DEFINING THE NEEDS AND DEVELOPING AN INFORMATION SYSTEM FOR THE MONITORING AND REPORTING OF LANDFILL GAS FOR MUNICIPAL LANDFILLS

POTREBA I RAZVOJ INFORMACIONOG SISTEMA ZA PRAĆENJE I IZVEŠTAVANJE O OSLOBAĐANJU DEPONIJSKOG GASA SA KOMUNALNIH DEPONIJA

Stefan MANDIĆ-RAJČEVIĆ^{1*}, Ana DAJIĆ¹, Alempije VELJOVIĆ²,
Mića JOVANOVIĆ^{3,4}

¹ Innovation Center of Faculty of Technology and Metallurgy Ltd. Belgrade,
University of Belgrade, Belgrade,

² Faculty of Technical Sciences Čačak, University of Kragujevac, Čačak,

³ Faculty of Technology and Metallurgy, University of Belgrade, Belgrade,
⁴ Academy of Engineering Sciences of Serbia, Belgrade

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Serbia is the largest country in the region, and with a little over 7.5 million people has more than 3600 waste dumpsites. When low level of recycling (less than 10%) and existence of only 7 larger landfills is taken into account, it becomes clear that there is a need for upgrading the waste management in our country in order to prevent the negative influences on the environment and human health, but also to satisfy the requirements necessary to join the European Union. There are many models allowing estimating the quantities of landfill gas, and several calculators exist in the form of Excel sheets, but there is no integrated software solution which would facilitate monitoring of municipal waste landfilling, estimating emissions, and reporting. The aim of this paper is to analyze the needs for a software solution of this kind in Serbia and present the basic steps in the development of this software solution.

Key words: software development; landfill gas; modelling; quantification

Srbija je najveća zemlja u regionu, i sa svojih 7,5 miliona stanovnika ima 3600 nelegislativnih deponija. Kada se uzme u obzir veoma nizak nivo recikliranja (ispod 10%), i postojanje samo 7 regionalnih (većih, uređenih) deponija, jasno je da se upravljanje otpadom u našoj zemlji mora unaprediti kako bi se zaštitila životna sredina i stanovništvo, ali i da bi se ispunile zakonske obaveze i omogućilo pridruživanje Srbije Evropskoj Uniji. Trenutno postoji veliki broj modela za procenu oslobađanja deponijskog gasa, kao i nekoliko kalkulatora u obliku Excel tabela za praktičnu upotrebu, ali ne postoji softversko rešenje koje bi olakšalo praćenje deponovanja komunalnog otpada, upravljanje emisijama i izveštavanje. Cilj ovog rada jeste da se analiziraju potrebe tržišta u Srbiji za ovakvim rešenjem i predstave osnovni koraci u razvoju ovakvog informacionog sistema.

Ključne reči: razvoj softvera; deponijski gas; modelovanje; kvantifikacija

1 Introduction

Waste disposal is the last but very important step in waste management. One of problems, which should be solved in landfill project design, is landfill gas collection and treatment. Since over 2.4 tons of waste is placed on landfills annually, there is great potential of landfill gas generation (Stanisavljević, Ubavin, Batinić, Fellner, & Vujić, 2012).

Landfill gas emissions (LGE) are big environmental problem, but it could also be renewable source of energy emerges as product of microbiological degradation of waste. Therefore, economic benefits could be obtained if landfill gas is managed in good manner.

1.1 The landfilling system in Serbia

In Serbia, waste is disposed on 3600 landfills distributed all over the country. Those landfills are legal and illegal. Almost no landfill (except a few regional ones built in the last decade) has been built according to national legislations. They are characterized with small total volume deposition depth and volume of waste less than 10,000 m³. Conclusion from industrial practice is that optimal high of waste for successful gas extraction is between 5 and 30 m including sufficient amount of minimum 100,000 m³. In Serbia only 50

* Corresponding author: stefan@tmf.bg.ac.rs

landfills have average waste high over 3 m with amount more than 100,000 m³ (Karanac, Stevanović, Mandić-Rajčević, Jovanović, & Jovanović, 2017).

