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Municipal Solid Waste as an Ecological Threat for the Countries with "Transitional" Economy

Abstract: The paper discusses results of experimental researches regarding ecological threats from municipal solid waste (MSW) on the examples of four real large landfills (in fact, unequipped MSW dumps) of typical Ukrainian industrial city. Special attention is given to such problems as biodegradation and self-ignition of MSW in unequipped dumps, as well as emission and spreading of greenhouse and toxic gases, toxic leachate including toxic (heavy) metals which differently pollute air, the soil and water.
Keywords: *municipal waste, unequipped landfill, biogas, environmental threats.*

I. Introduction

For countries similar the Ukraine with "transitional" economics, the municipal solid waste (MSW) management is a particularly critical problem. Approximately 5 billion m^3 (over one billion tons) of MSW have been accumulated in Ukraine; it are disposed at 800 large municipal landfills, and their total surface is more than 50 thousand hectares (including 500 m of sanitary zone). Many of them are 60-90% full. Some landfills are overfilled and should have been closed a long time ago. Also, there appeared thousands of unauthorized ("wild") MSW dumps *(Krasnyansky, 2005; Krasnyansky, 2011).*

A lot of Ukrainian MSW dumps are permanently smoldering or even burning, especially during summer time. It has been shown that the maximum quantity of dioxin can be produced there under the temperature of 250°C up to 450°C *(Sao, 1990; Lopes, 2015).* Concentration of dioxins in air (2 m above of one ton of combusted waste) vastly exceeded the European Union standard of 0.1 nanogram/m^3 *(Council, 1999).*

When wastes are disposed in a landfill, the available oxygen may be quickly used up, so that the subsequent microbial activities are anaerobic. These biological processes of MSW degradation have been described *(Møller, 2009; Gomez, 2012).* MSW can cause a significant damage to the environment if they are not stored in a properly engineered system. Some of the problems that might occur are the following: emission of biogas and other toxic gases, spread of pathogenic bacteria, and pollution of soil and groundwater by leachate. Leachate is forming when rain or thawing snow pass through the waste and absorb toxic organic compounds and heavy metals, thus the leachate can become a highly toxic substance *(Renou, 2008).*

Considering the number of solid waste disposal sites in typical Ukrainian city as well as the fact that so many of them are not properly engineered, it is necessary to assess their impact on the environment *(Krasnyansky, 2005).*

Thus, the purpose of this research was to provide a qualitative and quantitative estimation of the degree of environment pollution by poorly equipped MSW landfills.

II. Materials and Techniques

II.1. Measurement of <u>biogas emissions for real landfill</u> in typical Ukrainian industrial city (Donetsk) was fulfilled with the help of an individual multi-channel gas analyzer "MX-21-Plus" (France) and portable mobile ionic spectrometer "Multi-IMS" ("Drōger", Germany). The most "young" landfill No. 4 was chosen by us for gases analysis (see Tab. 1). The measurements of biogas were done in 8 boreholes of 2 m deep; each hole was at the square of 20 x 20 m. An average value was used on the basis of 3 measurements performed with an interval of 10 minutes. Analysis of atmosphere above the real landfill was fulfilled on 1 m over surface. The inaccuracy of all measurements did not exceed 8%.

In order to calculate the maximum theoretical biogas production at MSW landfills of Donetsk city we used the following formula for first order reactions:

$$\mathbf{V = \Sigma V_0 Q e^{-k\tau}} \qquad \textbf{(Eq. 1)}$$

where:
$\mathbf{V_0}$ – the theoretical MSW methane production potential, m^3/t (for "average" Ukrainian MSW is equal 80);
Q – the average quantity of MSW received at a landfill, t/year (see Tab. 1);
k – the average constant of methane production, l/year (food – 0.35, paper – 0.12, textiles – 0.05, plastic – 0.01);
τ - the time of landfill operation, year (see Tab. 1).

