Study of the processes of Physico-chemical treatment of landfill leachate

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Abstract. The work proposes a method of purifying landfill leachate. The method is based on a combination of physicochemical and membrane methods of water purification with the extraction and removal of the main part of the sediment at the initial stage of the purification process. This approach allows reducing the load on the subsequent stages of purification, including reverse osmosis. The paper presents a technological scheme for landfill leachate treatment and sediment transfer to the solid phase. In the process of work, an experimental stand was created, and research was conducted on the treatment of landfill leachate. The results obtained indicate the effectiveness of the proposed method.

1. Introduction

As a rule, the full cycle technology of wastewater treatment of complex composition, such as landfill leachate, should include mechanical, physico-chemical and biochemical treatment. This is necessary to completely remove suspended, colloidal and dissolved organic and inorganic impurities from water. Depending on the properties of the source water and the requirements for the quality of purified water, the use of these methods or their combination when choosing a technological scheme is often different [1-3].

There are many technical solutions and technological schemes for landfill leachate purification [4-7]. Each of them has its advantages and disadvantages. Recently, a landfill leachate purification system based on reverse osmosis technology has become widespread in Russia [7]. The disadvantage of this technology for purification landfill leachate without proper preliminary preparation is high economic losses due to wear and frequent replacement of expensive reverse osmosis membranes. Moreover, the content of pollutants in the concentrate after reverse osmosis is several times higher than the values in the original leachate, which is also a big environmental problem.

When treating the landfill leachate, it is advisable to carry out a series of measures for preliminary water treatment, including the reagent treatment stage, which allows the conversion of most of the main pollutants into solid-phase sludge, thereby reducing the burden on subsequent stages of treatment. This can significantly increase the efficiency of further stages, including the reverse osmosis purification stage.

To carry out reagent processing and intensify the processes of coagulation and flocculation, it is necessary to take into account the individual characteristics, composition, and concentration of
pollutants, and to carry out the purification process it is necessary to achieve efficiency due to the correct choice of reagents and their dosages.

This work aims to develop a complex system for landfill leachate purification, containing a reagent and membrane purification stages, as well as to study the leachate purification processes, including the search for the most optimal reagents and their dosages. At the same time, special attention should be paid to the system for the utilization of sediments formed at almost all stages of leachate treatment.

2. The technological scheme of the experimental plant
The system of complex treatment of landfill leachate according to the proposed method is based on physico-chemical and membrane methods of purification and consists of the following stages:
1. Preliminary mechanical treatment of contaminated water from coarse impurities;
2. Reagent treatment with the extraction of most of the contaminants at the stage of clarification and flotation.
3. Ultrafiltration on tangential filters with the discharge of concentrate into the sludge treatment unit for dewatering;
4. Ultraviolet (UV) disinfection of purified water;
5. Demineralization by reverse osmosis (nanofiltration).
6. Collection and treatment of sediment of coagulated contaminants and concentrate from all stages of purification with their subsequent transfer to the solid phase.

In the course of work, the authors developed an experimental stand that includes the listed stages of purification. The basic technological scheme of the stand for leachate and sludge treatment is shown in figure 1.

![Figure 1. The basic technological scheme of the stand for leachate and sludge treatment; ST – strainer, CP1, CP2 – centrifugal pump, F1-F4 – flow meter, PG1-PG3 – pressure gauge, CV1-CV5 – check valve, PP1 - peristaltic pump, SC – sediment collector, FL – flotator, UF – ultrafiltration filter, UL – ultraviolet lamp, BV – ball valve, RO – reverse osmosis filter.](image-url)
Following the proposed method, the purification system works as follows. Using the drainage pump, the initial landfill leachate enters the wastewater receiving tank, where the coarse fraction of suspended solids is separated. This is followed by mechanical cleaning on the strainer ST, after which the leachate, with the help of the centrifugal pump CP1, enters the clarification stage (primary reagent treatment).

Reagent treatment of leachate involves the extraction of as much of the contaminants as possible by coagulation, sedimentation, and flotation of impurities to reduce the burden on subsequent stages of purification. In the clarification stage, the leachate is processed using iron-containing coagulants - chloride or iron (III) sulfate. The coagulant solution is introduced into the stream using a peristaltic pump PP1. The choice of these coagulants is justified by their high efficiency in the treatment of waters of complex composition, as well as a wide operating range of pH, at which coagulation is observed. They dissolve well in water and form large, rapidly precipitated flakes of iron (III) hydroxide.