Regional landfills built in the last few years have installed system for gas collection, mostly bio-spines. New designed landfills, regional and landfills in general, are obligated to have gas collection systems. In order to collect gas efficiently, landfill should meet the requirements and recommendations of Serbian and European regulations. Technical requirements are about structural characteristic of landfill, volume and composition of waste, characteristics of system for the gas collection and the specially designed generator for gas burning. Table 1 shows the list of Serbian regional landfills.

Table 1. The list of regional landfills, which already have a project proposal

No.	Regional landfill	Population (1000s)	MSW (2015) (t)
1.	Beograd	1,500.0	558,060
2.	Subotica	286.1	75,067
3.	Kragujevac	219.0	59,641
4.	Zajecar	236.4	87,139
5.	Uzice	346.7	76,100
6.	Nis	324.1	82,322
7.	Krusevac	317.8	100,752
8.	Novi Sad	370.0	142,988
9.	Zrenjanin	193.3	49,123
10.	Loznica	138.7	34,120
11.	Leskovac	296.3	75,273
12.	Vranje	216.1	85,090
13.	Pancevo	138.1	55,103
14.	Lapovo	150.0	38,106
15.	Sombor	164.1	41,675
16.	Kikinda	143.2	36,368
17.	Vrsac	111.0	28,215
18.	Indjija	250.0	63,510
19.	Smederevo	147.6	37,492
20.	Sabac	201.9	51,297
21.	Jagodina	160.0	40,646
22.	Nova Varos	107.2	27,239
23.	Pirot	106.5	27,055
24.	Ub	362.0	91,962

National Waste Management Strategy for the period 2010-2019. envisages a system of 24-29 regional landfills by 2025 (Vlada Republike Srbije, 2010).

1.2 Requirements for emissions' reporting in Serbia

Proper management of landfill gas reduces the emissions of GHG (greenhouse gases). Although efforts are made for that proposes, there are still uncontrolled air emissions. The Monitoring Mechanism Regulation (MMR) is an EU legislative act that regulates the effective monitoring and reporting of all anthropogenic (human-induced) greenhouse gas emissions and is a legal framework for policymaking and measures in that area. The main objective of the Regulation is to fulfill the obligations of the countries of the EU under the UNFCCC that, in the same or similar form, apply to Serbia as a member of the UN Framework Convention on Climate Change. Certainly, the obligation to implement the requirements of this Regulation derives from the process of harmonization of national legislation with EU legislation. Serbian registry of information and data on environmental contaminations, an integrated cadastre of pollution (IKZ), provides a starting point for identifying and monitoring sources of pollution. Based on the principles of the PRTR protocol, the Aarhus Convention and harmonized with the applicable regulation of the European Union. According to Environmental Protection Law, plants recognized as a source of emissions and environmental pollution should report emissions (Ministarstvo zaštite životne sredine, 2007; Skupština Republike Srbije, 2016). Reports should be submitted until March 31 for the previous year. The aim of this paper is to analyze the needs for a software solution of this kind and present the basic steps in the development of this software solution.

2 Landfill gas emissions

Considering the low, or almost non-existent separation of waste in Serbia, more than 50% of landfilled municipal solid waste (MSW) is biodegradable waste. When biodegradable waste is landfilled, microbial populations mediate the transformation of carbon to CH_4 and CO_2 (Doorn, Barlaz, & Thorneloe, 1995). The high fraction of organic compounds in MSW results in potentially high quantities of methane, which can be released into the atmosphere.

The Global Warming Potential (GWP) of methane is considered 25 times higher than that of carbon monoxide, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change of July 2014. Therefore, methane released from landfills with high organic fraction contributes directly to global warming. Having in mind studies which estimate that methane can remain in the atmosphere and produce the said effect for up to 12 years, the importance of estimating and reporting landfill gas emissions is underlined (Anderson et al., 2010).

