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Automated Process Control of Sanitary Municipal Solid Waste Landfill

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Abstract: We have developed the algorithms for state of municipal solid waste (MSW) landfills control affected by different external factors to determine the dependence of statistical characteristics on their condition. To achieve our goals, the optimal parameters of biological destruction of wastes on MSW landfill were determined experimentally and theoretically. Identification of certain specific factors influencing the biodegradation of wastes allowed us to develop a model of efficient system management of MSW landfill. In order to make effective decisions on development of the safe system of MSW landfill, the special software, which includes a unit "automated work place (AWP) of assessment of MSW landfill safety," was designed to evaluate the safety both at the development stage and the stages of the operation and reclamation of MSW landfill.

Key words: Municipal solid waste · Automatic control system of technological process (ACSTP) · Sanitary landfill of municipal solid wastes

INTRODUCTION

Municipal solid waste landfills are the source of the long-term negative effects on the environment are solid domestic waste [1]. In the Russian Federation, landfill waste disposal technology is the main way of municipal solid waste disposal. Despite the fact that MSW landfills are limited by operating period (in average 30 years), the full life cycle of the natural and technical systems after their closure and reclamation continues for thousands of years with constant emission of environmentally hazardous products [2]. Therefore, the formalization of general models for management of MSW landfills based on the analysis of material, energy and information flows, as well as the development of algorithms for structural and parametric synthesis and automatic control, to create an automated system for monitoring and control of MSW landfills are relevant in present time. In present, the operational control of the landfill waste disposal in Russia is hardly used, what was the reason for the development of automated control system over MSW landfill [3].

Monitoring and analysis of the environmental condition of the MSW landfill, embodied in software and technical control solutions, ensure the operating control of the landfill processes. Integrated automated control system will significantly improve the quality of ground monitoring. The unit structure of the system will ensure the structural flexibility of structural implementation considering overall specific characteristics of the region with MSW landfill. Implementation of this software will ensure the information support for the entire life cycle of MSW landfill and increase efficiency of control and operation safety.

MATERIALS AND METHODS

The systems analysis method, general systems theory, automatic control theory and methods of mathematical and simulation modeling were used to substantiate the methods and algorithms of management of the waste disposal facilities. Material-energy and information flows which occur on the waste disposal landfills and considered as the simulation and control objects served as the present study objects.

RESULTS AND DISCUSSION

On a functional basis, the studied system was logically divided into five units represented by engineering, technology and management solutions in the life cycle of the MSW landfill. The engineering unit is to calculation of the basic parameters of the landfill including the dynamics of emission flows of leachate and biogas. Automated data processing unit (ADPU) is automated

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work place of landfill operator. ACSTP unit is to automated control of technological process on the landfill. The unit of simulation modeling and forecasting is to the computer simulation of processes. Unit of ecological and economic calculation is to technical and economic substantiation of the project implementation [4].

Functional System Specifications

Automated Development System of MSW Landfills: In present, numerous organizations develop the MSW landfills which aim to create the landfills, complying with the sanitary and environmental safety standards. However, there is no special software to achieve this. At the same time, numerous professionals have been involved into development of software programs that will help implement the goals, using the experience and the work of other organizations focused on this problem. The effect of uncertainty factors can be simplified due to special software of automated development of natural and technical systems. Efficiency improving of the software development of natural-technical systems of waste disposal using CAD is achieved due to the specific composition of the wastes, intensity of the biochemical processes occurring in waste massif and external factors in adaptation to specific environmental conditions.

Automated work place for engineer-developer of MSW landfill (AWP-MSW) has been developed using parametric modeling in AutoCAD. Design of MSW landfill begins from the task decomposition to the main informational flows. Allocate receive data for the design of the MSW landfill, including the order for the design and initial data, the rate of accumulation of waste climatogeographic conditions, etc. There is a data allocation for design of MSW landfill including the order for design and initial data, the standards of waste volume, climatic and geographical conditions and etc. Automated calculation of the following tasks: The following tasks were automated: determination of the MSW landfill volume based on the operational period; choice of technological system of the process control of MSW landfill based on specific features; automated processing of technical documentation; and automated processing of graphic documentation based on parametric programming.

