances, such as fertilizers, pesticides, fungicides, herbicides, and insecticides, which can be toxic and even lethal. The waters diverted by livestock and poultry complexes are characterized by microbial and organic pollution, which requires microbiological and parasitological analysis.

To disinfect such wastewater, deposition is carried out beforehand with subsequent purification. Regulation of the water purification process implies compliance with MU 2.1.5.800-99 "Organization of state sanitary and epidemiological supervision of wastewater disinfection. Methodical guidelines".

Conclusion

There is a wide range of methods for wastewater treatment that are available to businesses and organizations. Wastewater treatment is an important step to maintain environmental sustainability and compliance with pollution regulations. Choosing the most effective purification methods is very important to prevent a negative impact on the environment.

However, the choice of the purification method should not be limited only to its effectiveness concerning specific contaminants One needs to consider the complexity of the wastewater compositions, the degree of sufficiency of the extraction of contaminants, and the possibility of recuperative extraction of valuable components. It is necessary to develop a wastewater treatment technology considering the individual characteristics of the enterprise, its location, and the characteristics of the water body which receives the wastewater.

Besides that, to ensure the efficiency and effective control of the purification process, it is necessary to regularly monitor indicators such as the level of pollution and the degree of purification, and regulate the purification processes depending on regulatory requirements and the maximum permissible load on ecosystems.

A rational approach to purification will minimize the negative impact on the environment without profound

changes in production processes and significant economic costs.

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Competing Interest

The authors declare that there is no conflict of interest.

Author Contributions

All authors worked together in the writing and final revision of the manuscript.

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