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Indoor Air Quality Assessment on Polygons for Solid Municipal Waste for Microbial Contamination and a Method of Cleaning It

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Abstract—Landfill biogas contains large amounts of toxic and harmful impurities and may be a source of microbiological contamination of both the complex municipal waste landfill itself and adjacent territories. This paper uses modern biotechnologies designed to protect the environment to study the quantitative and qualitative composition of biogas for harmful factors, as well as for harmful substance removal from biogas. An assessment was made of air purification in the premises near landfills and adjacent territories using green plantations and a biological system based on an apparatus–biological complex for purification from microbiological contamination. The data obtained in our laboratory studies show that such apparatus–biological complexes can reduce the negative influence on the personnel and workers at operative points and on the inhabitants of adjacent territories by air purification.

Keywords: indoor air, apparatus–biological complex, air purification, microbial pollution, dust particles, landfill, adhesion, *Tradescantia fluminensis*

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INTRODUCTION

In Russia, the most common method of waste disposal is burial. Municipal solid waste (MSW) landfills pose a danger to the environment and public health not only during operation, but also for a long period after their closure. The main reasons for the long-term negative impact are air pollution with biogas emissions and pollution of surface and groundwater with toxic leachates (Maslikov et al., 2012; Nolasco et al., 2008).

The main component of biogas is methane (a strong greenhouse gas and a valuable fuel (Zinchenko et al., 2002)). A large accumulation of this gas can cause fires at MSW landfills, which are almost impossible to extinguish. In addition, biogas contains not only a large amount of harmful and dangerous impurities (Palmiotto et al., 2014), but can also be a source of microbiological contamination of the MSW landfill and adjacent areas. Emissions of microorganisms from landfills and composting plants, as well as the smell they give off (Herr et al., 2003), often cause complaints from residents, in particular people living near such plants (Albrecht et al., 2008; Zhang et al., 2014).

A significant number of MSW landfills in Russia do not meet the sanitary, hygienic, and environmental standards (Ryzhakova et al., 2014). The construction of systems for the collection and utilization of biogas will not only make it possible to produce electricity and heat for off-grid loads (Chusov et al., 2013; Zubkova et al., 2014 *a*, *b*; Zhazhkov et al., 2015), but will also be an effective way to protect the environment. However, the direction of using biogas from MSW landfills for energy purposes in Russia is just beginning to develop (one of the pilot projects is the construction of a biogas collection system for energy production at the Novyi Svet MSW landfill in Leningrad oblast (Maslikov et al., 2013)). In addition, this direction requires significant capital investments, which often exceed the investment opportunities of municipalities. Therefore, it is extremely important to develop other, fairly cheap, but effective measures to protect the environment from the impact associated with MSW landfills.

The novelty of this study is the investigation of the organoleptic characteristics of the MSW landfill in Novoselki, as well as the neighboring “Severnyi” landfill for storing wastewater treatment sludge in St. Petersburg. It is noteworthy that in Russia there are no regulations governing the smell in settlements. In accordance with the Hygienic Requirements adopted in 2001 by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare (Rospotrebnadzor) of Russia, atmospheric air in settlements must be controlled for the content of harmful substances in it. Excessively high concentrations of such substances are classified as a violation. But the presence of a strong unpleasant smell is not always accompanied by the presence of excessively high concentrations of harmful substances in the air. The landfill in Novoselki began operation in 1972 and has been closed for many years, but the government has not managed to create a modern replacement for this MSW landfill. The Severnyi landfill began to work later, in 1986. Residents' complaints about the bad smell have appeared only in the last few years, which may be due to the clearing of a nearby forest (which was a natural stabilizing barrier between residents and landfills) to create an industrial park for Nissan and Hyundai factories. In addition, the landfills are adjoined by one of the main transport arteries of the city, the Ring Road.

In this regard, special attention must be paid to the use of modern biological approaches to protect the environment (Soreanu et al., 2013; Andrianova et al., 2014) as well as to reduce the spread of biogas and study the quantitative and qualitative content of harmful microorganisms in it.

The assessment of biological air purification of landfills can be divided into two main categories: air purification indoors and outdoors around them (in the field conditions).