To accomplish these tasks, a program for initial data processing (based on quantitative and geometrical parameters) entering the workplace of engineer-developer was developed. Next step is the development of detailed conceptual projects of MSW landfill using parametric design which begins with entering of initial data in to software interface. The results are used for landfill sectioning (Fig. 1).

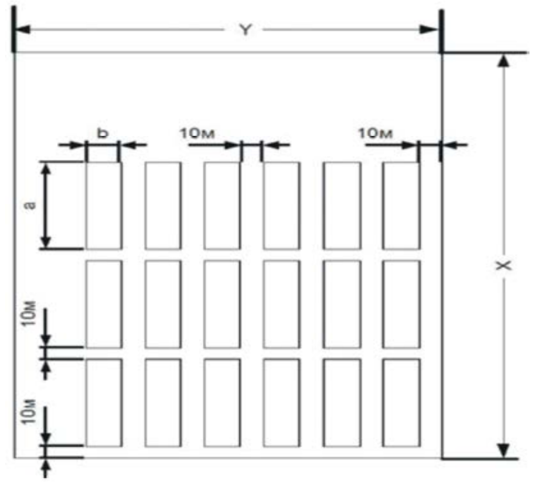

Fig. 1: Automated sectioning of landfill: X, Y - length and width of landfill; a, b - dimensions of a landfill section.

Implementation of the program allows: calculation of the geometric parameters of the MSW landfill based on operational requirements; choose technological system of automated control of MSW landfill based on the individual characteristics (climatic, geographical, hydrological, geological, etc.); automatize the development of technical and graphical documentation based on parametric programming.

Automated Information Processing System (AIPS): Automated information processing system (AIPS) is to control the waste utilization from industries to landfills, control of emissions of biogas and leachate from the MSW landfill, creation of the reports on availability of landfills and filling dynamics. The system consists of reference directory - the database on the morphological composition of the wastes, the characteristics of landfills and initial data of industries which dispose the wastes to the landfills. There are three types of reports: on landfills, industries and emissions. Reports on landfills allow the information control of the dynamics of landfill load and calculation of the available landfill volume as the difference between the incoming wastes and emissions of biodegradation products. Reports on the industries show the information about the wastes of the industries disposed on the landfill over certain time period. Reports on emissions indicate the data on the volumes of biogas and leachate on selected landfills over certain time period. Each report is preceded by settings window. For example, to create a report on the landfill, first, the landfill must be specified and after, the time period for graph construction. Each element of program can be launched from Menu and some of these, from the Quick Launch panel.

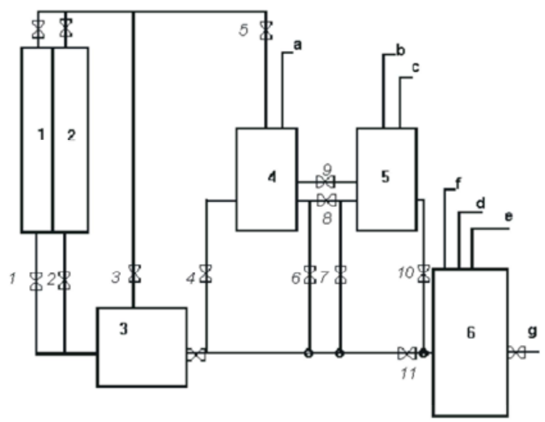

Fig. 2: Schematic diagram of MSW landfill: 1 - section with old wastes; 2 - section with new wastes; 3 - retention drainage; 4 - liming stage; 5 - coagulation- flocculation stage; 6 - hydrobotanical site (hydrobiological facilities). a - addition of lime milk; b - addition of coagulant (aluminum sulphate); c - addition of flocculat; f - water for dilution; d - addition of biogenic additives; e - addition of wastewater, enriched by organic components (in the case of mixture of the leachate with "old leachate"); g - release of treated wastewater into surface water sources. *1 ÷ 11* - taps.

