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Environmental management modelling in the areas of waste landfilling

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Abstract. The article justifies the need to reduce the landfill impact zone of municipal solid waste (MSW) landfills by methods of rational design and effective management. The physicochemical characteristics of the waste and products of their biodegradation, as well as the choice of engineering structures of the MSW within the territory alienated for the construction of the MSW land, were selected as controlled factors. It is shown that the load and environmental impact of a high-loading landfill will extend over longer distances and over a longer time even after its recultivation, and this fact should be taken into account when predicting the zone of impact of such landfills to clarify and justify the size of the sanitary protection zone. In order to minimize air pollution from the MSW landfills on the border of the nearest territories to normalized indicators of habitat quality, a spatial-dynamic model for managing emissions from the MSW has been developed. The numerical calculation of the emission of impurities in the atmosphere was carried out using the AnsysWorkbench.

1. Introduction
Measures for managing processes at municipal solid waste (MSW) landfills [1] can lead to different results, so it is necessary to identify and take actions to reduce their negative impact on the population and environment at the design stage of the landfill. An effective measure is the removal of waste disposal facilities from the places of population residence. In this case, the distance will play a protective (buffer) role in relation to populated places. This method of reducing the environmental burden on the population can be considered the best now and in future. However, it is necessary to think about a more distant future in connection with the expansion of urban development.

2. Equipment and devices used in the studies
When justifying the methods and algorithms for controlling the MSW landfill, the methods of system analysis, the theory of automatic control, the methods of mathematical and simulation modelling were used.

3. The results of the study and their discussion

The technologies used in MSW disposal differ not only economically, but also with respect to the duration of the final return of biodegradation products to the natural biogeochemical cycle, as well as to the possible distance (volume) of the MSW landfill impact zone. The need for the earliest return of the land from the landfill impact zone into the efficient land release dictates the need to introduce technologies that ensure the least pollution of biosphere objects during the operational period of the MSW landfill and ensure the most rapid land restoration during its recultivation [2].

In order to choose the control method that is optimal for each specific case, it is necessary first of all to single out the factors that influence the final result. Secondly, from the general list of factors one need to choose those by controlling which one can achieve the best result and choose the technological, constructive and planning methods for managing the MSW landfill. In the task to reduce the impact of the MSW landfill on the environment in a specific given landscape, one should build on the existing climatic, hydrological, geomorphological, geological, biological and economic conditions and select technological and design solutions that are consistent with them.

Physicochemical characteristics such as humidity of waste entering the landfill, their morphological composition, density, particle size distribution, chemical composition of the filtrate and landfill gas, as well as the layout of MSW landfill facilities within the designated area can be distinguished as controlled factors.

According to the current version of Standards and Regulations [3], the estimated size of the sanitary protection zone (SPZ) for all solid household (municipal) waste landfills is 500 metres. However, the load and environmental impact of a high-loading landfill compared to less loaded ones will extend over longer distances and for a longer time even after its recultivation, although this fact has not yet been taken into account when justifying the SPZ at high-loading MSW landfills.

Previously, we determined the parameters of the facility for waste disposal and decontaminating [4], which have the most significant impact on air pollution at the border of the nearest territories with normalized indicators of environmental quality. For this, a set of options for waste disposal and decontaminating was considered, in which the impact of the object on the state of atmospheric air at the border of the nearest territories with normalized indicators of the quality of the habitat was minimal. On the basis of these studies, a mathematical model was developed to optimize the location of the object and decontaminate waste to the borders of the nearest territories with normalized indicators of habitat quality. The control mechanism of the landfill is to maintain the flow of pollutant emissions that do not exceed the MAC at the border of the sanitary protection zone (SPZ), and the physicochemical parameters of the array that affect the emissions studied earlier will act as control parameters. As a criterion for landfill management, it is proposed to use the indicator of the relative deviation of the pollutant emission flow:

$$\int_{t_0}^{t_k}\int_{x_0}^{x_k}\int_{y_0}^{y_k}\left|q(x,y,t)\right|\mathrm{d}x\mathrm{d}y\mathrm{d}t \to \min. \tag{1}$$

Management of the landfill with recurrent connections of the flow deviation $q(x,y,t)$ and pollution concentration $\rho(x,y,t)$ from the required mode is formalized by the system of equations [5], characterizing the state of the object in deviations from the specified mode and controlling the object with using velocity v or flow rate q of the emissions to atmosphere:

$$\begin{cases} \dfrac{\partial q}{\partial t} = -\dfrac{\partial \rho(x,y,t)}{\partial x} - \dfrac{\partial \rho(x,y,t)}{\partial y} + b(x,y,t) \\ v(x,y,t) = -k_1(x,y,\tau)\displaystyle\int_t q(x,y,t)dt \end{cases} \tag{2}$$

$$x_0 \le x \le x_k,\ y_0 \le y \le y_k,\ t \ge t_0,\ q(x_0,y_0,t) = q_0(t),$$
$$q(x_k,y_k,t) = q_k(t), \rho(x,y,t_0) = \rho_0(x,y),$$
$$\rho_x = vq_x, \rho_y = wq_y.$$