II.2. The quantity of <u>leachate</u> ($\mathbf{V_f}$) which might be produced at the working area of the landfill (dump) depends mainly on the amount of annual precipitation **(P)** of the region , evaporation **(V),** and water absorption by landfill wastes (**W**) (see, for example (Qasim, 1995). However, we added to this formula another summand **R**:

$$\mathbf{V_f = [(P\text{-}I\text{-}W\text{-}F) \bullet S \bullet 10^{-3}] + R} \qquad \textbf{(Eq. 2)}$$

where:
P – precipitation for this area, $mm/y\text{-}m^2$ (1 mm = 10 tons of precipitation per hectare; for East Ukraine P=500);
V - evaporation rate, $mm/y \bullet m^2$ (for East Ukraine V=200);
W - water absorbed by solid waste, $mm/year \bullet m^2$ (for East Ukraine W=100);
F - water drained, $mm/year \bullet m^2$ (for East Ukraine F=10);
S - landfill working area, m^2;
R - water produced during MSW degradation, m^3/year, which is 0.3 m^3 (tons) of H_2O for every 1000 m^3 of natural biogas emitted.

Underground water samples were taken at the landfill border at the depth of 10-15 m. Altogether there were 8 wells: 2 at each of 4 sides. Three samples were taken from each well. The result of the analysis is an average value received for 3 samples. After that, an average value was obtained for all wells. Soil samples were taken at the distance of 500 m (sanitary zone) from the landfill border at the depth of 0.2-0.3 m also from four sides. From each side 3 samples were taken. After that all samples were averaged through quartering and the analysis was fulfilled. Atomic absorptive spectrophotometer "MGA-915" (Russia) was used to measure toxic (heavy) metals in soil, water and ash (samples of MSW were incinerated for that). The inaccuracy of the analysis did not exceed 9%.

II.3. Chromatograph "Chromatech" (Russia), which has been modified by us for heating of columns up to 325°C, was used to study <u>combustion of MSW</u>. MSW sample (225 g; composition is according to Tab.1; the speed of air supply into column was constant, being 1 liter/min). The tests were conducted with MSW being heated (in the thermostat) by +70°C, 120°C, 170°C, 220°C, 270°C, and 325 °C (when the temperature was higher than 300°C some of MSW components started to burn - for instance, the temperature of self-ignition of pressed paper is about 250°C).

On border of a sanitary zone (SZ) of the burning real MSW dump No. 3 (a concentric circle of 500 m from edge of a dump) we analyzed of toxic gases in air samples (1 m over ground) with help portative analyzers "MX-21-Plus" and "Multi-IMS" and also soil (samples of air and soil were selected and delivered to laboratory for analysis of the heavy metals with help atomic absorptive spectrophotometer).

We have studied concentrations of toxic gases produced after MSW incineration and total concentrations of “heavy” (toxic) metals in the ash. We measured the part of heavy metals, which transforms in more “volatile” forms and is emitted into atmosphere together with combustion gases as well as the part of heavy metals that enter the ash. Besides, we studied a part of heavy metals in the ash, which is “labile” and can migrate into soils. The inaccuracy of all measurements did not exceed 7-9%.

III. Results and Discussion

III. 1. General research of 4 real MSW landfills

In fact, it is not a classic landfills, it is a large unequipped dumps because the MSW are delivered there by dump trucks, it is bulking and then it is rammed by a tractors (up to density 0.6 t/m^3). These "landfills" aren't equipped with any technical means for collecting biogas and leachate. Besides, the wrong storing leads to self-heating and smoldering inside the MSW, and then to spontaneous ignition of separate sites of a dump.

