Data analysis in the fire safety system of rail transportation and dumping of municipal solid waste

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Abstract. The problems concerning the municipal solid waste (MSW) management have been discussed. A particular attention has been payed to the fire safety solutions. An original system of the MSW flammability classification that is based on the exergetic coefficient was introduced. The advantages of the application of this system to the MSW railway transportation and burial have been discussed. To implement the exergy approach, a data mining system has been developed. The input data includes the following characteristics: separate waste collection, the waste morphological composition; the location, capacity, inclination, a load level, and the number of the waste containers; the MSW temperature, the explosive gases concentrations, and other parameters. The analysis of data obtained with the waste management system allows us to optimize processes for the waste collection, transportation, and burial. This approach is proved to optimize the waste transportation and stocking, and improve the fire safety. This article provides the best practices for landfilling and burying MSW for Siberia.

1. Introduction
At present, the waste management becomes an extremely important challenge for industrialized countries. However, none of the countries could completely resolve the waste recycling and burial problems [1, 2].

The most frequently used scenario for managing municipal solid waste (MSW) is the waste burial in landfills. At the same time, increasing the number of illegal landfills, and the legal landfills situated near human settlements, results in the environmental degradation and increases the risk of emergencies.

The disposition and recycling MSW is a very serious problem for big cities [3-5]. Accounts Chamber of Russia reported that 65 million tons (or 450 kg per a person) of MSW had been produced in 2019. The major part of MSW (about 90%) is sent to landfills. The treatment plants can process only 7% of waste. This situation is caused by a poor infrastructure for transportation, collection, safe saving, and processing MSW. In Siberia, the MSW landfills are situated near settlements that results in the environmental degradation. This situation is considered to be critical.

The disposal of garbage from big cities becomes more and more important challenge [6]. From this point of view, the railroad transport is considered to be the safest and perspective for MSW transportation.
The technologies for MSW management used in Russia have a number of weaknesses. For example, a system of collecting and analyzing statistical information about MSW does not take into account all sources of MSW. There are no reliable techniques for accounting the quantity of the produced MSW and their properties. It is necessary to pay more attention to the fire safety during transportation and processing MSW.

A lot of fires often take place in the Siberian landfills. For example, in last years, the following important fires occurred: a fire in the landfill situated in Ivanovka settlement, Chita region (January 2019); the fire in the MSW landfills situated near Ust-Abakan settlement, Khakasiya, and Yarovoe, Altay region (July 2020). A fire occurred in a waste landfill in Novosibirsk (August 2020); an important smoldering fire occurred in Surgut (October 2020).

Thus, the observation of the fire safety procedures for handling, burial, and transportation of MSW is an actual challenge.

2. Methods and scenarios of use

The Waste management system is aimed to decrease the waste impacts on the human health and environment. In this scenario, the logistic support considerably influences the process efficiency. The railroad transportation of MSW requires a comprehensive approach to the use of the Waste management system (Figure 1).

![Figure 1](image)

The use of the MSW management system for organization of the railroad transportation.

The work [7] proves the use of the exergy approach for studying the fire risks in the MSW railroad transportation. The use of the exergetic coefficient lets us standardize an estimation of the MSW flammability evolution during their life cycle. This approach also lets us estimate the role of the environment parameters, such as the temperature, pressure, and the MSW composition. With this method, it is possible to derive real conditions for the MSW inflammation, improve estimations of fire risks, and forecast the fire development.

Due to studying the chemical, physical, and the flammable properties of MSW, we could systemize MSW by their exergetic coefficient (Table 1) and prove advantages of this systematization for organization of the MSW railroad transportation and burial.
Table 1. MSW systemized by the exergetic coefficient.

| Flammability group  | Exergetic coefficient | Flammability rating                  |
|---------------------|-----------------------|-------------------------------------|
| Non-flammable       | $\Pi_e < 0.1$         | E0 – non-flammable                   |
| Low-flammable       | $0.1 \leq \Pi_e < 0.5$| E1 – low value of the exergetic coefficient |
| Flammable           | $0.5 \leq \Pi_e < 1.0$| E2 - middle value of the exergetic coefficient |
|                     | $\Pi_e \geq 1.0$      | E3 - high value of the exergetic coefficient |

$\Pi_e = \frac{e}{30}$

$e$ is the exergetic ratio of the transported MSW (in MJ/kg) that is calculated as a sum of the physical and chemical exergetic contributions;

30 [MJ/kg] is a minimum exergy of MSW with the flammability rating E3 (high value of the exergetic coefficient).