After the initial reagent treatment, the coagulated suspension is fed to a sediment collector SC for filtration, where it is filtered through a bag filter of non-woven material to remove related impurities. At the same time, the sediment remains in the bag and, as it accumulates, is transported for disposal, and clarified water enters the bottom reservoir for subsequent reagent treatment.

After the initial reagent treatment with iron salts, the clarified leachate enters the flotation stage in the flotator FL, which consists of dosing devices for feeding reagents and mixing chambers. For the flotation extraction of dissolved components, a hybrid aluminum-silicon reagent [8] and activating additives, flocculants, are used. Water-soluble polymers can be used as reagents for flocculation treatment of the leachate. In the chamber for mixing reagents with treated water, if necessary, it is possible to implement a hydrodynamic cavitation regime and additional aeration using ejectors. This provides a lower dose of reagents and a higher degree of purification. The residence time of water in the flotator is 10 to 15 minutes. The flow of flotation concentrate, up to 5% of the original, together with the foam from the reaction chamber of the flotator enters the sediment collector SC for its dehydration and drainage. Purified water is pumped to the ultrafiltration filter UF, working on the principle of tangential filtration, using the CP2 centrifugal pump.

The ultrafiltration filter UF is designed to extract, formed as a result of reagent processing, coagulated suspension and its separation from the liquid phase. As a filter element, a membrane with a filtration fineness of 0.1-2 microns is used. The membrane is made by SHS technology of porous titanium carbide with a selective layer deposited. The filter has one inlet (source water) and two outlets (concentrate and filtrate). The principle of operation of the filter is as follows. Water under pressure (about 6 bar) enters through the inlet pipe into the gap between the filter housing and the filter element and is purified by passing through the pores of the filter element, and then through the outlet pipe leaves in the form of a filtrate. The amount of filtrate depends on the degree of contamination of the water. If the amount of filtrate is about 50% of the feedwater flow, then the pressure loss on the filter does not exceed 0.5 bar. This makes it possible to use the low-pressure reverse osmosis stage RO at the residual pressure. The various water contaminations are retained on the surface of the selective layer of the filter element, washed off by the concentrate through the outlet pipe of the concentrate and sent to the sediment collector SC.

After the ultrafiltration stage, the water is sent to the disinfection and demineralization stage. The disinfector is a UV sterilizer, which is a metal case inside which there is a bactericidal lamp. She, in turn, is placed in a protective quartz tube. Water interacts with a quartz tube, is treated with ultraviolet light and, accordingly, is disinfected. The disinfection stage is intended for additional purification of water from bacteria and organic compounds.

The stage of demineralization is intended for the final desalination and production of industrial water and, depending on the salt content of the initial leachate, may be a desalination system on reverse osmosis or nanofiltration membranes. After the demineralization stage, purified water (permeate) enters the storage tank or can be discharged into the city's sewage system or used for various technical needs, such as washing the road surface, wheels of vehicles, irrigating cultivated
areas, etc.). The concentrate enters the inlet of the ultrafiltration filter UF, providing recirculation of the flow.

The flotation concentrate flows and separated sediments from the flotator, as well as a concentrated stream from the ultrafiltration filter, enter the sediment collector SC. Processing of the obtained precipitates is carried out using a flocculant. The flocculant structures the sediment, allows it to be intensively compacted, to effectively give moisture during dehydration. This provides a comprehensive solution to the problem of processing landfill leachate and improving the environmental situation by reducing the burden on the environment.

The features of the proposed method of purification of leachate are:
- The ability to clean the leachate from various groups of contaminants, taking into account their complex and variable composition due to complex processing by various methods;
- The possibility of varying the composition and combination of purification stages depending on the properties and indicators of contaminated water and the quality requirements of the treated water;
- The ability to adjust the operating parameters taking into account temporary changes in the composition of effluents;
- The economic effect of water treatment before the reverse osmosis stage, due to the deep removal of impurities;
- Collection and dehydration of concentrates of pollutants and sediments with their transfer to the solid phase.

3. The results of the landfill leachate treatment

One of the tasks of experimental research was to find the most optimal coagulant for primary reagent treatment (clarification) of landfill leachate. As coagulants were used iron-containing coagulants – chloride, and iron (III) sulfate. The dosage of coagulants was varied from 0,225 to 2,25 g per liter of leachate.