Table 1. Real landfills characteristics *(data 2013)*

Landfills	Years of operation	Average quantity of MSW received each year (tons)*	Working area, hectares	Depth, m (average)	Average composition (mass. %)
No. 1	47	115000	11	25	food-25; plastic-20; paper-11; glass-6; wood-8; metal-8; textiles-4; stones-6; sweepings**-11.
No. 2	37	51000	4	12	
No. 3	29	48000	5	10	
No. 4	15	155000	24	18	

**) The bulk density of incoming MSW is 0.25 t/m^3, after landfill compaction it is 0.6 t/m^3.*
***)Approximately 1/3 of sweepings is an organic matter.*

The volumes (theoretical maximum possible) of biogas emitted from real Donetsk landfills No.1-4 were calculated according formula (Eq.1). The results are illustrated at Fig. 1.

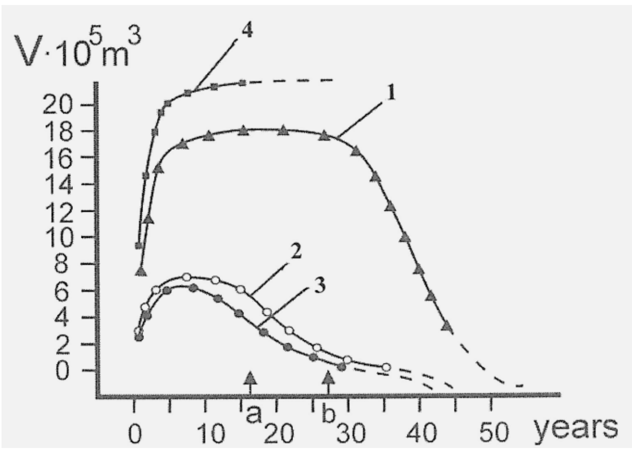

Fig. 1. The volumes (theoretical maximum possible) of biogas emitted from real Donetsk landfills No.1-4
("a" is sign when delivery of MSW to No.4 landfill was limited; "b" is the same for No.2 and No.3 landfills)

As we can see from Fig. 2, the biogases emitted from the No.1-4 landfills during biodegradation term reach their maximum at 1/4 – 1/3 of the full working period that is connected with activity of bacteria and also alterations of pH and temperature in a dump body on a similar curve for the overturned parabola (*de Bok, 2001, Gautam, 2012*). However, in fact, their conditions and statuses are rather different. For example, No.4 landfill quickly filled about 80% and authority was forced to limit delivery of MSW to No.4 landfill because it has very small working area (11 hectares only), it accepts too much MSW (135,000 t/year), and (this is main thing!) it is located too closely to habitation. Landfills No.2 and No. 3, in fact, were already almost full 10 years ago. But MSW delivery wasn't stopped there, only limited as this zone of Donetsk has no other place to store MSW; other dumps, first, too are crowded, secondly, authority will be forced to deliver the MSW through a large number of residential blocks. Therefore, these landfills are actually neither closed, nor opened; they are sort of "semi-legal" or "semi-illegal" MSW dumps. (Landfill No.1 is closed completely).

At the depth of 25 m, from the bottom layers of No.1 landfill there have been also taken samples of "residual" MSW. The age of these MSW layers corresponds to 35-40 years. The samples were tested for the level of moisture and the share of organic components. The average result received on the basis of three samples is the following: level of moisture - 5.1%, the share of organic components - 13.5% (the initial share 25 years ago was about 75% - see Tab. 1). Thus, during 47 years MSW have been considerably mineralized as a result of a deep biodegradation of organic component of MSW.

Measurements of biogas (greenhouse gases) emissions at 4 real landfills (from 2 m deep boreholes) show the following composition of biogas (see Tab. 2).

Table 2. Biogas (greenhouse gases) emission from real landfills

No.	2008		2013	
	CO_2,%	CH_4,%	CO_2,%	CH_4,%
1	69	31	69	31
2	65	35	67	33
3	57	43	60	40
4	50	50	55	45

In fact, the data of Tab. 2 have shown: at such landfills as No. 1-2 the process of biodegradation has almost finished, while at No. 3 and especially No. 4 «young» landfills (see Tab. 1) it is still active.