Studies have estimated that landfills can contribute to between 5 and 10% of global methane emissions. This represents around 10% of the total anthropogenic fraction of methane (Bingemer & Crutzen, 1987). Contrary to fossil fuels which have an extremely high contribution to greenhouse gas emissions, methane emissions from landfills have a substantial time delay depending on the biodegradable content in the waste (Baldasano & Soriano, 2000). A mass of around 1 t of biodegradable municipal solid waste can be responsible for intensively releasing landfill gas for up to 30 years (a liability into an Asset, 1996).

2.1 Quantifying landfill gas emissions

In Serbia, some estimates put the levels of emissions from landfills, expressed as CO_2 equivalent, to almost the same as those from all parts of the national industry put together (UN Climate Change Secretariat, 2015). More than 95% of the CH_4 emissions are generated on largest Serbian landfills. Nevertheless, all methane emissions from municipal landfills, dumpsites (with irrelevant contribution due to aerobic conditions of decomposition), and the few regional landfills which have been built so far is currently being released into the atmosphere as pure pollution, and a major challenge remains estimating the gas quantities.

Landfill gas quantities depend on the waste contents, age (time passed), the height of the landfill, type of waste transformation (aerobic vs. anaerobic), climate (rainfall, temperature, etc.), pH, presence of other substances, and several other factors. The quantity of landfill gas is the highest in the anaerobic phase of decomposition. First models for landfill gas quantification have been developed in the 70s by the United States Environmental Protection agency. Models can be of zero, first and second order, multiphase models, or their combination. Most important parameters, also the input variables for the models, are the methane generation rate constant (k), methane generation constant (L_0), the quantity and waste composition (Karanac et al., 2017).

2.2 Available software solutions, advantages and problems

To facilitate managing the entire greenhouse gas cycle, an adequate and well-designed software solution is needed. It should help organize the emission inventory, collect and verify waste data, produce emission estimates, help monitor emissions, and comply with local regulations. The United States Environmental Protection Agency has developed a simple software solution, based on Microsoft Excel, for the quantification of landfill gas emissions (Model, 2005).

This software solution requires the user to input some basic information about the landfill, waste quantities and composition (see **Figure 1**), as well as to add and/or modify possible pollutants, their molecular weights and quantities (see **Figure 2**). At the end of the process, the expected quantities of landfill gas, together with the CO_2 and CH_4 quantities are calculated for the selected years.

Although several other free and commercial software solutions exist, they cannot be considered adequately developed for the Serbian landfill management system, nor the requirements for reporting by the Serbian Environmental Protection agency. Our aim is, therefore, to develop an informational system adequate to respond to the environmental protection and emissions reporting needs of landfill management companies in Serbia, having in mind the current situation in the waste management sector in Serbia, as well as the scope of the waste management legislation in our country.

USER INPUTS Landfill Name or Identifier:

1: PROVIDE LANDFILL CHARACTERISTICS

Landfill Open Year
Landfill Closure Year
Have Model Calculate Closure Year? ☐ Yes ☒ No
Waste Design Capacity megagrams

2: DETERMINE MODEL PARAMETERS

Methane Generation Rate, k (year⁻¹)
0.05
Potential Methane Generation Capacity, L_0 (m³/Mg)
CAA Conventional - 170
NMOG Concentration (ppmv as hexane)
CAA - 4,000
Methane Content (% by volume)
CAA - 50% by volume

3: SELECT GASES/POLLUTANTS

Gas / Pollutant #1
Total landfill gas
Gas / Pollutant #2
Methane
Gas / Pollutant #3
Carbon dioxide
Gas / Pollutant #4
NMOG

4: ENTER WASTE ACCEPTANCE RATES

Input Units: Mg/year

Year	Input Units (Mg/year)	Calculated Units (short tons/year)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		

Description/Comments:

INTRO USER INPUTS POLLUTANTS INPUT REVIEW METHANE RESULTS GRAPHS INVENTORY REPORT

Figure 1. LandGem User Inputs window (sheet)

POLLUTANTS Landfill Name or Identifier:

Enter New Pollutant Parameters Edit Existing Pollutant Parameters

Default parameters will be used by model unless alternate parameters are entered.