Preliminary studies have shown that the flow rate of coagulant solutions should be on average 9 ml per liter of leachate. At this dosage, the greatest degree of clarification of the leachate and the most intense sedimentation is observed. Table 1 shows the research materials of the Yadrovo landfill leachate (Moscow, Russia) before and after treatment with iron-containing coagulants (1,35 g/l).

| Parameter                    | Yadrovo landfill leachate | The leachate after treatment with FeCl₃ | The leachate after treatment with Fe₂(SO₄)₃ |
|------------------------------|---------------------------|----------------------------------------|-------------------------------------------|
| Transmittance, %             | 2                         | 97                                     | 94                                        |
| COD, mg O₂/l                | 11970                     | 4104                                   | 1492                                      |
| Zinc, mg/l                  | 0,2                       | 0,08                                   | 0,06                                      |
| Chrome, mg/l                | 0,3                       | less than 0,01                         | less than 0,01                            |
| Total phosphorus, mg/l       | 20,07                     | 14,86                                  | 14,35                                     |
| Nitrates, mg/l              | 63                        | 16                                     | 28,5                                      |
| Nitrite, mg/l               | 15                        | 2                                      | 10                                        |
| Sulfates, mg/l              | 1050                      | 200                                    | 2100                                      |
| Chlorides, mg/l             | 1050                      | 1905                                   | 695                                       |

It has been established that during the reagent treatment of leachate with iron salts, pollution indicators are significantly reduced. This applies to both the COD value and the content of heavy
metals. It can be seen (Figure 2) that the treated filtrate achieves a high degree of clarification. The transmittance of the clarified fraction is 97 and 94 % for chloride and iron (III) sulfate, respectively (Table 1). In this regard, it was concluded that these coagulants can be successfully used at the stage of clarification (primary reagent treatment) of the leachate.

![Figure 2. The leachate after purification and before purification with FeCl₃ solution](image1)

![Figure 3. Precipitate after treating and drying](image2)

After selecting a reagent for the primary clarification of the leachate, studies were carried out to purify the Yadrovo landfill leachate at the developed experimental stand. The results of the Yadrovo landfill leachate before and after treatment at the experimental stand at various stages (reagent treatment, ultrafiltration and reverse osmosis) are presented in table 2. Iron chloride - FeCl₃ was used as a reagent for primary reagent treatment. The dose of leachate treatment with iron (III) chloride was 1,35 g/l. As a reagent for processing the leachate at the flotation stage, a hybrid aluminum-silicon reagent developed and patented by the authors, possessing the properties of both a floculant coagulant and a sorbent, was used. The effectiveness of this reagent in wastewater treatment was confirmed in [8, 9]. The reagent dose was 50 mg/l in terms of aluminum oxide.

![Table 2. The degree of purification of leachate.](table)

| Parameter                  | The degree of purification, % |
|----------------------------|--------------------------------|
|                            | Reagent treatment | Ultrafiltration | Reverse osmosis |
| COD                        | 85,0              | 91,5            | 99,9            |
| BOD₅                       | 80,0              | 88,5            | 99,8            |
| Organochlorine compounds   | 70,0              | 87,5            | 99,8            |
| Ammonia and ammonium salts | 40,5              | 85,0            | 99,7            |
| Phosphates                 | 55,2              | 96,5            | 99,9            |
As can be seen from table 2, after the stage of reagent treatment (clarification) and flotation, the COD and BOD$_5$ of the leachate are reduced by 85% and 80%, respectively. The content of organochlorine compounds, ammonium salts and phosphates is reduced by 70%, 40.5%, and 55.2%, respectively. The next stage of treatment - ultrafiltration, allows for post-treatment and to increase the degree of purification of the leachate by main pollutants to 85-96.5%. and reverse osmosis brings the degree of purification to more than 99%

Figure 3 shows the sludge that has been accumulated in the sediment collector. The precipitate was treated with a flocculant and dried within 16 hours.

The resulting precipitate is odorless, safe, and therefore can be deposited into the body of the landfill. This can significantly improve the environmental situation in the territory and near the landfill since the treated sludge does not pose a threat to the environment.

4. Conclusions

Studies have shown that when using iron-containing coagulants, it is possible to significantly reduce the initial color and turbidity of the leachate. In the subsequent flotation stage, it is possible to significantly reduce the concentrations of the main pollutants and the COD value up to 85%, which greatly facilitates the subsequent membrane post-treatment, including reverse osmosis. In this case, after reverse osmosis, the degree of purification of the filtrate according to the main indicators, such as COD, BOD$_5$, the content of organochlorine compounds, ammonia, and phosphates reaches values over 99%. The results obtained indicate the effectiveness of the proposed method for purification of landfill leachate. The proposed method provides highly efficient removal of organic and inorganic compounds, bacterial contaminants and the complete purification of landfill leachate water due to the integrated use and the optimal combination of physico-chemical and membrane processes. Processing and drying the sludge makes it safe for the environment. Thus, an integrated approach to purify leachate and utilize sludge is implemented.

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