The description of the pollution dispersion in the atmosphere is based on the Euler's equation (conservation of mass) with allowance for perturbations b (x, y, t) caused by external and internal factors. When forming a model of the impact of a landfill on atmospheric air, it is assumed that the transport of pollutants in the atmosphere is carried out by wind winds taking into account their small-scale fluctuations. The averaged flux of substrates carried by air masses, as a rule, has advective and convective components, and the averaged fluctuation movements can be interpreted as diffusion against the background of the main averaged movement associated with it.

3.1. Analytical solution of the emission flow control problem

The impurity transfer will be mainly influenced by wind flows. If we assume that the wind speed in the direction of the *y* axis is $w = 0$, then the equation of motion in the particular case can be written in the following form (3):

$$\frac{\partial q}{\partial t} = -\frac{\partial \rho(x,t)}{\partial x} + b(x,t) \tag{3}$$

Small-scale fluctuations of air masses can be described as a disturbance $p(\xi,t)$.
Introducing the emission control function from the landfill $u(x,t)$, we will write the system of equations:

$$\begin{cases} \dfrac{\partial q}{\partial t} = -\dfrac{\partial \rho(x,t)}{\partial x} + b(x,\tau) \ \textit{object} \\ q(x,t) = -u(x,t) + p(\xi,t) \quad \textit{management} \end{cases} \tag{4}$$

We will describe the control function as a proportional controller $u(x,\ t)=k_1 q(x,\ t)\ +\ +k_2\rho(x,t)$, substituting the control function in (4) and separating the variables we will obtain:

$$\begin{cases} q_t'(1-k_1) + k_2 q_x' = -k_2 b + p_t', \\ \rho_t'(1-k_1) + k_2 \rho_x' = -(1-k_1)b + p_x'. \end{cases} \tag{5}$$

The system of equations (5) has an analytical solution with known initial and boundary conditions, which can be obtained on the basis of the Dirac impulse function [6]. Green function is a solution of the equation for the considered boundary value problem:

$$q(x,t) = \int_{t_0}^{t}\int_{x_0}^{x} G(x,\xi,t,\tau)\omega(\xi,\tau)d\xi d\tau \tag{6}$$

For system (5) of the value function *G* has the following form:

$$G(x,\xi,t) = \frac{1}{\beta}\exp\left[-\frac{\varphi}{\beta}(x-\xi)\right]\delta\left[t-\frac{\alpha}{\beta}(x-\xi)\right]1(x-\xi).$$

When using the polynomial δ-function form, while formalizing the disturbance function $p(\xi,t), b(x,\tau)$, the solution for controlling the emission flow of biogas *q* from fluctuations in the amount of contamination when reacting with the external environment $b(x,\tau)$ takes the following form:

$$q(x,t) = \frac{1}{\alpha}\int_{t_0}^{t}\frac{k_2\delta(\tau)}{\xi_1^2+1}d\tau.$$

The control of the biogas emission flow from fluctuations of air masses $p(\xi,t)$, is described by the equation:

$$q(x,t) = \frac{2t}{\sqrt{(\alpha x - \beta t)^2 + \alpha^2}} \cdot \mathrm{arctg}\,\frac{\alpha t}{\sqrt{(\alpha x - \beta t)^2 + \alpha^2}}$$

Thus, by controlling the emission flow of biogas, it is possible to regulate the maximum permissible concentration of pollutants at the boundary of the residential zone.

3.2. Simulation modelling of pollutant emissions

Investigating the meteorological characteristics of the landfill location area, the source data were determined for atmospheric pollution modelling: the average outdoor air temperature is 25.2º C, the coefficient depending on the temperature stratification of the atmosphere is 160.0. Coefficient of relief is 1.0. The threshold of calculation expediency for the contribution of emission sources of 0.01 MAC is set.

3.2.1. Numerical simulation. Modelling of the non-stationary simulation process was performed in ANSYS CFX-Pre (figure 1).