Gases sampled above (1m) the real landfills surfaces were tested for dust, H_2S, NO_2, NH_3, SO_2 and carbon monoxide (CO) - see Tab. 3. These results show that the local atmospheric concentrations above the landfills were often far behind the norm (especially for dust and NO_2). At landfills with smoldering of waste - No. 1 and (a little) No. 2 landfills - the share of carbon monoxide sharply increases.

Table 3. Atmosphere composition at the level of 1 m above the landfill ground (mg/m^3)

Paramete r	No. 1	No. 2	No. 3	No. 4	MPC*
Dust	0.8	0.5	0.6	0.3	0.15
H_2S	0.01	0.053	0.05	0.003	0.005
NH_3	0.013	0.01	0.04	0.023	0.04
NO_2	0.09	0.05	0.06	0.052	0.04
SO_2	0.14	0.05	0.012	0.018	0.05
CO	3.1 (smoldering)	5.6 (smoldering)	1.6	0.7	3.0

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

III.3. Leachate pollution

Despite of the fact that none of the four landfills has a leachate collection system, we can see many holes at each landfill where the leachate was cumulated. We have analyzed leachate composition at No. 3 landfill; the data are listed in Tab. 3. We have studied the composition of underground water the samples of which were taken from the wells surrounding No. 3 landfills. The sampling was done from the depth about 5-10 m.

Table 4. Leachate composition at No. 3 landfill

Parameter	Concentration (mg/l)	MPC*
BOD**	2130	350
Oil products	110	0.5
Ammonia nitrogen	512	10.0
SSAM***	0.3	0.01
Fe	190	0.3
Ni	0.3	0.1
Zn	11.4	1.0
Pb	4.1	0.03
Cd	0.06	0.001
Cr	0.4	0.05
Hg	0.2	0.0005

**) MPC- maximum permitted concentration;*

***) BOD - biochemical oxygen demand - is the amount of dissolved oxygen needed by aerobic biological organisms in a water;*

****)SSAM - synthetic superficially-active materials.*

Data of Tab. 4 demonstrate that concentration of toxic substances in leachate in hundreds, and sometimes thousands times more sanitary norms (MPC), i.e. leachate is highly toxic and very dangerous liquid.

The calculation of leachate produced at No. 3 landfill has been done by formula (Eq. 2). If to apply the equation to No. 3 landfill, which occupies 3.1 hectares (Table 1), using R = 200 m^3/y and the values shown in Table 7, the expected annual leachate production will be 298 m^3/y:

$$V_f = [500 - 200 - 100 - 10] = 190 \text{ x } 5 \text{ x } 104 \text{ x } 10^{-3} = 5890 + 300 = \mathbf{298\ m^3/year.}$$

Uncontrolled production of such big volumes of toxic leachate should inevitably worsen ecological conditions of nearby underground water and soil.

For check of possible soil pollutions on border of a sanitary zone (SZ-border) No. 3 landfill (a concentric circle of 500 m from edge of landfill) were analyzed samples of soil (see Tab. 5).

Table 5. The results of soil research on the SZ-border for No. 3 landfill

Parameter	**MPC** (mg/kg)	**Real concentration**	**Outreaching**
Cd	0.2	0.78	4
Ni	4.0	3.3	7
Pb	6.0	1.9	3
Hg	0.05	0.3	6
Nitrates	10	82	8
Oil products	0.3	3.6	12

The data of Tab. 4 confirm the worst fears regarding high danger of leachate from unequipped MSW dumps.

III.4. The danger of MSW combustion processes

For studying of danger of self-heating and self-ignition of MSW stored on unequipped dumps, samples of MSW (in briquettes with density 0.6 t/m^3) were exposed to thermal destruction in laboratory installation (Fig. 1) at temperatures of 100-375 °C. Results of measurements – in Tabs. 6-7.