Automated Supervisory Control System: Includes the following components: control of landfill sections using leachate recirculation; pH adjustment step; coagulation-flocculation step; and purification of leachate and surface drainages of MSW [5, 6].

Functional Diagram and Control Algorithm of the Landfill: Schematic diagram of the landfill is shown in Fig. 2. Waste storage at the overloaded landfill with square more 15 ha occurs in the separate sections (square, in average by 5 ha each) [7].

The leachate with low pH, high chemical and biological oxygen demand, releases over some time at the filling of first section (1). Releasing leachate is collected in a storage tank (3). At high concentrations of heavy metals and low pH, the leachate should be supplied to the liming stage (4) before recirculation. The abundance of leachate, one its part preliminary limed redirects to recirculation and another, to treatment facilities. Recirculation of the "new-formed" leachate from section (2) through the old waste section (1) without liming stage is possible during transition from acidic to methane stage, filling section (1) and the opening section (2). It is recommended to redirect a part of the "new-formed" leachate to recirculation through the liming stage and another part to the stage of biological purification (hydrobiological site) at the redirection of one section to acidic stage and second to methane. The advantage of the proposed scheme is the low costs of engineering facilities and applied reagents, which reduce the leachate pollution until maximum permissible concentrations.

Automated Diagram: Figure 3 shows the automated the MSW landfill. Temperature (indirect), humidity and environmental reaction are regulated on the landfill. Temperature control is realized by thermoelectric converters TCA-0179 (position 1 and 2a). The scheme also stipulates the control of active reaction (pH) of media, which characterizes the acidic or alkaline properties of aqueous solutions and determined by pH. Control of pH is carried out in points of leachate inflow after the landfill sections before and after the liming stage. The pH level at the neutralization (liming) stage is controlled by PM-C3 pH meter. This device is to monitor and control neutralization processes of circulating and waste water. The limits of pH are 2-10. The tool kit includes the sensor, the transmitter P-201, KSPZ device to formation of control signals to operating mechanism of batcher of lime milk supply and control of taps on the lines: supply of the leachate to plant biological purification and further, to the liming stage.

If leachate pH is below 9, the tap opens on the supply line of liming stage (position 4) and leachate fully inflows to liming. If pH > 9, the tap opens on the supply line of leachate to biological treatment. Thus, a part of leachate supplies to a biological treatment and another to recirculation. The scheme stipulates the automated flow control when: a) the leachate outflowing from MSW sections with old and new wastes (position 8 and position 9); and b) solution supplied to irrigation of section with wastes (position 7 and position 10). Choice of devices for flow control is based on the computer calculation of flow meter. As we have mentioned above, humidity of MSW is also controlled. If implementation of fixed devices for humidity control is difficult, it is proposed to use the humidity meter VZM-1 which usually used in laboratory and field conditions.

Mathematical Control Model of Landfill Sections: Several studies [8-10] are devoted to development of mathematical models of pollution biodegradation where numerical solutions of substance transport models were considered taking into account hydrochemical multi-component processes.