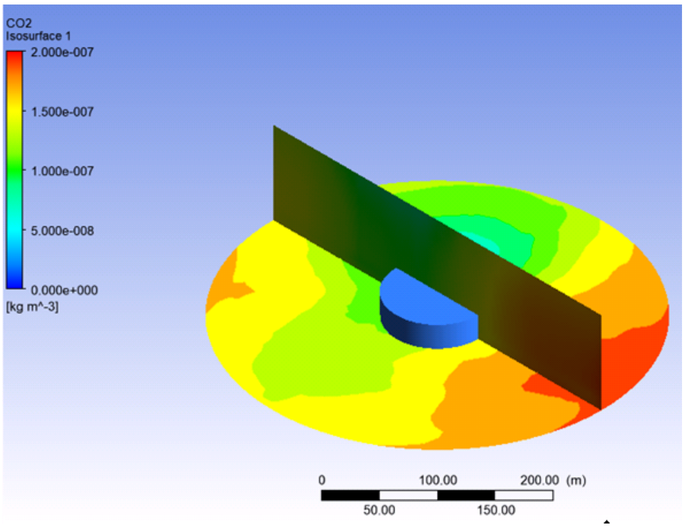

Figure 1. Isoparticle dispersion COX.

The results of numerical CO2 dispersion modelling showed that at the boundary of the atmosphere monitoring zone (250 m) the concentration of COX varies from 0.05 mg/m^3 to 0.2 mg/m^3 and does not exceed the MAC, the value of which is 5.0 mg/m^3.

3.2.2. The calculation of harmful substances contained in the emissions of enterprises according to the method of assessing the concentration in the atmospheric air. To make a comparison, the calculation of atmospheric pollution for the substance "Carbon oxide", carried out in accordance with [7], was fulfilled using a unified program for calculating atmospheric pollution UPRZA "ECO Centre". To calculate the pollution of the atmosphere, first of all, the maximum carbon monoxide emissions from all emission sources of the landfill at the time of its operation were determined: boiler house, internal combustion engines of vehicles and special equipment moving and working under load, waste storage sites. The coordinates of the emission sources on the map are determined. It is assumed that all sources operate simultaneously. 12 design points are set at a height of 2 meters above the ground at the border of the sanitary protection zone and the nearest places with normalized indicators of the quality of atmospheric air. In addition, a design site of 3,000 x 2,000 metres with a pitch of 100 metres is set (the total number of grid nodes is 651). Detailed calculations of carbon monoxide dispersion in the atmosphere are conducted. The situational map-scheme of the location of the enterprise with the applied isolines of the calculated concentrations, expressed in fractions of the MAC, on the settlement site is shown in scale 1:20,000 in figure 2. The values of surface concentrations at each calculated point in atmospheric air are the total maximum achievable concentrations corresponding to the most unfavourable meteorological conditions. The values of maximum concentrations at calculated points are shown in figure 2.

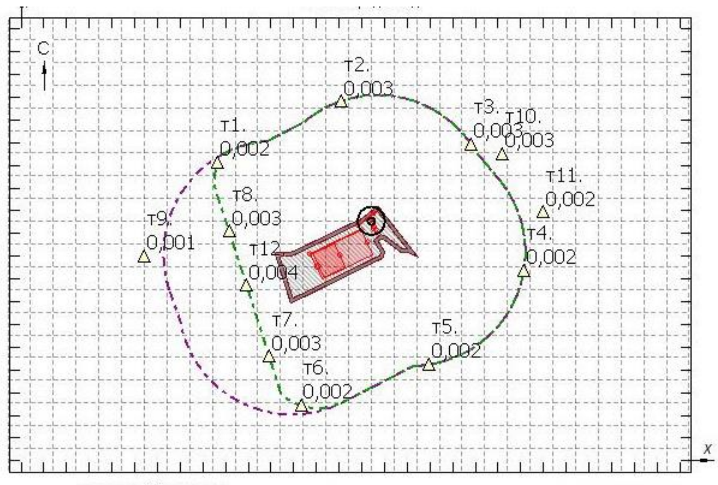

Figure 2. The map of the MSW landfill with the results of the carbon monoxide dispersion calculations.

3.2.3. Simulation result analysis. The results of the calculation showed that the concentration of carbon monoxide at the border of the sanitary protection zone and at the border of the nearest territories with normalized indicators of air quality will not exceed the standard hygienic criterion of 5 mg/m^3 and range from 0.001 to 0.004 MAC, or from 0.0073 to 0.02 mg/m^3. The results of numerical simulation showed a level of pollution from 0.05 mg/m^3 to 0.2 mg/m^3, which also meet the regulatory standards.

4. Conclusions

When determining the SPZ, it should be taken into account that, in accordance with the methodology [10], for emission sources of individual enterprises, zones of influence are calculated, including circles of a certain radius, conducted around each of the main emission sources (pipes or other sources) of an enterprise, and terrain areas where the total concentration of pollutant from the entire set of sources of this enterprise exceeds 0.05 of the maximum one-time maximum permissible concentration. Impact zones should be calculated for each pollutant (a group of pollutants of the combined harmful effect) separately.

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