We have studied concentrations of toxic gases produced after MSW incineration and total concentrations of "heavy" (toxic) metals in the ash (within device on Fig. 1). We measured the part of heavy metals, which transforms in more "volatile" forms and is emitted into atmosphere together with combustion gases as well as the part of heavy metals that enter the ash. Besides, we studied a part of heavy metals in the ash, which is "labile" (soluble) and can migrate into soils (if will be washed out from ash by rain). The results of the measurements are provided in Tabs. 6-7.

Table 6. Concentration of emitted toxic gases after MSW incineration (mg/m^3)

Concentration of toxic gas							
CO	**SO_2**	**H_2S**	**C_6H_5OH**	**NO_2**	**HCL**	**HCN**	**CH_2O**
678	8.8	13.7	5.7	41	0,2	0,12	19.8

Table 7. Concentration of toxic metals in initial MSW and MSW's ash

Parameter	**Concentration of toxic metals in MSW ash (mg/kg)**						
	Pb	**Ni**	**Cr**	**Cu**	**Zn**	**Hg**	**Co**
Sample of initial MSW	511	140	190	1270	2410	3.2	46
Sample of MSW' ash	288	120	180	1100	2080	0	36
Quantity of toxic metals that was washed out from the ash – imitation of rain	48.3	8.5	9.9	15.7	23.8	0	1.34

By comparing the data of Table 7 we can see that ash accumulates all of toxic metals, excluding mercury and lead: mercury completely vaporizes into air and lead – half-on-half.

So, we have established that during incineration of MSW the vast emission of toxic gases in an atmosphere will take place. Some parts of each of the heavy metals are taken to the atmosphere together with combustion gases, the other parts enter the ash. At the same time some parts of heavy metals that have passed into ash are in a soluble form, i.e. they might (in case of precipitation of ash on wet soil) to enter in the soil. It is interesting to note that each heavy metal has its "own character".

For check of air pollutions on border of a sanitary zone (SZ-border) for burning No. 1 landfill (a concentric circle of 500 m from edge of landfill) samples of air were analyzed (see Tab. 8).

Table 8. The results of research of the SZ-border for No. 1 landfill (mg/m^3)

Parameter	MPC	Number	Exceeding
NO/NO_2	0.035	0.55	16 *(times)*
H_2S	0.05	0.39	8
HCl	0.2	0.8	4
Ash	0.1	0.71	7

Evidently, combustion gases from the burning dump have high toxicity (see Tab. 8) and high dander for environment.

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Thus, the data of Tabs. 1- 8 and Fig. 1,2 show that Ukrainian MSW landfills which are not equipped by collection systems for biogas (including toxic gases) and leachate, present a big threat for the environment and human life – see Fig. 2.

It would be desirable to note: deep studying of unequipped and illegal large MSW dumps is accompanied by huge technical complexity and labor input and even some health hazard of researchers. Perhaps, it is one of the main reasons why in scientific literature the vast studying of real large MSW dumps are in many times less, than of "laboratory dumps".

The problem of danger of unequipped MSW dumps is typical for the majority of the countries of South America, Asia, and Southern Europe. So, in Brazil from 2003 to 2011 1.5 million tons per year of CO_2 (an average) were emitted into the atmosphere *(Methane, 2011).* According to the Environmental Sanitation Technology Company (CETESB) study, the 6,000 waste sites in Brazil receive 60,000 tons of waste per day. 76% of this waste goes to dumps with no management, gas collection, or water treatment and 83% of Brazil methane gas emissions come from uncontrolled waste sites.

But this problem exists and for economically developed countries. So, in Canada, landfill sites produce about 27 million tons of carbon dioxide and methane annually, and only 6.9 million tons (25%) from that are collecting *(Canada's, 2012)*.

We don't share opinion *(Manfredi, 2009)* regarding "Significant amounts of biogenic carbon may still be stored within the landfill body after 100 year". MSW sample from the real Donetsk landfill of No.1 at a depth of 25 m and the having age about 40 years - contained 13.5% organic components only.

