SOLVING TECHNICAL PROBLEMS THROUGH EQUATIONS

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Abstract: The need for solid household waste (MSW) generated by economic and domestic activities is continuous and should be imposed to protect the health of the population and environmental factors. After sorting the generated waste, „the remaining residue" favours the occurrence of some pollutants, among which we mention suspended particulates, disagreeable odours, greenhouse gases, etc. This waste has to be managed in safe health and environment, no matter where it was generated. Managing them means either storing in statutory environmental protection facilities or incinerating in authorized installations with integrated environmental permitting. Waste storage may be subject to a mathematical equation called the time equation of a landfill. On the basis of such equation, it will be possible to calculate annually the amount of degraded waste gas generating gas (LFG) containing CH_4 and CO_2. The amount of degraded waste means waste with high dissolved organic carbon (DOC).

Keywords: landfill equation, CH_4, CO_2, remaining residue

1. INTRODUCTION

On January [1], 2016, according to INS [1], Romania had a population of 20121641 inhabitants, of which 56.41% in urban environment and 43.59% in rural areas. Recognizing that 1.7 kg of waste per inhabitant per day is generated in the urban environment and 1.1 kg of waste per inhabitant per day in rural areas, a waste amount of approx. 7400 Gg/year waste have to be disposed off in landfills complying with environmental legislation. Knowing the waste generation index (in kg of waste/inhabitant/day) and the number of inhabitants assigned to the waste collection system, the land used needs to be calculated for the location of a landfill [2, 3]. The calculation relationship is determined based on the following algorithm:

1. the daily waste generation rate is calculated:

$$Q_{MSW\ generated/day} = N_{loc} \cdot I_{mrd} \cdot k_1 \cdot k_2\ [Gg/zi]\ [2,3] \tag{1}$$

where $Q_{MSW\ generated/day}$ – the daily waste generation rate; N_{loc} – the number of inhabitants generating waste; I_{mrd} – waste generation index [kg/inhabitant/day]. It can take values between 0.9 – 2.1 kg/inhabitants/day (it is an estimate for Romania, year 2050); k_1 – conversion factor of unit of measure (from kg to t); k_2 – unit conversion factor (from t to Gg);

2. the area required for the storage of the waste is estimated:

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$$S_{required\ landfill/zday} = \frac{\frac{Q_{MSW\ generated/day} \cdot 1000\ kg/t}{\rho_{dens\ MSW}}}{h} [m^2/day] \quad (2)$$

where $Q_{MSW\ generated/day}$ – the daily waste generation rate [t/day]; $\rho_{dens\ MSW}$ – density of collected waste [kg/m^3]. For Romania the values are between 350 – 450 kg/m^3 [2]; h – the height of the waste deposited in one day [m]. h can take values between 6 – 30 m;

The storage space required for one year will be:

$$S_{required\ landfill/year} = \frac{S_{required\ landfill/day} \cdot 365\ days/year}{1000\ m^2/ha}\ [ha/year] \quad (3)$$

where $S_{required\ landfill/day}$ – the area required for storing waste for 1 day [m^2/day]; 365 days/year – calendar year; 10000 m^2/ha – the area of one hectare.

The following example aims to determine the waste storage area required for 200,000 inhabitants (waste generators), knowing that the rate of generation is 1.7 kg/people/day, density of waste at collection is ρ_{dens} MSW = 450 kg/m^{3,} and the waste height in the deposit is h = 10 m after compaction.
Solution:
1. the daily waste generation rate

$$Q_{MSW\ generated/day} = N_{loc} \cdot I_{mrd.} \cdot k_1\ [t/zi]$$

$$Q_{MSW\ generated/day} = 200{,}000 \cdot 1.7 \cdot 0.001 = 340\ Mg/day = 0.340\ [Gg/day]$$

2. the area required for the waste storage

$$S_{required\ landfill/day} = \frac{\frac{Q_{MSW\ generated/day} \cdot 1000}{\rho_{dens\ MSW}}}{h} [m^2/zi]$$

$$S_{required\ landfill/day} = \frac{\frac{340\ Mg/day \cdot 1000}{450\ kg/m^3}}{10\ m} = 76\ m^2/zi$$

The required annual area will be:

$$S_{required\ landfill/year} = \frac{S_{necesar\ depozit/zi} \cdot 365\ zile/an}{1000\ m^2/ha}\ [ha/an]$$

$$S_{required\ landfill/year} = \frac{76\ m^2/day \cdot 365\ days/year}{10000\ m^2/ha} = 2.775\ ha$$

The calculated area should be increased by 30 – 50% due to other requirements: office buildings, car park building, building for weighing vehicles that discharge waste, access roads, technical locations (flame burner, station for filtration – retention of CO_2, CH_4 engine station, leaching treatment plant, access to utilities). Account shall also be taken of the contours of the landfill (protective curtain, surrounding fence).