Analysis of the literature has shown that air quality at a landfill depends on various factors. These parameters include the quality of compost obtained from landfills. Compost can pollute the environment through the release of the following pollutants: heavy metals (Deportes et al., 1995; Hargreaves et al., 2008) and toxic components and volatile organic compounds (Soreanu et al., 2013). It has also been proven scientifically that it can harm health (Fischer et al., 2008; Kalwasinska and Burkowska, 2013; Wery, 2014), as well as cause inconvenience due to odorous compounds (Herr et al., 2003; Vitezova and Vitez, 2013; Palmiotto et al., 2014). The air of compost heaps contains various groups of microorganisms represented by psychrophilic and mesophilic bacteria (Kalwasinska et al., 2014), microscopic thermotolerant fungi (Vitezova and Vitez, 2013), thermophilic actinomycetes (Fischer et al., 2008), etc.

In particular, exposure to bioaerosols associated with atmospheric dispersion or compost treatment (Bünger et al., 2007) poses a health risk to exposed groups (Deportes et al., 1995; Gorny et al., 2002). These include both working personnel and the population of neighboring residential areas (Le Goff et al., 2012). Bioaerosol or organic dust is a term used to describe airborne microorganisms such as fungi or bacteria, or by-products such as endotoxins and glucans (Douwes et al., 2003; Taha et al., 2006; Wery, 2014), which can lead to allergic reactions, may affect respiratory health (Le Goff et al., 2012) or have other effects (Nikaeen et al., 2009; Hung et al., 2010; Liang et al., 2013).

Moreover, analysis of the literature has shown that there are strong differences in the indoor air quality at landfills and adjacent areas (Alikbaeva et al., 2010; Kalwasinska et al., 2014). Office air near landfills was characterized by increased concentrations of airborne bacteria and fungi (Lis et al., 2004). The study by D.O. Lis (Lis et al., 2004) shows that offices near landfills can be categorized as having high and very high bacterial and fungal indoor air contamination. The influence of the season on the concentration of bacteria as well as fungi is noted: it is higher in summer than in winter (Grisoli et al., 2009). A seasonal decrease in the concentrations of bacterial and fungal aerosols can be caused by low air temperature and frozen soil or snow cover, which are the conditions that are unfavorable for the reproduction and spread of pathogenic microbes by the "dust" route (Lis et al., 2004; Huttunen et al., 2010).

In addition, the transfer of solid and liquid volatile dust particles can increase the number of microorganisms, which are typical aerosol pollutants of atmospheric air.

Based on the analysis of the literature, the small-leaf spiderwort *Tradescantia fluminensis* was chosen to study the cleansing ability of plants from microbial contamination. This is an unpretentious plant that multiplies rapidly and increases its mass. *T. fluminensis* effectively absorbs pollutants and intensively releases oxygen and phytoncides.

First of all, plants are presented as the main filters, which have a developed surface area with a waxy formation, a cuticle that has good retention properties in relation to microorganisms and volatile particles. In addition, all plants have a variable ability to release phytoncides for self-defense of plants from harmful microorganisms, as well as to influence the composition of the environment actively. Moreover, phytoncides produced by the leaf surface can be considered as a biological agent that prevents the reproduction of microorganisms attached to the leaf surface (Tsybulya et al., 2000).

The main goal of this study is to assess the possibility of cleaning the air of the premises of landfills and territories adjacent to them from microbiological pollution by green spaces using a biological treatment system based on an apparatus–biological complex.

MATERIALS AND METHODS

Laboratory Test Chamber

A laboratory test chamber was created to study the possibility of air purification from dust particles containing various types of bacteria, fungi, and actinomycetes by green small-leaf spiderwort plants (*Tradescantia fluminensis* Vell.) (Fig. 1). The body of this unit was made of stainless steel and transparent plexiglass, the volume of the chamber was 300 liters. A fan was used to create an air flow into the test chamber at an average speed of 0.5–1 m/s.

Laboratory experiments were carried out on a model of a recirculation-type apparatus–biological complex (laboratory test chamber). The design of this complex is shown in Fig. 1.

To study the effect of air ions on the test plants, the model of the apparatus–biological complex was saturated with negative or positive ions at concentrations up to 200000 ions per cm^3. During the studies, special attention was paid to particles with a size of 1–5 μm. Ions were generated directly in the chamber in an air flow created by a fan and passing through the corona discharge zone.

