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RESEARCH ARTICLE

Microbial Activity in the Unequipped Municipal Solid Waste Landfills

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Citation: Mikhail Krasnyansky (2022) Microbial Activity in the Unequipped Municipal Solid Waste Landfills. Stech: Arch of Earth and Env Sci 2: 104

ABSTRACT

Abstract: The paper discusses a critical situation regarding unequipped municipal solid waste (MSW) landfills. Emissions of toxic gases from a "close laboratory dump" and a real smoldering solid waste landfill have been measured. Special attention is given to such problems as bio-degradation and self-ignition of MSW dumps caused by bacterial activity in the body of the landfill. The paper describes the materials as well as techniques used for experiments and calculations of results. Dynamics of development of microorganism colonies within the body of MSW has been studied experimentally and a mathematical model of these processes was developed. A method for extinguishing a smoldering MSW landfill has been developed and tested.

Keywords: Municipal Waste; Unequipped Landfill; Microorganisms; Toxic Gases; Smoldering

Introduction

A large number of countries in the world (mainly in Africa, Asia and South and Central America) dispose their unsorted MSW in unequipped landfills with nothing but a bulldozer that levels and compacts the MSW layers (from about the original 250 to the final 600 kg/m³) [1].

For such landfills and even at equipped landfills, biochemical processes and the role of bacteria for them have been little studied. One of the most impressive studies on this problem has been described in article [2]: the most predominant bacterial representatives were Gammaproteobacteria, Firmicutes, Bacteroidetes, and Pseudomonas; also, Fusobacteria and Tenericutes were found for the first time. Besides, landfill air is dominated by microbial dust or various pathogenic microbes like Enterobacteriaceae, Staphylococcus aureus, Clostridium perfringens, Acinetobacter calcoaceticus, and Aspergillus fumigatus [3].

When MSW are disposed in a landfill and it pressed by a bulldozer, the available inside oxygen may be quickly used up, so that the subsequent microbial activities are anaerobic [4, 5]. The first stage of anaerobic decomposition of disposed MSW is hydrolysis of organic polymers such as cellulose into less soluble compounds: $(C_6H_{10}O_5)n + nH2O = n(C_6H_{12}O_6)$; the second stage is a biochemical decomposition of smaller compounds such as glucose into short-chained volatile fatty acids (VFAs) such as acetic or propionic acids, for example: $C_6H_{12}O_6 = 3(CH_3COOH)$; and third stage is an anaerobic decomposition of VFAs into methane and carbon dioxide: $CH_3COOH = CH_4 + CO_2$. The result of these biochemical processes is production and emission of "greenhouse biogas" and other toxic gases (H_2S+SO_2, NH_3, NO+NO_2) from unequipped landfills.

Also, these biochemical reactions, in total, are exothermic, so the temperature inside this MSW landfill rises and all these reactions seem to self-accelerate (in some cases, interior smoldering and toxic gas emission begins there over a large area which is very difficult to extinguish). The water added to landfill with rains or snow increases its moisture increase and also can stimulate microbial activity in the waste layers. It can further increase the temperatures inside the landfill: so, after three years of disposal the temperature at the depth of 2-4 m can reach 40-45°C even if the ambient temperature was 0 °C [1]. (Problems of toxic leachate are not discussed in this paper.)

Materials and Techniques

A "laboratory composition" of MSW for our "artificial close laboratory MSW micro-dump" was obtained by crushing and mixing various components (food, paper, plastic, wood, glass, etc.) which corresponds to the average composition of MSW in a large city of Ukraine [1]. We refused from using "natural" MSW as in such a case the results of experiments were badly reproduced. For more detailed examinations of MSW biodegradation, within laboratory conditions an artificial «closed MSW micro-dump» was created. It is a 10 cm- layer of "laboratory composition" of MSW (180 g of dry MSW) and 20 g of "seeds" from bacteria and mushrooms (it is about 10 %, that in the sum with already available nitrogen approximately corresponds to its quantity in natural food waste) and 100 ml of water so that the "natural" humidity of MSW was about 30%) was placed in a glass jar with, its diameter being 15 cm. At the top of the layer a 2 cm soil-layer was placed. A polyethylene cap sealed the jar (not tightly), leaving a 20 cm air-space above the soil (under the cap). The number of "mesophilic aerobic and facultatively anaerobic microorganisms" (MAFAM) was calculated using the following procedure: a MSW sample was inoculated into a beef-extract (agar) and maintained at 37 °C for 24 hours. The grown colonies were counted after incubation (by means of a microscope) and reported as "colony forming units" (CFU) per 1 g of dry MSW. The capacity of the experimental chamber and weight of MSW were adjusted based on preliminary experiments so that the period of "laboratory biodegradation" of MSW was about 2-4 months.