Unfortunately, we didn't study the smoldering Donetsk dumps concerning dioxine due to the lack of access to reliable analyzers of dioxine. Therefore the scientific paper *(Mazza, 2015)* well fills up a gap in our studying. At research of influence of the illegal burning dumps (including toxic waste) in Italy (province of Campania) on health of local population, it was found high concentrations of dioxins (≥5.0 pg TEQ/g fat) in sheep and cow milk samples, and also dangerous contamination of dioxin and polychlorinated biphenyls in woman milk samples from those living in Campania (at 16.6 pg TEQ/g of fat).

In Tab. 4, the results of measurement of toxic metals concentrations in leachate are illustrated. But researches (Baun, 2004) testify that these data (and also data of many other authors) could be underestimated. Baun and his colleagues evidently showed that colloids as well as organic and inorganic complexes take place for all heavy metals in landfill leachate. The free metal ions constitute less than 30% total metal concentration, and no standardized procedures exist for assessing the content of "associated" metallic ions in leachate.

Unequipped dumps are a powerful source of greenhouse gases and, therefore, it is one of "responsible" for negative climate change. In Fig. 1 of our paper it is visible, what huge volumes of greenhouse gases (which are estimated by hundreds of thousands or millions of cubic meters) are emitted by each of four Donetsk dumps during the activity (20-40 years). According to calculations *(Monni, 2006)*, world emission of biogas (which greenhouse gas is) from 1990 to 2050 will increase by 9 times (from the real 340 Mt in 1990 up to calculated 2900 Mt – if to change nothing in management of municipal waste).

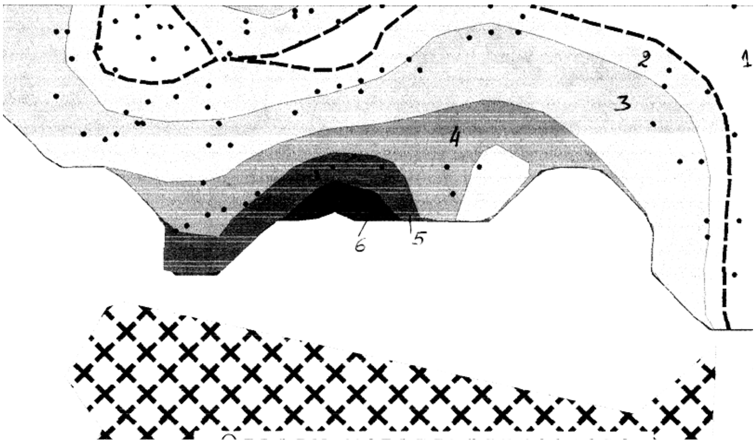

Fig. 2. The map of average life expectancy of the people living near unequipped Donetsk MSW dump (the place of a dump is marked by crosses; scale: 1sm-1km): zone 1 - 65 years, 2 – 62 years, 3 – 60 years, 4 – 55 years, 5 – 50 лет, 6 – less 50 years

IV. Conclusions

1. In their present state these researched MSW dumps don't have any engineering infrastructure (gas collection, water treatment, etc.) ensuring public health and environmental safety.
2. These studies has provided qualitative and quantitative assessments of such danger factors for unequipped MSW dumps as generation of greenhouse gases and toxic gases, allocation of toxic metals between air, ash, and soil, and also self-heating and self-ignition of MSW dumps because of bacteria activity.
3. It was established that each heavy metal during incineration of MSW has its own “character”. For example, ash accumulates all of heavy metals, excluding mercury and lead: mercury completely vaporizes into air and lead – half-on-half.
4. These problems are also typical for many other countries with transitional economies as their municipal budgets are not sufficient to solve similar problems.
5. Thus, the biggest problem is that countries with transitional economics are to learn то how to store and to incinerate MSW not only for the benefit of the economy, but (and it is the most important!) without damaging of health of population and the environment.

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