For each study, eight specimens of small-leaf spiderwort *T. fluminensis* were placed in the test chamber. The total leaf surface area is 48 ± 8 dm^2.

The additional illumination of the plants was 1100 lx, and the ion concentration was 200000 ions per cm^3.

The number of dust particles with a size of 1–5 μm that passed through the test chamber was estimated using a particle counter for the inlet and outlet air flows. The number of ions for all ranges was calculated as a percentage of the base value, which was found after the first minute of the experiment. All studies were carried out with real air flows, so the spread of counted particles can exceed 100%.

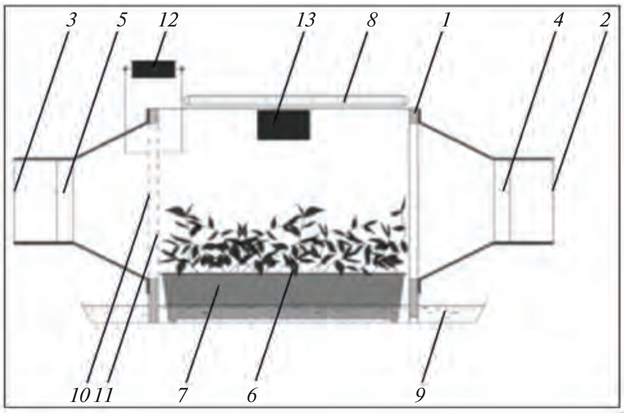

Fig. 1. Test chamber for studying the efficiency of air purification from aerosols using plants: *1*, a box; *2*, air inlet; *3*, air outlet; *4*, fan; *5*, bipolar ionizer; *6*, plants; *7*, flower pots; *8*, lamps; *9*, water tank; *10*, *11*, perforated metal grid; *12*, direct current source; and *13*, unipolar ionizer.

Microbial Contamination

To study the content of microorganisms, the relatively simple, but very demonstrative Koch natural precipitation method is used. A particle counter is used to study the efficiency of facilities for treatment of air of different quality, which both contains and does not contain air ions of aerosol pollution.

The Koch analysis is a classic method for the determination of microorganisms and spores adsorbed and circulating in the air by dust particles. This method uses open Petri dishes by natural sedimentation of dust particles by microorganism spores. In connection with the experiment, Petri dishes were exposed for 15 min in the laboratory to the outflow of purified air from the test chamber with and without plants and positive and negative ions at the end of the experiment.

Airborne microorganisms associated with dust particles settled on the surface of the nutrient solution. Then Petri dishes were covered with simple agar and transferred to a thermostat, where they were incubated at 37°C for three days. At the end of the incubation period, the identification and counting of microorganism colonies were carried out. The repetition rate for each experiment was 10. Thus, the total amount of measurements was 40.

Evaluation of the Degree of Cleaning by Green Plantings

The coefficient of efficiency of air purification by plants depends on time. It is calculated according to the following equation:

$$K_{ef} = \frac{N_{in} - N_{out}}{N_{in}} \times 100,$$

where N_{in} and N_{out} are the concentrations of aerosols of the corresponding dispersion at the inlet and outlet of the complex.

Preliminary data processing and analysis were carried out using Microsoft Office Excel 2010 (Microsoft Corp.).

RESULTS AND DISCUSSION

Laboratory Experiments with the Test Chamber

The results of changes in the concentrations of dust particles with different variations in test conditions and variations in the size of air particles from 0.3–0.4 to 2–5 μm are shown in Fig. 2.

An analysis of the graphs shows that the concentrations of aerosol particles at the outlet of the complex have low values that almost tend to zero, which clearly emphasizes the efficiency of the apparatus–biological complex.