Measurement of gas emissions at real landfills was conducted with the help of an individual multi-channel gas analyzer "MX-21-Plus" (France). An average value was used, received on the basis of 3 measurements performed with an interval of 10 minutes.

The analysis of gas samples of mini-lab-dump was carried out with the help of a modern gas chromatograph in accordance with its instruction.

Results and Discussions

Mathematical model of microbial activity

As the process of biodegradation is determined by development (i.e. growth and death) of bacteria colonies in the landfill body (waste layers), it might be interesting to try to develop a mathematical model of the number of mono colonies of microorganisms within a "closed" (i.e. in non-renewable MSW mass). There has been offered a mathematical model which is described by the following system of equations:

$$\frac{dN}{d\tau} = \beta N - \gamma NR; \qquad \frac{dR}{d\tau} = \lambda N \qquad (1)$$

where:

N(τ) is the number of active microorganisms in MSW;

R(τ) is the factor of "reverse catalysis", i.e. the sum of all factors inhibiting or stopping the growth of bacteria colonies: poisoning by products of vital activities, reduction of the access to food, etc.;

β, γ, λ are the constants which are defined on the basis of experimental examination of the dynamics of propagation of microbial cells N(τ);

By solving the system of equations (1), we receive:

$$R = \frac{\beta N - \frac{dN}{d\tau}}{\gamma N} = \frac{1}{\gamma}\left(\beta - \frac{1}{N}\frac{dN}{d\tau}\right) \qquad (2)$$

Differentiating (1) and placing the result into the left part of the second equation of the baseline system, we come to the following:

$$\frac{1}{N^2}\left(\frac{dN}{d\tau}\right)^2 - \frac{1}{N}\frac{d^2N}{d\tau^2} = \gamma\lambda N \qquad (3)$$

Or:

$$\frac{d^2N}{d\tau^2} - \frac{1}{N}\left(\frac{dN}{d\tau}\right)^2 = -\gamma\lambda N^2 \qquad (4)$$

Considering the baseline conditions and the known value of the function in the peak point, let us draw a system of equations for constant values C:

$$N_o = -4N_m \frac{\bar{C}}{(1-\bar{C})^2}; \quad N_m = -4N_m \frac{\bar{C}e^{C\tau_m}}{(1-\bar{C}e^{C\tau_m})^2} \qquad (5)$$

From the equations (5) is follows that:

$$\bar{C}^2 - 2\left(1 - 2\frac{N_m}{N_0}\right)\bar{C} + 1 = 0 \qquad (6)$$

The root of the quadratic equation has a physical meaning:

$$\bar{C} = -2\left[\left(1 + \sqrt{1 - \frac{N_0}{N_m}}\right)\frac{N_m}{N_0}\right] \qquad (7)$$

If to assume that:

$$C = -\frac{1}{\tau_m}\ln(k\bar{C}) \quad (k = -1)$$

As a result:

$$N = 4N_m \frac{\Delta^{1-\frac{\tau}{\tau_m}}}{\left[\Delta^{1-\frac{\tau}{\tau_m}}+1\right]} \qquad (\Delta = -C) \qquad (8)$$

One of the variants of the numeric calculation is provided at Fig. 1 for β = -0,44 1/day and $N_0 = 1{,}5{\cdot}10^6$).