Enter User-specified Pollutant Parameters for Existing Pollutants:

	Compound	Gas / Pollutant Default Parameters:		Enter User-specified Pollutant Parameters for Existing Pollutants:	
		Concentration (ppmv)	Molecular Weight	Concentration (ppmv)	Molecular Weight
Total landfill gas			30.03		
Methane			16.04		
Carbon dioxide			44.01		
NMOG		4,000	86.18		
1,1,1-Trichloroethane (methyl chloroform) - HAP		0.48	133.41		
1,1,2,2-Tetrachloroethane - HAP/VOC		1.1	167.85		
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC		2.4	98.97		
1,1-Dichloroethane (vinylidene chloride) - HAP/VOC		0.20	96.94		
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC		0.41	98.96		
1,2-Dichloropropane (propylene dichloride) - HAP/VOC		0.18	112.99		
2-Propanol (isopropyl alcohol) - VOC		50	60.11		
Acetone		7.0	58.08		
Acrylonitrile - HAP/VOC		6.3	53.06		
Benzene - No or Unknown Co-disposal - HAP/VOC		1.9	78.11		
Benzene - Co-disposal - HAP/VOC		11	78.11		
Bromodichloromethane - VOC		3.1	163.83		
Butane - VOC		5.0	58.12		
Carbon disulfide - HAP/VOC		0.58	76.13		
Carbon monoxide		140	28.01		
Carbon tetrachloride - HAP/VOC		4.0E-03	153.84		
Carbonyl sulfide - HAP/VOC		0.49	60.07		
Chlorobenzene - HAP/VOC		0.25	112.56		
Chlorodifluoromethane		1.3	86.47		
Chloroethane (ethyl chloride) - HAP/VOC		1.3	64.52		
Chloroform - HAP/VOC		0.03	119.39		
Chloromethane - VOC		1.2	50.49		
Dichlorobenzene - (HAP for para isomer/VOC)		0.21	147		
Dichlorodifluoromethane		16	120.91		
Dichlorodifluoromethane - VOC		2.6	102.92		
Dichloromethane (methylene chloride) - HAP		14	84.94		
Dimethyl sulfide (methyl sulfide) - VOC		7.8	62.13		
Ethane		890	30.07		
Ethanol - VOC		27	46.08		
Ethyl mercaptan (ethanethiol) - VOC		2.3	62.13		

INTRO USER INPUTS POLLUTANTS INPUT REVIEW METHANE RESULTS GRAPHS INVENTORY REPORT

Figure 2. LandGem Pollutants window (sheet)

3 Developing an informational system for landfill gas monitoring and reporting

The development of an informational system for monitoring and reporting landfill gas emissions from municipal landfills begins by modelling the process and data. Next steps include constructing the database, developing the user interface, and finalizing the reporting system.

3.1 Process modelling

Modelling a process allows for a decomposition of a complex system into more simple components using the Top-Down methodology. This procedure results in a series of simple processes, which are easier to solve. The standard used in this procedure is the IDEF0 (www.idef.com), and the tool used is BPwin which is used to describe the process of decomposition using a series of diagrams, of which each represents a limited amount of details defined using the standard syntax and semantics (Veljović, 2011). The diagrams are

connected in a way to describe the hierarchal system, from the top to the bottom. Diagrams are made out of rectangles, which represent single parts of the whole process. The rectangles are connected with lines representing the relations between these parts.

Arrows on the left side of the rectangles define the Input. Arrows reaching the rectangle from the top are defined as Controls. Arrows exiting the rectangle on the right are Outputs, and the outputs can be data or objects, which are the result of the process.