Considering that in the 8 Environment Region Bucharest – Ilfov are 3 landfills, which comply with the legal provisions regarding the environment protection, where approx. 950 Gg of waste/year are deposited, shows that the rest of the country has to store 6450 Gg of waste per year in landfills complying with the environmental protection legislation.
This paper does not refer to hazardous waste and inert waste, although amounts of inert waste and land uncontaminated with dangerous chemical substances and preparations can be stored at landfills (MSW).

2. SCIENTIFIC RESEARCH – APPLICATIONS OF MATHEMATICS

In applicative fields such as science, technology and even scientific research, many problems are solved through equations. In all cases, the problem needs to be translated into mathematical language [4]. For example, the text

„If 7 adds to 3 times a natural number the same result is obtained as when this number is subtracted from 13” leads to the following equation:

$$3x + 7 = 13 - x,\ x \in N \quad (4)$$

where x is the discrete variable that takes values within a narrow range and its size depends on the environmental conditions.

For a landfill we can say that if 7 accumulates 3 times the quantity of waste deposited on a site, the same result is obtained as when a time t (expressed in months m) is decreased of the number (12n + 13), where n is the number of the year when the CH_4 emission estimation is calculated from the analyzed landfill.

Thus, the equation

$$3t + 7 = 13 - t \quad (5)$$

(x was replaced with time t, expressed by the number of months m) becomes the time equation of a landfill in the first year of storage. As a rule, storage continues to the projected capacity of the landfill. After the second storage year, the equation is generalized:

$$(3 + 8n)t + 7 = (12n + 13) - t \quad (6)$$

For each calculation year of CH_4 estimated emission, n = 1, 2, 3, ..., 30, …, the equation has another form. In a landfill, DOC degradation is not related to the half-life $t_{1/2}$, but is subject only to the duration of the environmental factors involved in the calculation year (precipitation season, dry season, freeze – thaw season, sunlight influence) expressed in number of months m. Figure 1 shows the operation scheme (waste disposal and CH_4 emission calculations) of a landfill.

The number of the calculation year is given by the values of n = 1, 2, ..., 30, ..., for n = 0 the equation (5) is obtained, i.e. the case of the first year of storage when it was agreed that are not CH_4 emissions from LFG. Although, an incipient emission of CH_4 is taking place. As it can be seen from equation (4), by dividing 3 : 7 = 0.43 results in low emission of CH_4 ($m_o = 0$).

Analytic determination of m values, $m \in N$, $7 \leq m \leq 18$.

Parameter m is defined as the number of months in which a maximum of 45% of the deposited MSW in the body of the warehouse is degraded or taken into account in the calculation year. For n = 1, the 1st year of calculation (after the 2nd year of MSW storage), the equation becomes:

$$11t + 7 = 25 - t \quad (7)$$

The variable m will be 7. From the equation (7) we can see that the time elapsed from storage to the calculation year is 24 + 1 = 25 months (1 month is the time of collecting information about the MSW deposit). The value of m can be 7, 8 or 9. Noteworthy is that the free term of equation (7) specifies the time since the beginning of waste storage expressed in months. In the CH_4 emission estimation year, this number should be decreased by 7 months (the last 6 months (01.07 – 31.12)) because the MSW deposited at the calculation year is considered not decayed. Also, for each year of CH_4 emission calculation, it is necessary that the sum of the values of m (as random variable) be less than the number of calendar months minus 7. The relationship is:

$$\sum_{i=0}^{n} m_0 + m_1 + m_2 + \cdots + m_n \leq [(12n + 13) - 7] \quad (8)$$

For n = 2, equation (8) becomes:

$$19t + 7 = 37 - t \quad (9)$$

The value of m is 7, but may be 8 or 9 or 10.