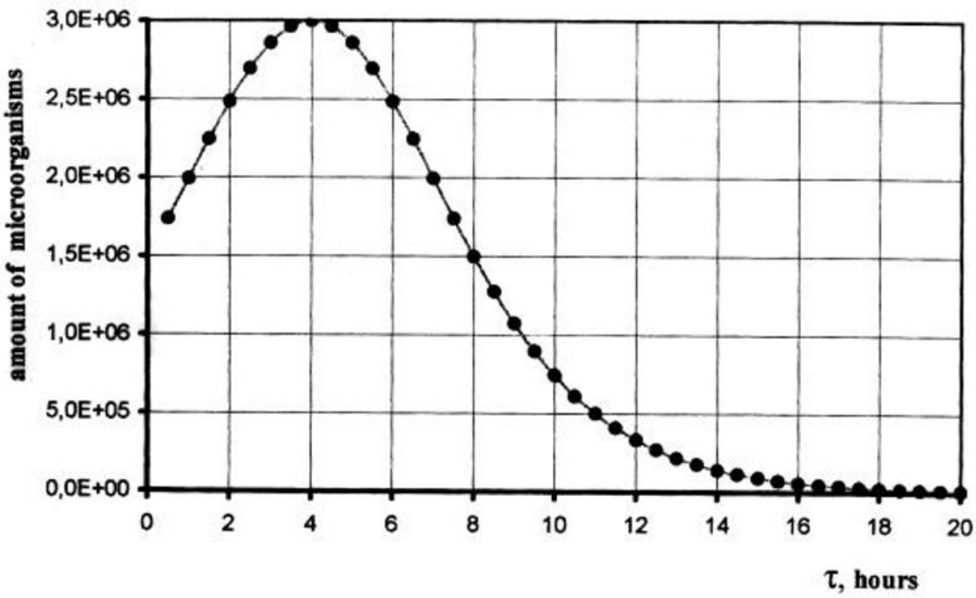

Figure 1: Theoretical curve of the MAFAM quantity dynamics

The results of the calculation received show (see Fig. 1) that with time (τ) the number of microorganisms (N) in MSW increases and reaches its maximum when τ = 4 hours, after that N decreases asymptotically reaching zero near 16 hours, i.e. before reaching the maximum the speed of microorganism propagation prevails over the speed of their self-destruction. At the right part (behind the maximum) it is vice versa.

Experimental results

We have also conducted experimental studies of this process for the so-called MAFAM group. When the population of MAFAM microorganisms in a "close laboratory dump" was measured over time, their number reached the peak after 30 days declining over the following 120 days (see Fig. 2).

As it can be seen at Figures 1 and 2, both theoretical and experimental results show that the curves reach their maximum during the first quarter of MSW biodegradation period at disposal sites (for "close MSW-bacteria system").

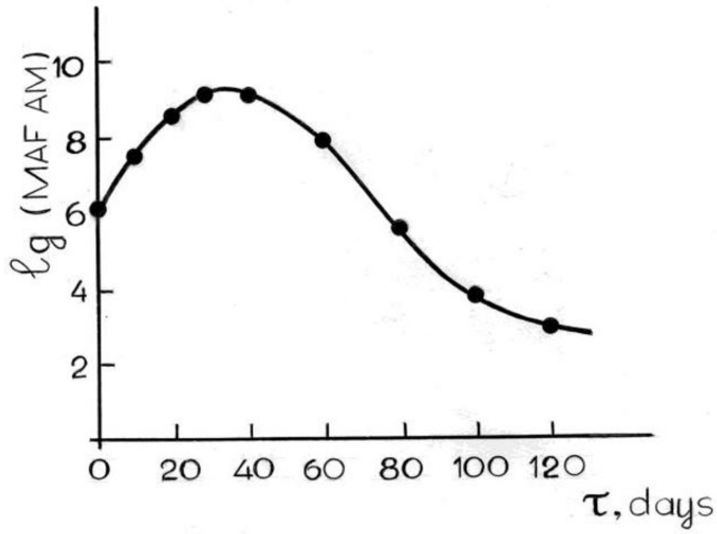

Figure 2: Dynamics of growth of MAFAM bacteria in a MSW microcosm

In order to check experimentally the correlation between the dynamics of microorganism colony development within a "closed laboratory MSW dump" and the character of gas emissions in this "close laboratory dump" we have implemented an additional analysis of gas samples within a glass vessel over a MSW layer - see Fig. 3.

