Designing of local constructions for decontamination and leachate recirculation at municipal solid waste landfills

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Abstract. The article discusses the results of studies on the design of a system for managing the leachate at the municipal solid waste storage facility (MSW landfill) in 4 km southeast from Ketovo, Ketovsky district of the Kurgan region with the possibility of using the hydrobotanical method and recycling the leachate. The work was carried out within the framework of the research of the Perm State Agricultural Academy, Contract 15/13 and PNRPU Contract No. 2013/379, as well as the license agreement under the patent RF 2162059. The article describes the main stages of designing a system for handling the leachate at the designed MSW landfill. The dynamics of formation of leachate is shown and the forecast of changes in the amount of leachate for the period of the landfill operation is presented. Seasonal changes in the amount of leachate under different conditions in the Kurgan region are shown. The calculations were performed in the “Ecolog” program, which allows to determine the performance of local structures for clearance and recycling of the leachate of MSW.

1. Introduction

In small settlements there is a problem of utilization of municipal waste generated by population, which should be deposited in special sanitary facilities - landfills. A distinctive feature of such objects is its relatively small area, which is designed on the basis of the population, the projected growth in the increase of solid waste, and the expected life cycle (usually 15-20 years). The main problem in creating such objects is the formation of MSW (leachate and surface runoff), which must be compiled and cleaned [1]. The leachate is squeezing water that occurs due to the water loss of MSW under the influence of the pressure of the waste, as well as due to the penetration of water, precipitation, storm and melt water.

An important task is the realization of forecast models for the amount of leachate formed and the planning of sewage treatment plant of MSW effluents. The composition of MSW drains is formed under the influence of various factors, which, in turn, affect the composition of MSW effluents, contain high concentrations of organic and inorganic substances, including microbial communities [2].

The composition and concentration of inorganic and organic pollutants in the leachate are determined by the chemical composition of the stored waste, anaerobic and aerobic decomposition processes occurring in the thick of the waste, the permeability of the waste layer, the intensity of precipitation, temperature, etc. The source of contamination of the leachate is mainly the products of decomposition of food waste and metal oxidation. In a relatively warm and humid climate, changes in
leachate formation are directly related to precipitation. In colder climates, where most of the precipitation falls in the form of snow, there is a delay in increasing leachate volumes after precipitation.

2. Object and research methods
The object of the study was a designated land plot for construction of a solid waste landfill located 500m east from the gardens of the Internal Affairs Directorate, 500 m north-west from the ZHBI-2 gardens, 500 m north-west from the Kurgandorstroy gardens (figure 1) [3,4].

Figure 1. The layout of the land.

The MSW storage area (waste disposal facility) occupies the main landfill area and is divided into two phases of operation. In areas close to the square, there are two phases of operation of the designed landfill, each of which will average 1.4–1.5 hectares. Calculations showed that the area under the treatment plant at this facility, is respectively 550 m$^2$ and 910.2 m$^2$. The task of the first stage was the specified calculation of the areas of accumulative ponds and sewage treatment plant, with the introduction of recommendations on the location and the necessary areas of ponds-averagers.

The detailed tasks and the main content of the research work on the development of technology for handling the leachate at the first stage of the research were:

- Conduct theoretical research on the quantity and quality of wastewater generated at landfills in the conditions of the Kurgan region.
- To calculate the amount of formed leachate and the predicted composition of the leachate on an annual basis at the designed MSW landfill.
- Calculate the load on the treatment plant and performance.

In the course of research, the possible effects of objects on the environment were characterized, and the components of the environment were analyzed: climatic, hydrographic, hydrogeological, and geological and geomorphological conditions, soils, flora and fauna, and dangerous man-made processes. To characterize the current ecological state of natural environments, an analysis of previously performed geoecological tests and chemical and analytical studies of atmospheric air, groundwater and soil was carried out.