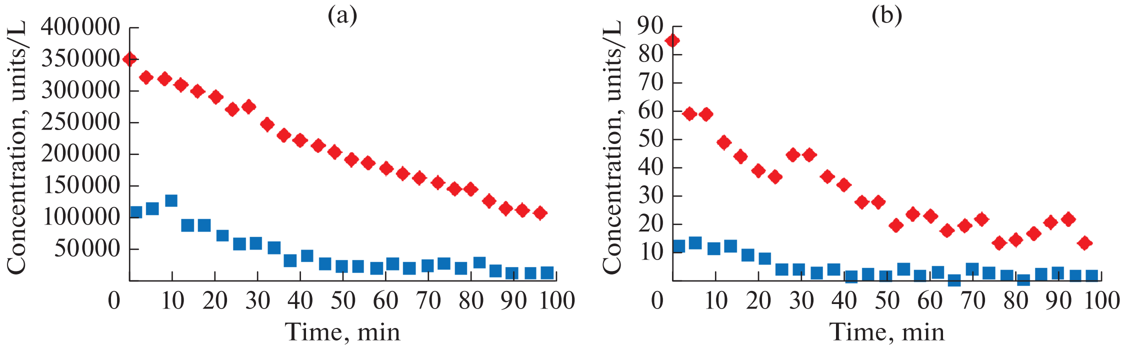

Fig. 2. Change in the concentration of dust particles with sizes within 0.3–0.4 (*a*) and 2–5 (*b*) µm in the inlet (◆) and outlet (■) air flows in an empty test chamber.

Microbial Contamination

A quantitative and qualitative analysis of bacteria, actinomycetes, and filamentous fungi in the air in the outgoing air stream from the test chamber was also carried out. The table 1 shows strong differences in the microbial composition of microorganisms of different species under the test conditions.

The largest number of microorganism colonies was counted in an empty chamber. The total amount of microbial colonies averaged 54 colonies. The minimum total number of microorganisms that was equal to 16 colonies was observed in the presence of plants in the test chamber.

The most common group of microorganisms is represented by bacteria in an empty test chamber and averages 18.2 per ten replications. The following are actinomycetes, which are represented by a total of up to 14 colonies in an empty test chamber. It should be noted that the average number of colonies of both bacteria and actinomycetes is halved in the presence of plants and air ionization. However, the number of bacteria and actinomycetes in the presence of plants decreases three times and amounts to 7 and 3 colonies, respectively.

Four species of fungi were identified. Mucor was the most capable fungus with an average of 12 colonies. However, for chambers with plants and the ionizer, its amount was reduced up to four times, and for chambers with plants it was reduced up to twelve times. *Penicillium*, *Cladosporium*, and *Fusarium* were represented by 5, 3, and 2 colonies in an empty experimental chamber, and their number decreased up to three times for each fungal genus.

Assessment of the Degree of Cleaning by Green Spaces

Figure 2 shows the differences between the efficiency factors calculated for both size ranges 0.3–0.4 and 2–5 µm. The maximum value of the degree of efficiency was recorded in the test chamber with a complex of *T. fluminensis*, the unipolar ionizer, and the blocking grid and is 94 and 97% for particle sizes of 0.3–0.4 µm and 2–5 µm, respectively. Under the conditions of the test chamber with *T. fluminensis*, the efficiency of the cleaning ability was halved for both 0.3–0.4 and 2–5 µm. In addition, during the study period, the efficiency ratio was stable in all cases.

Dust Particles

In the course of this study, the ability of green spaces to purify the air from dust particles 2–5 µm in size was studied. The selected sizes of air particles were used as large dust particles capable of carrying a signif-

Table 1. Contents of microorganisms in the air inside the test chamber

Type of microorganisms	Content of microbes in the chamber without plants (control)	Content of microorganisms in the chamber with plants	Content of microorganisms in the chamber with plants and during air ionization
Bacterium	18.2 ± 2.61	7 ± 1.22	10 ± 2.60
Actinomycetes	14 ± 1.41	3 ± 0.66	7 ± 2.12
Mucor Fresen., 1850	12 ± 1.52	1 ± 0.08	3 ± 0.76
Penicillium Link, 1809	5 ± 0.72	3 ± 0.55	1 ± 0.26
Cladosporium Link, 1816	3 ± 1.01	1 ± 0.07	1 ± 0.26
Fusarium Link, 1809	2 ± 0.93	1 ± 0.89	1 ± 0.57

icant amount of microbial contamination and spreading over landfills and adjacent territories.