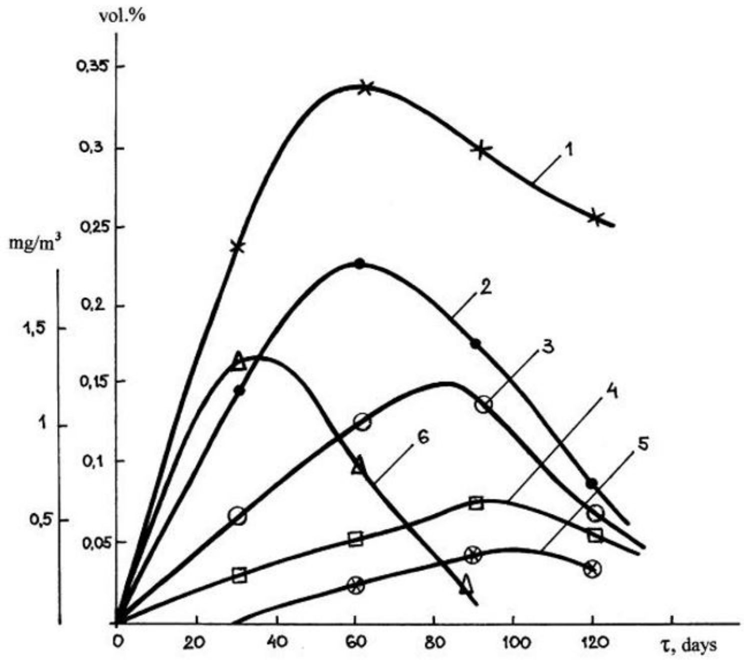

Figure 3: Experimental dynamics of toxic and greenhouse gas emissions from a "laboratory MSW micro-dump"

1 - carbon dioxide (vol. %); 2 - methane (vol. %); 3 - ammonia (mg/m3); 4 - hydrogen sulfide (mg/m^3); 5 - hydrogen chloride (mg/m^3); 6 - formaldehyde (mg/m^3)

As we can see from Fig. 3, the gases emitted from a "close" layer of MSW during biodegradation remind a theoretical curve at Fig. 1 and experimental curve at Fig. 2 – all curves reach their maximum at 1/4 – 1/3 of the full incubation period. The measurements of the temperature of the "laboratory" dump have shown that during the process of biodegradation the temperature increases up to 50-60 °C. It allows us to state that the processes of gas emission from the body of landfills are determined mainly by bacterial activity.

Smoldering of unequipped MSW landfills and its extinguishing

Since MSW biodegradation reactions are exothermic, there is a potential for self-heating and self-ignition of dumps (which is often a case). From classical thermodynamic is known that the process of self-heating transforms into burning when the heat flow (+Q) from exothermic reactions of oxidation exceeds natural heat removal (-Q) from the reaction zone. The interrelation of [(+Q) > (-Q)] often takes place during natural MSW biodegradation processes, especially in summer time - in this extreme case, the temperature inside the landfill can sometimes reach 150-200 °C (see Fig. 4).

Figure 4: Smoldering and self-ignition on the real unequipped landfill

We measured the concentrations of toxic gases at the border of the sanitary zone of a real non-equipped MSW landfill with visible intense smoldering and partial ignition (500 m from the edge of the landfill) - see Tab. 1.

Toxic gas	Concentration, mg/m^3	MPC*	Excess
CO	31.1	3.0	10.4 times
NO/NO_2	0.33	0.04	8.25 times
SO_2	0.8	0.05	16 times
CH_2O	0.02	0.003	6.7 times

*) MPC - maximum permitted concentration in air of settlements (average daily)

Table 1: Concentration of toxic gases for the unequipped smoldering real landfill (on its border of the sanitary zone)

As can be seen from Table 1, on the border of the sanitary zone of the landfill (this is 500 m from its edge!) there is a huge excess of permissible concentrations (from 6 to 16 times) of not just harmful, but extremely toxic gases. This means that a smoldering (especially burning) landfill is a real threat not only as fire, but to public health, and it must be extinguished immediately. However, one must understand that ordinary fire engines are unsuitable for these purposes: when landfill is smoldering, due to the burning out of large volumes of solid waste, huge "hot pits" are formed, and fire truck with a driver can completely fall into there.

That's why we have searched for potential technologies to suppress the activity of bacteria in the body of the unequipped landfill. "Lime milk" [suspension of $Ca(OH)_2$] has been selected as a simple, safe, and cheap reagent for that goal. We treated our "artificial laboratory MSW micro-dump" with a 10%-$Ca(OH)_2$ suspension using (at a ratio) 0.1 volume of suspension per 1 volume of MSW. As it follows from Fig. 5, after one day (24 hours) after the treatment, the quantity of MAFAM came close to zero (gas emission also stopped and the temperature inside the "laboratory dump" approached room temperature.)