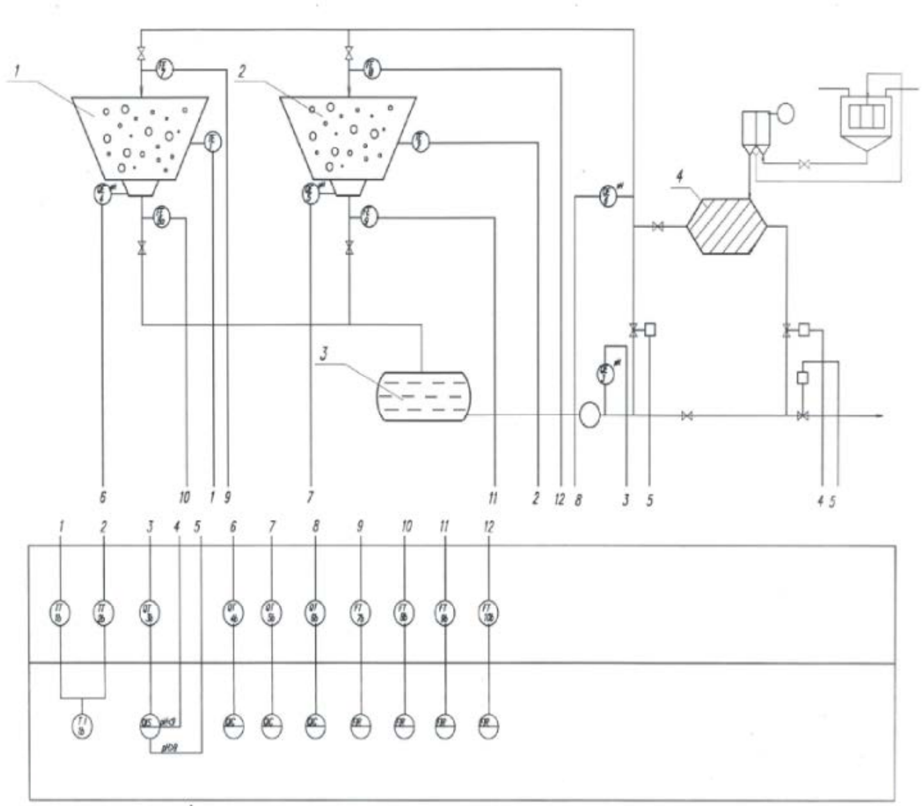

Fig. 3: Scheme of automated MSW landfill.

In present study, a model with distributed (space-time) parameters and deterministic disturbances [11, 12] was used as the mathematical control tool of landfill sections

$$\begin{cases} \dfrac{\partial c(x,t)}{\partial t} + \dfrac{\partial q(x,t)}{\partial x} = -b(x,t), \\ q(x,t) = u(x,t) + z(x,t). \end{cases} \tag{1}$$

where x - spatial coordinates (the depth of the landfill storage section); t - time; $c(x, t)$ - density of the material medium; q - material medium flow; $b(x, t)$ - agitations, related to the loss of material mass; $z(x, t)$ - function of humidity fluctuations due to internal processes without loss of material mass; $u(x, t)$ - control function; under conditions to variables: $x_0=x=x_k$; $t=t_0$, the following initial and boundary conditions: $c(x,t_0)=c_0(x)$; $q(x_0,t)=q_0(t)$; $q(x_k,t)=q_k(t)$.

The parameters of deviation of moisture concentration and the pH of environment on the landfill body from a stationary regime during entire control period were selected as quality indicators of a control:

$$\int_{t_0}^{t_k}\int_{x_0}^{x_k} \left|c(x,t)\right| dxdt \to \min_{u(x,t)}; \quad \int_{t_0}^{t_k}\int_{x_0}^{x_k} \left|q_{pH}(x,t)\right| dxdt \to \min_{u(x,t)}.$$

The simplest form of control function proportional relatively to the deviation variables $c(x, t)$ and $q(x, t)$ from stationary regime is as following:

$$u(x, t)=k_1 q(x, t) + k_2 c(x, t), \tag{2}$$

Using (1) and (2) and the method of separated variables, the following system of equations was obtained:

$$\begin{cases} q_t'(1-k_1) + k_2 q_x' = -k_2 b + z_t', \\ c_t'(1-k_1) + k_2 c_x' = -(1-k_1)b + z_x'. \end{cases} \tag{3}$$

Four variants of system solution were suggested by studying the effect of leakage of liquid substance $b(x, t)$ and fluctuation of liquid substance mass $z(x, t)$ in landfill massif on behavior of the model on state functions $q(x, t)$ and $c(x, t)$ settling the initial and boundary conditions equal to zero:

1) $q(x,t)=f_1(b(x,t))$; 2) $c(x,t)=f_2(b(x,t))$;
3) $q(x,t)=f_3(z(x,t))$; 4) $c(x,t)=f_4(z(x,t))$.