In the course of the work, topographic and thematic cartographic materials, literary and stock sources of information, Internet resources, the results of a full-scale survey of the territory, laboratory studies were used. Design work was performed using software systems AWS (Certificate of
3. The results of the study and their discussion

The project provides that the waste disposal plot (WDP) of the designed landfill will be divided into sections of WDP, each of which is planned for an average of 5–7 years and will be filled with waste according to a certain technology. After 2–3 years of exploitation, the section is overlapped with a layer of soil and the next section is filled. During this period, the waste of the first section when the waste is moistened, for example, using recycling technology, will be deposited (experience shows, on average, 1.5–2 m per year) [5] and section 1 is filled with waste, and then overlapped with the final soil layer. During the period of intermediate and final isolation of the section, the volume of leachate will significantly decrease, but the amount of surface runoff will increase. Calculations with the subsequent sections of the landfill are carried out the same way.

The amount of formed leachate will be affected by the amount of precipitation. The study area of the Kurgan region is characterized by climatic and geographical conditions, and particularly a temperate continental climate, characterized by a little snowy cold winter and a short but hot summer. The average annual precipitation is 381 mm. Climate formation and heat transfer conditions depend on the radiation factors: sunshine, total and absorbed radiation, effective radiation, radiation and heat balance. The number of hours of sunshine in the Kurgan region is 2150 per year. This indicator significantly varies during the year, the minimum it is in December. The radiation balance is 90 kcal/cm² per year, the highest values occur in the period from April to August.

The estimated size, type of overlap of the landfill sections and the dynamics of the formation of leachate, as well as the dynamics of the formation of leachate depending on size and type of overlapping sections are presented. When designing wastewater treatment plants, the main difficulty is forecasting the volume, quality of leachate and changes occurring with the “age” of the solid waste landfill. However, planning of leachate treatment facilities is necessary to implement simultaneously with the design of the landfill. In this regard, it is necessary to know the growth rate of the landfill, since the amount of leachate formed is directly related to the area of the landfill and the type of waste.

Leachate treatment facilities should be designed in a way that the biodegradation processes of organic substances proceed most fully. Therefore, it is offered to introduce the technology of recycling of leachate and measures to ensure the safety of the facility for the environment.

Each section of the designed MSW landfill will be calculated by filling for 6–7 years and filled with waste in accordance with the planning of the future territory with the final overlap of the soil layer before starting to fill the new section of the landfill. The calculations calculations performed by the designed MSW landfill showed that the average amount of leachate during operation of section 1 in the initial period will be 1440–1660 m³/year, and when entering 2 sections of the WDP (2 sections of the WDP at the same time) and the transition of the landfill leachate to the “old” one (after 8–10 years) this amount will reach 3,500–4,000 m³/year.

An important characteristic is also the surface runoff, which, according to the water balance equation, is actually excluded from the calculations. At a real landfill the entire surface runoff will be captured by highland ditches, and then sent to storage ponds, and thus the surface runoff affects both the storage pond capacity and the leachate composition (due to dilution).

In the first years of the landfill exploitation, the leachate will not actually form, and the accumulation of MSW drains at the landfill will be carried out due to precipitation and surface runoff. These drains will contain low concentrations of pollutants and will be virtually identical in composition to surface waters. Therefore, the first 2–3 years, the recycling of these effluents can be carried out without reagent treatment. During this period, it is necessary to carry out the construction of leachate treatment facilities. As the landfill site grows, the amount of leachate will increase and reach a maximum in the pre-cultivation period and then stabilize. It is offered to clean this amount of waste using the hydrobotanical method [1] and patent [6]. Figure 2 shows the dynamics of the expected amount of leachate and surface runoff at the projected landfill.
Practice shows that the performance of treatment plants averages 30% of the total annual amount of leachate [7]. Figure 3 shows that the average productivity of the cleaning equipment should be designed for 600 m³/month, and in the period of maximum formation of leachate, about 1350 m³/month. Therefore, taking into account the possible increase in the leachate volume, we will take the maximum leachate flow of 4000 m³/month. The calculations were carried out according to the “Ecolog” program [3] based on the monthly values of precipitation, the values of waste moisture, the area of the object (section) and the type of surface coverage of the exploited (reclaimed) section of the designed solid waste landfill. Based on the results, graphical dependencies are presented (figure 3).