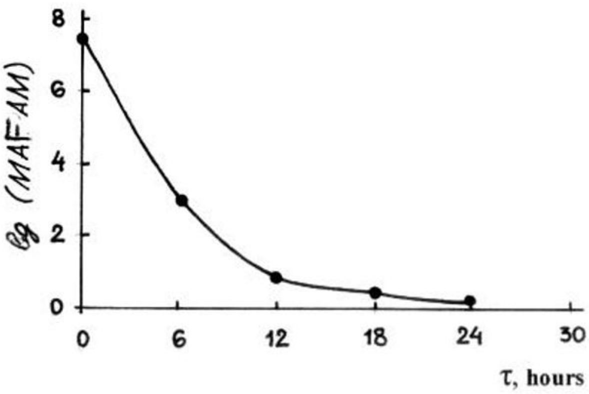

Figure 5: Dynamics of reduction of MAFAM population after MSW treatment with a $Ca(OH)_2$ suspension

Extinguishing focuses of smoldering at real unequipped MSW landfills can be carried out by pumping special solutions or suspensions into its body - Fig. 6. In this case, first of all, the bacterial activity is suppressed, then the smoldering center is cooled. To extinguish smoldering focus in real MSW landfills, we can accept the ratio: 0.1 m^3 of suspension per 1 m^3 of MSW in the center of the smoldering place.

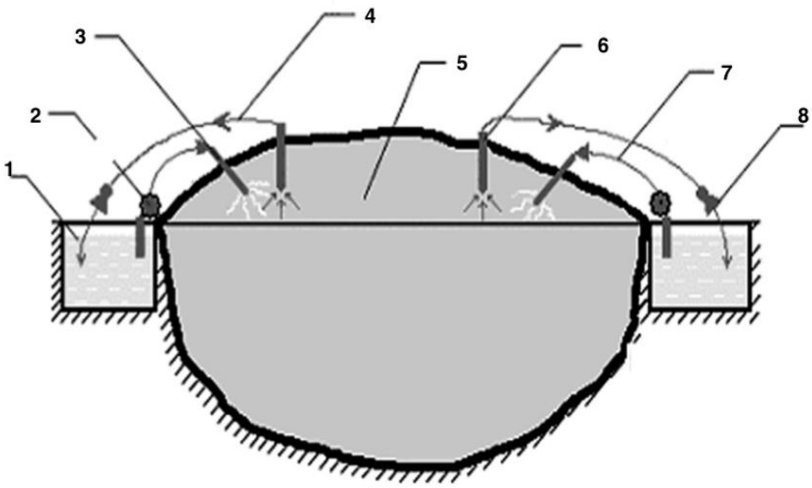

Figure 6: Technological scheme for extinguishing an unequipped MSW landfill with lime suspension $Ca(OH)_2$

1 - mixing tank (cistern) for the preparation and storage of lime slurry [$Ca(OH)_2$]; **2** - powerful pump, supplying (under pressure) lime suspension from the tank to the injector (up to 60 m^3/h);

3 - injector (pipe section 4-6 m long and 0.1 m in diameter with perforation and a pointed end) for injecting the suspension directly into the smoldering center in the body of the landfill; **4** - pipeline for the removal of combustible and toxic gases from the body of the landfill (they are pumped into the tank with $Ca(OH)_2$ for neutralization); **5** - MSW landfill body; 6 - powerful vacuum pump (gas capacity up to 1 m^3/s); **6** - perforated suction metal pipe (like injector, pos. 3) for venting gases from the landfill body; **7** - pipeline for supplying the suspension to the injector; **8** - powerful vacuum pump (gas capacity up to 1 m^3/s) for suction of hot and toxic gases from the body of the landfill near the smoldering center (they are pumped into a tank with $Ca(OH)_2$ for neutralization).

Conclusions and Recommendations

It is shown a significant role in unequipped MSW landfill biodegradation is played by microorganisms, i.e. they are responsible both for environment pollution of greenhouse and toxic gases and for heating of some of its areas that often leads to smoldering and even to spontaneous self-ignition of MSW.

The gas emission curves from a "close laboratory dump" of MSW during biodegradation and also theoretical and experimental curves – all of them reach their maximum at 1/4 – 1/3 of the full incubation period.

The measurements of the temperature of the "close laboratory dump" have shown that during the process of biodegradation the temperature increases up to 50- 60 °C.

On the border of the sanitary zone of the smoldering landfill there is a huge excess of permissible concentrations (from 6 to 16 times) of extremely toxic gases. This means that a smoldering (especially burning) landfill is a real threat to public health, and it must be extinguished immediately.

It is necessary to arrange a periodical treatment of an unequipped MSW landfill's "problem areas" with a 10%- suspension of a "lime milk" [$Ca(OH)_2$] to slow down microbiological activity and for prevention of MSW landfill smoldering and self-ignition.

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