An analysis of the graphs makes it possible to assume that there is a trend towards a decrease in the concentration of dust, depending on the size of the incoming and outgoing particles in the air flows. It is possible to reduce the concentration of aerosols due to their adhesion to the walls of the chamber and settling on surrounding objects. However, the reasons for this dependence are probably related to the different chemical composition of particles of different sizes, as well as their total charge.

Figure 2 shows that the presence of plants in the test chamber leads to a decrease in the concentration of dust particles. Plants fix dust particles on their surface and purify the air up to 30%.

Thus, the analysis shows a decrease in the concentration of dust particles when using *T. fluminensis*, the unipolar ionizer, and the blocking grid. The results obtained confirm the effectiveness of using the biological method of air purification, which can be used in office premises located at landfills, as well as in residential and office premises of industrial buildings located near MSW landfills.

Microbial Contamination

The results show that the test plants (*T. fluminensis*) in the closed volume of the test chamber have a pronounced antibacterial and antifungal effect. The accumulation of volatile substances in the volume of the test chamber in sufficient quantities significantly inhibits the viability of microorganisms that are present in the air. These data are consistent with the data obtained during the literature review and confirm the correct choice of test plants. In addition, there is a large cleansing ability of plants growing in Russia for various types of microbial contamination.

When determining the most effective microorganism suppression mode, it must be taken into account that the phytoncidal activity of the tested plants depends on the presence of ions in the air chamber.

In the case of unipolar ions with a high concentration, aerosols are charged in the test chamber. Due to electrostatic repulsion, aerosols begin to be intensively removed from the volume of the chamber onto the walls of the chamber and onto plant leaves. When a dust aerosol comes into contact with a grounded metal chamber wall, it loses its own charge. Due to low adhesion to metal, these aerosols again contaminate the air chamber. This explains the lack of practical effect in the air purification chamber in the presence of ions, but in the absence of plants.

Thus, plant leaves have a well-developed surface area due to the natural roughness of the stomata, etc., which significantly exceeds the geometric area of the leaf mosaic. In addition, aerosols that touch the surface of waxed leaves stick to the wax and do not return to the air chamber.

The data obtained indicate that plants are natural filters that have the ability to purify the air of landfills and adjacent areas from the microbiological pollution that is present in it. The data obtained were used to develop the principles of a system for biological purification from this type of pollution for an indoor air purification system.

Engineering Solution for Indoor Air Purification

The St. Petersburg Polytechnic University has developed a recirculation-type vertical apparatus–biological complex (*Ustroistvo povysheniya kachestva vozdukha*, 2008). This complex permits the air of the premises of nonindustrial buildings to be effectively purified from various kinds of pollutants.

Purification of indoor air is a local task and can be solved with the help of engineering structures called phytomodules (the apparatus–biological complex). A phytomodule is a complex engineering structure consisting of various plant species with a high rate of changing the physical and chemical composition of air to give it certain properties and characteristics, as well as technical means that ensure the vital activity of these plants, controlling the intensity of biological processes in plants (photosynthesis, absorption of aerosol pollutants, etc.).

The use of the specialized apparatus–biological complex will reduce the microbial load on the internal structures of landfills and structures in their adjacent territories.

The functional diagram of the apparatus–biological complex is shown in Fig. 3.

Polluted air is supplied by a fan (*2*) to the complex with units located on different tiers. The complex is equipped with a load-bearing vertical structure with planting sites, on which pots with plants are installed. The design allows for lower watering of plants. Hypoallergenic mineral soils used as soil for plants almost exclude the development of pathogenic microorganisms on their surface. Plants with an extended transpiration function are intensively illuminated with energy-saving lamps or LED spotlights (*10*), as a result of which the yield of moisture and biologically active substances, including phytoncides, from the surface of the leaves increases abruptly.

An apparatus module is at the top of the complex. It ensures the operation of the generator for the production of bipolar ions and their removal in the air of the premise. The control and monitoring modules process the information coming from the sensors and reflecting the presence of water in the tank (*13*) and on one of the planting sites and generate a command for the next watering of the plants. At the bottom of the complex, there is a tank for storing water.