The proposed method for calculating exergy, which is used to estimate the fire risks in the MSW transportation, includes two steps:

1) Determining an initial (zero) level of exergy (it depends on the environment parameters).
2) Forecasting changes of exergy caused by physical and chemical processes.

This exergy method allows us to estimate the possible fire risks, investigate negative impacts of MSW to the environment, and also estimate the exergy efficiency of possible techniques for the waste disposal [7, 8].

For practical implementation of this method, it is necessary to gather and analyze information about MSW during their collection, triage, transportation, and burial. This information helps us optimize the processes of the MSW stocking and transportation, and also select optimum methods for their processing and improving the fire safety.

The following is a list of the tasks to perform for analyzing data used by the system for fire protection in the MSW railroad transportation and burial:

- Estimating the temporal changes of quantities of MSW to be transported and buried.
- Planning the waste transportation, investigate the MSW morphological composition and take into account their changes.
- Preventing the fires, explosions, and to avoid the work downtime, optimize the procedures for MSW stocking and transportation including the following tasks: collecting, landfilling and burying the waste; a temporary stocking the waste; loading and unloading the waste.
- Monitoring the MSW parameters (such as temperature, pressure, humidity, etc.).
- Taking into account the environment parameters (temperature and pressure).
- Analyzing changes of concentration of the biomass and explosive substances, and early detect their critical values.
- Calculating the car filling level during the operations of the waste load, unload, or transportation.
- Forecasting the waste flammable properties, and the fire probability.

The obtained information is useful for developing the fire safety regulations for the waste management that takes into account the waste composition, their properties, and the environment parameters.

3. Results and discussion

3.1. Studies of the MSW morphological composition and their changes: an application for planning the waste transportation and burial

The data on the MSW morphological composition is a general information that can be used to estimate and forecast potential fire risks [5, 9]. An analysis of available data shows general trends in the MSW
composition changes, namely a rise in the proportion of polymers, food waste, paper, cardboard, and textile. The average data on morphological composition of MSW in big Siberian cities is shown in Figure 2.

Figure 2. An average MSW morphological composition in big Siberian cities (in percentages).

The following factors have significant effects on the self-ignition, flammability, and self-heating of MSW: a variety of the waste composition, the complex biological and chemical processes, changes in the oxygen concentration and in the decomposition products, catalysts, humidity, and other parameters. However, it is difficult to monitor and control those factors because of their temporal variability, local specificities, and the MSW inhomogeneity [9].

The most comprehensive information on variations of the MSW morphological composition has been collected in Moscow and Saint-Petersburg (former Leningrad). This information was used for calculating the exergy (Figure 3) with the use of the technique reported in [7, 10].

Figure 3. Variations of the MSW exergy from 1933 to 2015: a) Moscow; b) Saint-Petersburg (former Leningrad).

The plastics waste is found to have a maximum exergy. In big cities, the MSW has high values of exergy and those values continue to rise. On the one hand, the high values of the MSW exergy favor using MSW for biogenesis of energy. On the other hand, the high value of the exergy is an indicator of a high-fire risk. It is necessary to take into account both factors for organization of the safe transportation and burial of MSW.
3.2. Monitoring the MSW parameters

An increase of temperature is an indicator of the thermal, chemical, and microbiological processes giving off heat. The temperature rise depends on a ratio between the heat emission and heat removal. In some scenarios, the temperature rise might result in a self-ignition of MSW or their decomposition products, and in extension of the combustion zone. The physical exergy rises due to the increase of the difference between temperatures of the MSW substance and environment.

An increase of pressure does not change the ratio between a combustible and oxidizer, but could increase the volume concentration of the reagents. For the most of substances, this scenario results in the increase of the combustion reaction rate and even in an explosion. The physical exergy rises due to the increase of the difference between pressures inside the waste stock-pile and environment.

3.3. Changes in the biomass concentration, an analysis of the explosive substances concentrations, and a timely detection of their dangerous values

The simulations of the kinetics of the aerobic and anaerobic biological processes, which take place during a transportation and burial of MSW, allow us to forecast some of dangerous scenarios. For example, it is possible to simulate the temporary generation rate of the explosive gases, and estimate the effects of different parameters on the current processes. These studies help us suggest timely the measures to decrease the fire risks related to the MSW processing.

The changes in the concentration of the aerobic and anaerobic biomasses, methane, carbon monoxide, and oxygen define the temporal dependence of the MSW inflammability, and are initial data for calculating chemical exergy.