The analytical solution of the equation system (3) was obtained using the Green's function: 1 and 2 variants are the influence of liquid substance leakage $b(x,t)$ on the material medium at return couplings and proportional to $q(x,t)$ and $c(x,t)$:

$$q(x,t)=f_1(b(x,t)) \qquad q(x,t)=\frac{\alpha k_2}{(\alpha x-\beta t)^2+\alpha^2};$$

$$c(x,t)=f_2(b(x,t)) \qquad c(x,t)=\frac{\alpha(1-k_1)}{(\alpha x-\beta t)^2+\alpha^2}.$$

3 and 4 variants are the influence of fluctuations of the liquid substance at return couplings, proportional to $q(x,t)$ and $c(x,t)$:

$$q(x,t)=f_3(z(x,t))$$

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

$$c(x,t)=f_4(z(x,t))$$

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

These equations determine the character of changes in the concentration of the liquid state and intensity (variable) of the flow affected by a single agitation of physical or biochemical processes and the approximated by functions:

$$b(x,t)=\frac{\delta(t)}{x^2+1}, z(x,t)=\frac{\delta(x)}{t^2+1}.$$

Further, the model of material medium behavior on the landfill were studied taking into account the inclusion of the more complex dependencies from $q(x,t)$ and $c(x,t)$and derivatives and integrals into the law of a control (2). Thus, the task of control of MSW landfill sections, which is the monitoring and control of physical and chemical parameters of the landfill (humidity and pH) in the time-space aspect at the simulation of deterministic disturbances was designated.

Simulation modeling and forecasting system is designed to process simulation occurring on the landfill by calculation of final products of MSW chemical decomposition. The system includes the following modules: the calculation of the thermal fields; the calculation of the volume of leachate and biogas; forecasting of basic physical and chemical parameters of the landfill (the release volumes of leachate and biogas, pH of medium, temperature fields and concentration of heavy metals). The software allows the modeling of the morphological composition of the wastes, take into account the seasonal fluctuations and climatic features of the area.

Unit of ecological-economic calculation allows the calculation of environmental and economic efficiency of the system at different management costs with the choice of the most effective management option. The costs were calculated by two vectors: costs of active monitoring - $f(\omega)$; payment for loss due to implementation impact of crude leachate to sources hydrosphere - $f(t)$.

Experimental data in leachate pH changes caused by waste humidity: $f_{pH} = pH(t,\omega)$; dependence on gas volume release: $f_{bg} = q_{bg}(t,\omega)$ and amount of leachate on time: $f_l = q_l(t,\omega)$ were received in laboratory studies. Environmental-economic analysis conducted in our study has showed that the best economic efficiency is reached by the saturation of the wastes until 60-80% moisture by recirculation of preliminary limed what evidences the environmental and economic feasibility of implemented technology of recirculation of MSW landfill.

CONCLUSIONS

Monitoring and analysis of the ecological conditions of the MSW landfill, embodied in software and hardware management solutions, provide the operational control of the processes on certain landfill. Integrated automated control system of the landfill will significantly improve the quality of monitoring. Sectional structure of the system ensures the flexibility of structural implementation taking into account the individual features of a region of MSW landfill location. The implementation of this software will provide the informational support for the entire life cycle of MSW landfill and will increase the management efficiency and safety of its operation. Computer software of geoinformational modeling of natural-technical municipal waste disposal systems will maintain the functions of the geometric modeling and visualization of geometric objects of MSW landfill and its geometrical parameters, what can improve the efficiency of the development and operation of MSW landfills in specific climatic conditions.

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