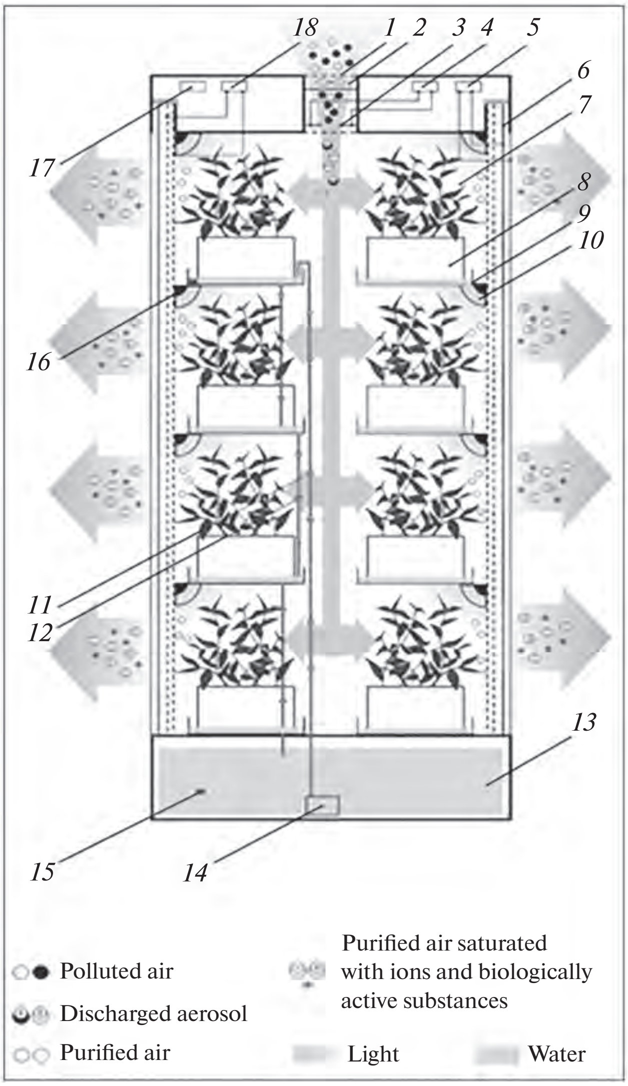

Fig. 3. Functional diagram of the apparatus–biological complex: *1*, air intake; *2*, fan; *3*, electrodes of the unipolar ionizer; *4*, power supply of the unipolar ionizer; *5*, direct current source; *6*, electrode of the bipolar ionizer; *7*, plants; *8*, flower pots; *9*, planter slats; *10*, light-emitting diodes (LED); *11*, *12*, plumbing; *13*, water tank; *14*, pump; *15*, *16*, water meter receiver; *17*, sensor; *18*, holding potential.

The air flow inside the complex is formed in such a way that aerosol accumulations passing through plant leaves settle on them. Wet leaves retain aerosols and phytoncides well and inactivate microorganisms. The presence of a retention potential (*18*) on perforated grids prevents the exit of charged aerosol clots from the enclosure. As a result, air purified from aerosol and microbial contaminants and humidified air that is rich in biologically active substances come out of the complex. Bypassing the grids, the air is saturated with light ions in concentrations according to the standards of the Russian Federation SanPin 2.2.4.1294-03 and distributed throughout the premise.

CONCLUSIONS

The laboratory experiments yielded the following results. Test plants (@T. fluminensis@) have a strong antibacterial and antifungal activity. This is characterized by an accelerated decrease in the microbial contamination of the air.

There is a theoretical possibility to control the release of phytoncides and hence to influence the bactericidal and fungicidal properties of plant complexes. The best results in terms of air purification ability were shown by the test chambers containing units for reducing aerosol air pollution with a barrier grid and a unipolar ionizer. The potential for air purification with all the necessary elements is several times higher than in an empty test chamber.

The studies show the effectiveness of the biological method for air purification from microbial pollution coming from landfills to premises of the operational center and to residential and industrial buildings located on the territories adjacent to them. Microbial pollution is associated with the release of biogas at landfills and can lead to poor health. Thus, the use of apparatus–biological complexes makes it possible to reduce the negative impact on the personnel and workers of operative points and on inhabitants of adjacent territories by cleaning the air.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflicts of interest.

ADDITIONAL INFORMATION

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