EVALUATION OF CHEMICAL PROCESS PARAMETERS IN WASTE DISPOSAL SITES BY SATELLITE IMAGES

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Abstract. The presented paper proposes a method for estimating parameters and characteristics of the chemical processes in large municipal landfills and solid waste disposal sites according to the waste monitoring from space. The model of chemical transformations in the waste disposal sites is described based on the idea of waste biochemical degradation in the form of the "transformations tree". The presentation of chemical transformations in the form of statistical integrated chemical equations allows us to describe the chemical system "a waste disposal facility" in the analytical form. The paper presents the main types of physical (volume and mass, thermal) and chemical (filtrate) characteristics which assessment could be made by data from satellite images. As an example the obtaining of the volume and mass characteristics of landfills in their 3D-models is described. Results of the algorithm on the example of a polygon of solid municipal and industrial waste in Salaryevo (Leninsky district of the Moscow region) are presented. As an example the assessment of volume and mass of landfill gas and its main component – methane is shown. An airborne image from year 2000 is compared with the satellite images in visible spectral range closed to its date. The main sources of errors in the evaluation of volume and mass characteristics are defined. The error which source is the spatial and spectral resolution of the satellite image is calculated.

Keywords: waste disposal facility, landfills, satellite images, chemical processes, chemical parameters, 3D-model

INTRODUCTION

In terms of biochemical processes dump is a chemically dangerous and one of the most complex objects, so complex that many chemical conversion and reaction products still remain a mystery. Solid waste landfill (SWL), especially municipal solid waste landfills (MSWLF), solid domestic waste (SDW) and industrial wastes (IW) are generators of extremely hazardous chemicals, such as dioxins and furans [1-4].

A common process for all SWLs is the formation of the three matter fractions: liquid – filtrate and filtration drains, gaseous - biogas, landfill gas, and solid - the landfill soil humus. Weather conditions, particularly thermal radiation and rainfall, activate multiple chemical mechanisms and processes in a dumping landfill body, producing liquid, gaseous and solid (complex) compounds [5-9].

MATERIALS

In [10] a comprehensive chemical analysis of SWL as a result of long-term and labor-intensive studies of various garbage dumps and landfills is described. On the basis of field and laboratory methods and compilation of statistical data we obtained classification types of chemical reactions and chemical substances, general laws of chemical processes in landfills and migration of substances in the dump body and beyond.

The stage (phase) of waste degradation is a condition characterized by the ratio of the

concentrations of indicator substances in the biogas and filtrate drain in the landfill which is in the current time (see Figure 1). Evolution of the dump passes in one direction: toward the decomposition of complex substances to simpler, oxygen consumption, complexation and humification, infiltration of volatile substances through the surface in the composition of biogas washing agents with weak association through filtrate, etc.[11-13]. The process of biochemical degradation of waste in a landfill is unidirectional [14], in spite of the numerous branches of this main direction of evolution, constituting a deviation from the mean. In this regard, the material [10] is reduced to the analytical model of chemical transformations on SWL. In the Figure 2 a model of chemical transformations tree whose branches are elementary chemical transformations is shown. In the Figure 2: QC - carboxylic acids; LCD - fatty acids; a / b - a substance or b; a, b - a substance and b; I - aerobic stage, II-IV - anaerobic stage (II - phase atsetogenesis, III - the phase of active methanogenesis, IV - phase of stable methanogenesis), V - stage of humification. For each chemical conversion by methods of mathematical chemistry [15] the statistical integral equation in the form can be calculated [17]:

$$\sum_{i=1}^m x_i A_i = \sum_{j=1}^n y_j B_j \quad (1)$$

where x_i - stochastic integral ratios of reactants,
 $A_i = \bigcup_{k=1}^l a_k(r_{ki})$, y_j - products $B_j = \bigcup_{k=1}^l b_k(s_{kj})$ (a_k
 and r_{ki} - chemical element, and the number of atoms
 of that element in the composition of compound A_i ,
 b_k and s_{kj} - B_j connection) or in matrix form:

$$R \cdot x = S \cdot y \Rightarrow K \cdot z = 0, K = [-R \ S], z = \begin{bmatrix} x \\ y \end{bmatrix} \quad (2)$$

$$x = [x_1 \ x_2 \ \dots \ x_m]^T, y = [y_1 \ y_2 \ \dots \ y_n]^T,$$

$$R = [r_{ki}]_{l \times m}, S = [s_{kj}]_{l \times n}$$

Fig. 1. Changes in the concentrations of substances in the composition of indicators, biogas, depending on the time evolution of the landfill

Fig. 2. Basic mechanisms of reaction in the landfills

Related elementary transformations in the composition of the tree are bound by common substances. When connecting one of the previous conversion products is one of the following reagents, in parallel - one of the products (reactants) converting one coincides with one of the products (reactants) of the other. Common substances correspond to z_1 independent solutions of the fundamental system of solutions of the homogeneous equation (2), the mass of which are given or derived from previous changes. M molar mass m and common substances:

$$M = E \cdot K, \quad m_i = \Delta m_i + q \cdot M_i, \quad q = \min_i \frac{m_i}{M_i},$$

$$E = [E_1 \ E_2 \ \dots \ E_l], \quad M = [M_1 \ M_2 \ \dots \ M_{m+n}]$$

where q - equimolar amount of a chemical substance conversion have - atomic weight - weight of the i -

substance is not entered into the transformation reaction.