For n = 3, equation (8) becomes:

$$27t + 7 = 49 - t \tag{10}$$

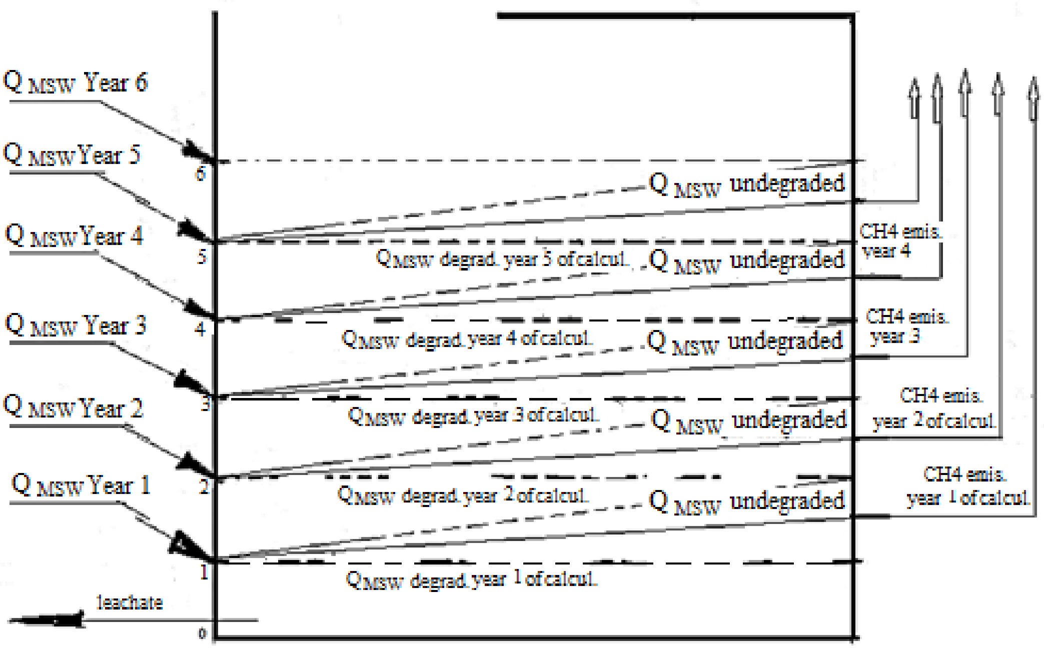

Fig. 1. Scheme of a complying landfill in activity: Q_{msw} – quantities of waste deposited annually: $Q_{msw.degraded}$ – quantities of degraded waste at the calculation year; $Q_{msw.undegraded}$ – amounts of non-degradable waste at the calculation year (taken into consideration the following year); CH_4 – methane gas contained in LFG deposit gas (LFG emission estimate calculation begins after the end of the 2nd storage year); leachate – due to the moisture content of the waste and atmospheric precipitation (the leachate needs to be cleaned)

It is found that the value of m is 7 (because $49 : 7 = 7$). Between the value of n = 3 and n = 8, the division of the free term to 7 determines the value of the random variable m. Therefore, it can be said that starting with the 3rd year of calculation of the CH_4 emission and up to the 8th year for calculating the value of the variable m it is possible to use the relation (1) $\frac{F.T:R}{7} \cong m$, [5, 6] where F.T.R is the free term of the equation for the calculation year, and 7 is the reference number.

Starting with the 9th calculation year (n = 9) and up to the 30th calculation year (n = 30), for determining the value of the variable m, we can use the relation (2) $\frac{F.T.R-C.t.L}{7} \cong m$, [7] where *FTR* is the free term of the equation for the calculation year, and *C.t.L.* is the coefficient of t from the left side of the equation (7) at the calculation year.

It is very important to note that the values of parameter m do not depend on the amount of stored MSW but generate the amount of degraded MSW in the calculation year; therefore, it is necessary to know the amount of MSW deposited annually in the deposit body.

3. RESULTS AND DISCUSSIONS

The CO_2 evolution graph for the MSW deposit in Galbinasi, Buzau County between 2003 – 2011 is shown in Figure 2. The store does not collect CH_4.

The calculations [7, 8] show that the amount of CH_4 generated (0.76401 Gg) in 2009 should be collected either for green energy production or for burning. In both cases, there is a decrease in the greenhouse effect.

The intensive generation period of CH_4 may vary between 20 – 25 years. With the cessation storage MSW LFG emissions, containing CH_4 at low intensity, can last for approximately 25 – 30 years.

The scheme for the collection of LFG gas containing CH_4 and CO_2 in a legal MSW landfill as well as vacuum calculations, the condensate collection scheme and the CO_2 retention scheme of the LFG storage gas are the subject of another article.

In case of MSW deposits collecting LFG storage gas, respectively CH_4, it is necessary to know the amount of collected or flame-burned gas and only then the calculation of the quantity of MSW degraded at the calculation year can be done.

Need of LFG collection occurs due to fire and explosion hazard. The MSW landfill location must comply with the provisions of Order no. 119/2014, for the approval of the Hygiene and Public Health Norms on the Living Environment of the Population, of the Ministry of Health, published in the Official Gazette no. 127/February 2014.