3.4. Using a data visualization system to estimate the fire risks in the MSW railroad transportation and burial

The following tools are required to collect and analyze data related to the MSW railroad transportation and their burial: the sensors for monitoring the container load level and temperature, a network equipment for data transmission, a software for data processing, and others.

The used cloud-based platform supports a daily information monitoring and the real-time management of the MSW data. This system allows the users to do the following: optimize the MSW collection, transportation, stocking, disposal, and burial; estimate the fire risks, and implement the fire protection measures. Due to the use of built-in GPS systems, it is possible to track the train routes and schedule.

This system uses the free analytics database management system (DBMS) for big data ClickHouse. The sensors send information through network to a server, and write data in the fact tables of the data model. MS Power Bi is used to automatically generate reports and visualize data. The data mining functionality is implemented using the Python algorithmic language. When the monitored parameters take critical values, the management system sends the mail or push notification messages.

Examples of the data visualization for a combined transportation scheme (railroad and truck transport) are shown in Figure 4.

The process of the data analysis starts at the MSW collection stage. The waste is collected into special containers installed in settlements (Figure 4a). The processing system considers the following parameters: a separate waste collection, the waste morphological composition, the location, capacity, and number of the waste containers. The software plots a map that displays the container positions, their load levels, and the MSW parameters (such as temperature). This information is used to optimize the traffic of the garbage trucks, estimate the MSW volume to be landfilled or transported, and minimize the vehicle idle time.

The proposed system for data mining can be used to monitor the container load levels and their inclination, the MSW temperature, and the explosive gas concentration. This monitoring can be performed during the MSW transportation or when loading or unloading MSW. Figure 4b displays reports generated using the obtained data (the table and visual formats are available).
The obtained information allows the users to calculate and forecast the MSW exergy changes. The data mining lets you handle the situation and timely take appropriate measures for minimizing the fire risks and environment pollution that could arise during the MSW collection, transportation or burial. This information is used to choose an optimal method for disposing the waste.

4. Conclusion

The implementation of the exergetic approach allows us to perform a complex energetic and environment estimation and forecast the fire risks related to the MSW handling. The indicators of the MSW fire risks, which have been obtained using the exergetic method, improve an objectivity of the procedure for classification of the hazardous materials for the railroad transportation. Our method lets the users take into account the conditions that favor the MSW inflammation during their transportation and burial in Siberia.

To implement the exergetic approach, it is necessary to gather and process information on the quantity, composition, and other properties of the MSW, and their temporal evolution during the waste collection, triage, transportation, and burial. The proposed method provides a possibility to choose a strategic approach to the waste handling procedures.

The use of the proposed system of data mining allows the users to optimize the waste stocking procedures and find the best solutions for ensuring the fire safety in the MSW railroad transportation and burial in Siberia.

References

[1] Bovea M D, Ibáñez-Forés V, Gallardo A and Colomer-Mendoza F J 2010 Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study Waste Management 30 2383-95
[2] Hong J, Li X, Zhaojie C 2010 Life cycle assessment of four municipal solid waste management scenarios in China Waste Management 30 2362-69
[3] Duan N, Li D, Wang P, Ma W, Wenga T, Zhong L and Chen G 2020 Comparative study of municipal solid waste disposal in three Chinese representative cities Journal of Cleaner Production 254 120134
[4] Lou C X, Shuai J, Luo L and Li H 2020 Optimal transportation planning of classified domestic garbage based on map distance Journal of Environmental Management 254 109781
[5] Di Foggia G, Beccarello M 2018 Improving efficiency in the MSW collection and disposal service combining price cap and yardstick regulation: The Italian case Waste Management 79 223-31
[6] Peri G, Ferrante P, Gennusa M La, Pianello C and Rizzo G 2018 Greening MSW management systems by saving footprint: The contribution of the waste transportation Journal of Environmental Management 219 74-83
[7] Khaydarov A G, Koroleva L A and Ivakhnyuk G K 2018 Exergetic assessment of fire hazards of cargo transportation on railway transport Fire and Explosion Safety 27(10) 26-37
[8] Laner D, Rechberger H, De Soete W, De Meester S and Astrup T F 2015 Resource recovery from residual household waste: An application of exergy flow analysis and exergetic life cycle assessment Waste Management, 46 653-67
[9] Moody C.M, Townsend T G 2017 A comparison of landfill leachates based on waste composition Waste Management 63 267-74
[10] Eboh F C, Ahlström P and Richards T 2016 Estimating the specific chemical exergy of municipal solid waste Energy Science & Engineering 4 217-31