Figure 3 represents the decomposition diagram of the municipal landfill management. This diagram clearly shows the horizontal relationships between the sub processes of Landfill characteristics, Cell characteristics, and Landfill gas emissions quantification.

Figure 3. The decomposition diagram for municipal landfill management

The landfill characteristics process is based on the input from the Serbian Environmental Protection Agency, various codebooks (cities in Serbia, types of ownership, types of landfills, and the list of business partners), and the output is the Landfill information sheet. The Controls used in this process are based on the Landfilling directive, Global Methane Initiative (GMI), and the International Panel on Climate Change (IPCC), which describe in more details all the necessary factors to take into account in order to properly describe a landfill and estimate the landfill gas generation.

The next process is the Cell characteristics process with Input information such as the type of cell and gas collection system. The output of this process is the cell information sheet. It uses the output of the landfill characteristics process. These two processes (landfill and cell characteristics) are a preparation for a more complex process of Landfill gas emissions quantification, which is decomposed on three additional processes: Defining the state of the cell (quantity of waste), Defining the type of waste, and Reporting the landfill gas quantities.

The sub process of Defining the cell state has Inputs of precipitation and the method for methane generation constant calculation, and the output is the Cell state sheet. The Controls are the Landfill information sheet and the Cell state. The sub process of Defining the type of waste is based on the inputs of the type of waste and as the output defines the percentage of the various types of waste in the cell. Controls used in this sub process are in relation to the sub process of Defining the cell state. Finally, the sub process of Landfill gas emission quantification is based on the percentages of various types of waste in the cell and has as the output the Methane quantification report. Controls used in this sub process are connected to the methodologies for methane quantification (GMI, IPCC).

3.2 Data modelling

Data modelling is done using the Bottom-Up methodology using the IDEF1X standard. The tool used in this process is Erwin.

Data modelling defines the entities, attributes and their connections. This way a logical data model is defined, and it contains all the necessary information, their grouping, as well as relationships, which allow to perform the activities/processes defined in the decomposition diagrams.

Figure 4 shows the data model, which was created for methane emissions quantification and reporting, based on the decomposition diagrams presented in the previous section.

The database is generated based on the user requirements. In this case, Microsoft SQL Server is used for the server side, and Microsoft Access for the client side. Figure 5 shows the user interface (client side) of the process Methane emissions quantification and reporting.

Figure 4. Data model created for methane emissions quantification and reporting

Figure 5. User interface for the process of methane emissions quantification and reporting

3.3 Potential market

Developing a software solution would allow municipal landfill management companies a simple, rapid, and reliable quantification and control of waste and landfill gas. As the software system would be developed based on the local regulation, the reports of landfill gas quantities would satisfy national requirements and allow for comparing between different users of the software. In addition, the mentioned software solution would be available not only to public and private enterprises managing landfills, but also to the Environmental Protection Agency, as well as other public agencies dealing with environmental protection. This way, verifying the reported quantities of pollutants from various landfills is rendered almost automatic, allowing for a higher level of control of the reported data. At least 25 regional landfill management companies (private and public) would benefit from the availability of this software solution, with additional 100 in the general sector of landfilling, and 5-10 among the public bodies dealing with environmental protection. Considering that landfilling is an interesting topic in the whole region, the number of potential users could be much larger.

4 Conclusions

The problem of municipal waste landfilling represents one of the major issue in Serbia's environmental protection. The correct MSW management policy not only protects the environment from various methods of municipal waste disposal currently in use, but also allows for a more advanced management of landfill gas emissions. These emissions can contribute to global warming, but, if managed correctly, represent also a renewable energy source. The software solution presented in this paper is being developed to achieve these aims: to facilitate the waste management and adherence to the legislations of Serbia and European Union, as well as to promote the use of renewable energy sources, such as the landfill gas.

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