**Figure 2.** Dynamics of the forecast formation of leachate and surface runoff at the projected MSW landfill, m³/year.

**Figure 3.** Change of the amount of leachate $Q_L$ in the conditions of the Kurgan region from sections of the WDP landfill, m³/month.
It is shown that due to low temperatures local structures for neutralizing the leachate during the period November-February will not function due to a slight release of the leachate. To collect this leachate, it is offered to use a storage pond (reservoir-averager). In dry summers, a decrease in leachate due to evaporation can be observed, which will reduce both the activity of microorganisms and the processes of biodegradation of waste, as well as this will contribute to the fire hazard of the object. Therefore, the wastewater accumulated in the pond-averager, must be periodically recycled through the array of MSW.

Purified leachate is allowed to descend in the direction of the existing liquid waste pond (see figure 1) in the autumn months or during the “big” water period (spring–autumn). The volume of solid waste can vary up to ±50% depending on the season. The average amount of leachate formed on the WDP of the landfill of 3 hectares, according to calculations will be about 2–3 thousand m³/year (max up to 4 thousand m³/year). Then, the annual volume of accumulated leachate in accumulative ponds-averagers, taking into account the shutdown of treatment facilities in the winter period, will amount to 0.75 thousand m³/year (max 1.2 thousand m³/year) at the designed landfill.

Based on the calculated amount of leachate by season (figure 4), the load on the treatment plant was calculated. When introducing (opening) two sections into operation, the quality of the leachate will change significantly. COD load, in general, will be 40% higher than the BOD₅ load during the acid stage, during the intermediate stage it will be 5 times higher and in the methane stage it will be about 10 times more. The nitrogen load is estimated in proportion to the hydraulic load, with the Nₜotal content will be almost constant for at least the first 10 years of the landfill exploitation and will reach 1000 mg/l. The expected nitrogen load based on the design hydraulic load of the N-NH₄ is 90% of the Nₜotal.

Increasing the leachate at the landfill will directly proportional to the increase in the area of waste storage and the introduction of new sections. During the operation of the landfill section, the BOD₅ indicator (on average for a young leachate BOD₅ =1500 mg/l) will decrease with time (up to 200 mg/l) due to the transition of processes to the methane phase and a decrease in organic pollution in the leachate. Based on these data, the load on COD, BOD₅ and N was calculated during the commissioning of two sections of the WDP (figure 4).

![Figure 4](image-url)

*Figure 4. Calculation of the load of wastewater treatment plants by year during the early recycling at the working section of the designed landfill.*
Changes in the load on BOD$_5$ (kg BOD$_5$/day), COD (kg COD/day), nitrogen (kg N/day), depending on the amount of $Q_l$ and the quality of leachate when introducing the early recirculation of the leachate, showed that while using recirculation technology of a pre-calcined leachate during the acid stage, the transition to the methane phase will occur in 2–3 years. A direct consequence of the irrigation of the landfill with pre-agitated leachate is an increase in the humidity and alkalinity of the environment, which affects the change in other parameters (parameters of COD, BOD, concentration of heavy metals, etc.).

4. Conclusions
1. Based on the obtained calculations and forecast models, given that the operation of the landfill will be carried out on 2 working sections, the loads are calculated in accordance with changes occurring in the chemical composition of the generated waste streams.

2. Since the conditions of the Kurgan region during the cold period, sewage treatment plant will not function, accumulation of leachate for six months (from October to March) in the buffer tank (storage pond-averager) has been offered. In this regard, the daily amount of leachate supplied to the sewage treatment plant will be affected by the amount of effluent generated on this day and the amount of leachate accumulated in the pond-averager.

3. It is shown that in the first years of the landfill exploitation (2–5 years), the entire drainage leachate will be in the acid stage and have high loads on BOD$_5$, COD, ammonium nitrogen, and heavy metal concentrations. In the next 5 years, the second working section of the landfill will be put into operation, while the leachate from the first section will be an “average” leachate, and acidic effluents (“young” leachate) will flow out of the other two sections, therefore a comprehensive cleaning of the leachate is proposed, including authoring, patents and software systems.

4. The offered technology using recycling reduces the “life cycle” (acid stage) of the landfill, reduces the concentration of pollutants in the leachate and, thus, minimizes the environmental damage caused by discharging contaminated organic compounds and heavy leachate metals.

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