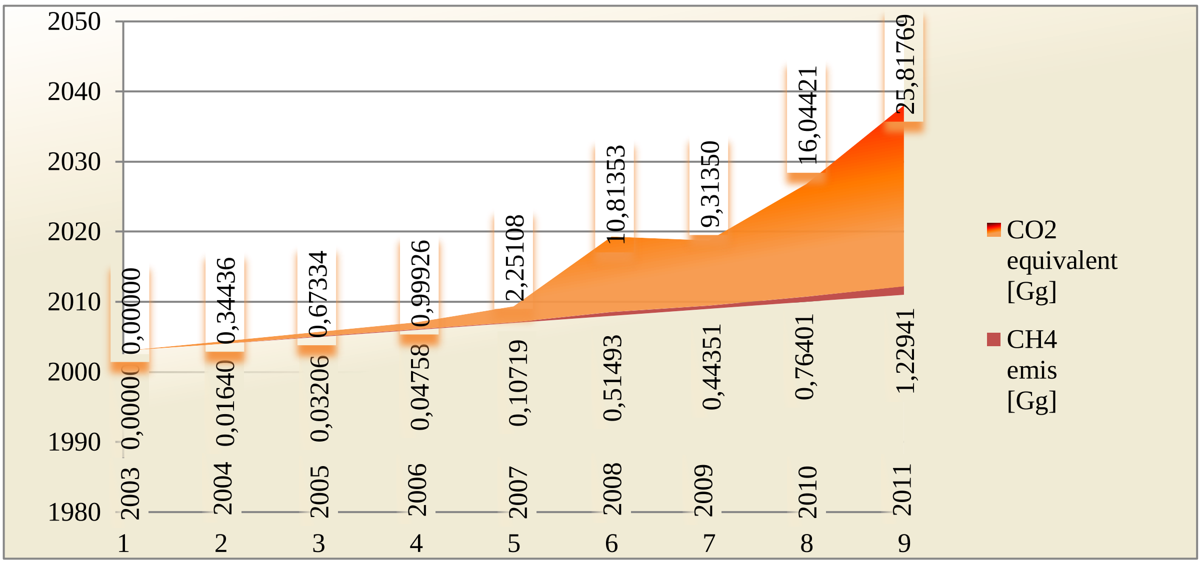

Fig. 2. Waste deposit in Galbinasi, Buzau County – development of equivalent CO_2 during 2003 – 2011.

For the 8th year of calculation, the deposit equation is:

$$67t + 7 = 109 - t \tag{11}$$

Table 1. Quantities of MSW deposited in the body of the landfill as a result of the information sent by the territorial environmental authority and the number of months m set at the year of calculation of the degraded MSW amount.

Reference years	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stored MSW quantities [Gg]									
MSW amount	9.958	54.153	69.330	76.184	93.100	137.895	161.400	164.581	145.131
Number of months m (in the years of calculation), according to nomogram									
Number of months m	0	9	9	9	8	18	17	15	11

It is easy to note that the sum of the months set in the calculation year is $96 \leq 109 - 7$ (see equation (11) of the 8th year of calculation), i.e. $96 \leq 102$.

For calculating the degraded MSW amount at the calculation year, for the Galbinasi landfill, Buzau County, the percentage composition of MSW in the landfill body is presented in Table 2.

The percentage composition of the waste in the body of the MSW deposit can be changed annually or 3 to 5 years depending on the economic and social development of the county.

Table 2. MSW percentage composition in case of Galbinasi landfill body, Buzau County for the period 2003 – 2011.

Types of MSW deposited in the landfill body	%
Biodegradable MSW, including from markets and fairs	58.20
MSW from gardens and parks, including cemeteries	14.00
Non-recyclable waste paper and cardboard	9.50
Wood waste (non-recyclable) and straw	3.40
Non-recyclable textile waste	3.20
Sludge from sewage plants not used in agriculture, sewage sludge	2.50
Industrial waste similar to household waste, sterilized sanitary wastes (from hospitals, dispensaries, clinics, private clinics, veterinary units)	9.20

4. CONCLUSIONS

The storage of residual waste after sorting solid municipal waste into storage sites with storage capacities of about 150 Gg/year leads to CH_4 emissions that generate greenhouse effects for long periods of about 50 years. Decrease in greenhouse effect can be achieved by collecting CH_4 and use it for green energy production or flaming combustion of collected gas.

CH_4 collection means studies on the extraction wells location, i.e. the technological capacities development for the implementation of the methane collection system and the management from thereof.

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