Equation (1) is a statistical, because substance A_i and B_j have a probabilistic nature, defining entire classes of chemicals. In this connection, the elements of R and S matrices are given by the statistical characteristics: expectation, standard deviation, correlation coefficients, initial and central moments.

ALGORITHM

Methods of space monitoring [18-21] enables to score a variety of chemical processes associated with the signs, which are reflected on the surface of the ground in the area of warehousing and in the vicinity: surface temperature, soil types and formations of fluid (Table 1).

Table 1. Basic physical and chemical parameters and characteristics of SWL and IW polygons

Type	Parameters
Volume and mass characteristics	The volume and weight of components and biogas, volume of the solid element clusters and landfill space and time, the density of matter, process parameters (compression ratio, shrinkage, etc.)
Thermal performances	The amount of heat generated, the stage and stages of degradation, the intensity of biochemical processes, thermal conductivity, heat balance
Features of the filtrate	Water balance, filter coefficients and velocity of spectra landfill filtrate and soil, types of chemical reactions, the chemical composition and the soil components

Let us describe the preparation of certain body-mass characteristics of SWLs. For this purpose, radar images and statistical data on the chemical processes in landfills (biogas composition, the filtrate, they change depending on the stage, etc.), are derived from the normative-technical documentation or research [22].

Decomposition of 1 m^3 of solid waste provides 1.5 m^3 of biogas, i.e. [22], $V_z = 1.5 \cdot V_{swl}$, V_{swl} - the volume of solid waste, V_g - limiting the amount of biogas from the decomposition of V_{swl} volume m^3 of SWL. Volume ratio of the main components of biogas:

$$V_{zi} = k_{zi} \cdot V_z, \quad \sum_{i=1}^l k_{zi} = 1, \quad \sum_{i=1}^l V_{zi} = V_z, \quad (3)$$

$$V_{zi}(t) = k_{zi}(t) \cdot V_z, \quad \sum_{i=1}^l k_{zi}(t) = 1, \quad (4)$$

$$\sum_{i=1}^l V_{zi}(t) = V_z(t), \quad t = \text{const}$$

l - number of basic components, $l = 5$: methane (1), carbon dioxide (2), nitrogen (3), oxygen (4), hydrogen (5); k_{zi} - the share component of the gas. In the case of (3) the coefficients k_{ri} is permanent and can be taken for a typical composition of the landfill gas: CH_4 - 0.474, CO_2 - 0.47, N_2 - 0.037, O_2 - 0.0008, H_2 - 0.0001, H_2S - 0.00001, CO - 0.0001, paraffin carbohydrates - 0.0001, aromatic carbohydrates - 0.0002, trace components - 0.0005. In the case of (4) k_{ri} change in chronological time t [year] from stage to stage in the slow change in the concentration ratio of the components (see Fig.1).

The volume of landfill element: $V(x, y) = k \cdot M(x, y)$, $k = k_1 k_2 k_3$, where $V(x, y)$

- the volume of a cuboid formed by the P area $k_1 k_2$ [m^2], k_1 and k_2 - the spatial resolution of the high-rise image length and width, k_3 - coefficient of transformation of COS in the physical units of height [m], $M(x, y)$ - COS pixel (x, y) stereometric picture.

The volume V of the dump body on the field U :

$$V = \int_{(x,y) \in U} V(x,y) dx dy.$$

Displacement V_{swl} evaluated in terms of the corresponding element $V(x, y)$ or the whole body V landfill:

$$V_{swl}(x, y) = k' \cdot V(x, y), \quad V_{swl} = k' \cdot V$$

where the coefficient k' accounts for the ratio of the thicknesses of alternating insulating layers of soil and waste. This ratio may be considered waste and soil compacting, shrinkage ratio (by technological impact on surface and the impact on the depth of precipitation), and the final coating layer (nominal thickness of 2.5 m). One can put a $k' = 1$ (nominally [23] $k' = 7/8$: 2 m 0.25 m borne waste soil).

Own waste density ρ'_{swl} spread on the storage map without sealing could be taken as the constant. In view of the seal ρ_{swl} waste density in the body of the landfill (landfill soil) $\rho_{swl} = k'' \rho'_{swl}$ where $k'' = 1-4$ - compression ratio. On the other hand, you can set $\rho_{swl} = \rho_{\pi}$ - soil density, set time. In this case the landfill ground is modeled as a homogeneous throughout. Then the mass of solid waste:

$$m_{swl} = \rho_{swl} \cdot V_{swl}$$

The change in volume over time, that is the influx of new waste, can be found in space or aerial stereo images of high spatial (given k_1, k_2) and radiometric (given k_3) permission for the corresponding width of the time interval $\Delta t = t_2 - t_1$, $t_2 > t_1$ - moments of the shooting time. Spatial and temporal changes in the body and MSW in time:

$$\Delta V(x, y) = V(x, y, t_2) - V(x, y, t_1),$$

$$\Delta V = V(t_2) - V(t_1)$$

$$\Delta V_{swl}(x, y) = V_{swl}(x, y, t_2) - V_{swl}(x, y, t_1),$$

$$\Delta V_{swl} = V_{swl}(t_2) - V_{swl}(t_1)$$

According to body - mass characteristics one can assess compliance with certain provisions of the legal regime of landfill operation. In particular, waste treatment income is estimated as a series $\{\Delta V_{swl}\}$ of successive time intervals. Hence its difference from the nominal number of waste receipts evaluates violations in the amount of waste taken over the operation of the project and through a license agreement. Considering the density of component ρ_{ri} biogas constant, its quantitative composition in biogas over a long period of time (e.g. one year): $\Delta m_{ei} = \rho_{ei} \cdot \Delta V_e$, ΔV_e - the volume of gas released from the landfill for a period of time (at nominal or actual receipt of waste, estimated from space or aerial photographs).

RESULTS

We show assessment of biogas yield and methane in the landfill Salaryevo example (Fig.3). In airborne image data volume of SWLs for 2000 gives: $V = 1.12 \cdot 10^7 m^3$. Spatial resolution: length k_1 and k_2 width - 60 m, height k_3 - 1 m. Then the error of amount estimation: $\varepsilon \sim L k_1 k_2 k_3 \approx 4.1 \cdot 10^5 m^3$ ($L = 113$ - the number of pixels of the object on airborne image).

Total volume V_r of biogas produced by the landfill for the time of its activity (as well as volumes of any other components of biogas) is the constant of the landfill and is calculated based on the maximum volume V , which it takes to the final point in time of its operation. In 2000 the volume of $V_{wsl} \sim k' V = V$ waste ($k' = 1$), the total amount of biogas produced from a given amount of: $V_e = 1.5V \sim (2.52 \pm 0.062) \cdot 10^7 m^3$.

Fig. 3. Landfill Salaryevo: (a) a visible image (Google Earth, summer 1998); (b) the radar image (SRTM project, Winter, 2000); (c) 3D-model

Volumes of the main components of landfill gas can be taken on the basis of its average composition.

For example, assuming that the composition consists of 60% methane biogas [10], i.e. $k_{gi} = 0.6$, $i = 1$,

we obtain the average volume of methane output $V_{gl} = 1.512 \cdot 10^7 \text{ m}^3$. Assuming that the density of methane $\rho_{gl} = 0.72 \text{ kg / m}^3$, its mass: $m_{gl} = \rho_{gl} \cdot V_{gl} \sim 10886 \text{ t}$.

CONCLUSIONS

The design of a model of chemical transformations of matter on large landfills, together with the proposed method of assessment of chemical parameters of SWL by space images enables to assess the danger of biochemical degradation of the waste caused by the municipal landfills. The signs of hazardous chemical processes are often reflected on the surface. In particular, the filtrate of SWLs as a result of chemical transformations, being submitted to the surface, stores information about the main types of occurring chemical reactions. The comparison between in-situ (sampling and chemical analysis of the filtrate) and satellite data (spectral brightness curves of filtrate) and carrying out a regression analysis will reveal bandwidth (high intensity places spectral characteristics) of various fractions of matter, thus evaluating the contents of the substances on the satellite images of the filtrate.

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ОЦЕНКА НА ПАРАМЕТРИ НА ХИМИЧНИ ПРОЦЕСИ В ОБЕКТИ ЗА СЪХРАНЕНИЕ НА ОТПАДЪЦИ ПО САТЕЛИТНИ ИЗОБРАЖЕНИЯ

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Резюме. В настоящата работа се предлага методика за оценка на параметрите и характеристиките на химичните процеси в големи общински сметища и в обекти за съхранение на твърди отпадъци като се използват данни от дистанционен мониторинг на Земята. Описан е модел на химични преобразувания на веществата в местата за изхвърляне на отпадъци, който се основава на идеята за биохимичното разграждане на отпадъците и е показан под формата на "трансформационно дърво". Представянето на химичните трансформации под формата на статистически интегрирани химични уравнения ни позволява да опишем химичната система "съоръжение за обезвреждане на отпадъците" в аналитична форма. Работата включва основните физични (обем и маса, топлинна) и химични (филтрат) характеристики, чиито оценки могат да бъдат направени по данни от сателитни изображения. Като пример е описано получаването на обема и масата на сметището по неговия 3D-модел. Представени са резултатите от приложението на алгоритъма за района за съхранение на твърди битови и промишлени отпадъци в Саларево (Ленински район, Московска област). Като пример е приведена оценка на обема и масата на газа в сметището и на неговата основна съставка - метан. Аероснимка от 2000 година е сравнена със сателитни изображения във видимия спектрален диапазон от близки дати. Определени са основните източници на грешки при оценката на характеристиките обем и маса. Изчислена е грешката вследствие на ограничената пространствена и спектрална разделителна способност на използваните спътникови изображения.

Ключови думи: обектите за съхранение на отпадъци, сметища, спътникови изображения, химични процеси, 3D-модел

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