**A system of fire protection for MSW railroad transportation and burial: data analysis**

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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, we proved the use of the comprehensive waste management system for collection, triage, burial, disposal, and transportation of MSW. 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 not 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]. 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 disposition of garbage from big cities becomes more and more important challenge. From this point of view, the railroad transport is considered to be the safest and perspective for MSW transportation [4].

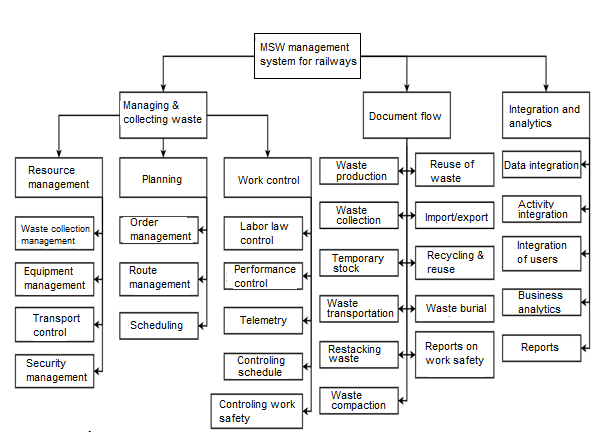
The technologies for MSW management used in Russia have a number of weaknesses. For example, a system of collecting and analyzing statistical information about MSW does not take into account all sources of MSW. There are no reliable techniques for accounting the quantity of the produced MSW and their 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.

1. **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 (see Figure 1).



**Figure 1** - The use of the MSW management system for organization of the railroad transportation.

The work [5] proves the use of the exergy approach for studying the fire risks at 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 (see 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

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| **Flammability group** | **Exergetic coefficient** | **Flammability rating** |
| Nonflammable | <0,1 | E0 - nonflammable |
| Low-flammable |  | E1 – low value of the exergetic coefficient |
| Flammable |  | E2 - middle value of the exergetic coefficient |
|  | E3 - high value of the exergetic coefficient |

, where

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 at 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.

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 an analysis of data used by the system for fire protection at the MSW railroad transportation and burial:

* Estimating the temporal changes of quantities of MSW to be transported and burried;
* For planning the waste transportation, investigate the MSW morphological composition and take into account their changes;
* To prevent the fires, explosions, and to avoid the work downtime, optimize the procedures for MSW stocking and transportation including the following tasks: collecting, landfilling and burrying 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.

1. **Results and discussion**
   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 [6]. An analysis of available data shows generals trends in the MSW composition changes, namely a rise in the proportion of polymers, food waste, paper, cardboard, and textile. The morphological composition of MSW in Nizhnevartovsk in 2018 is shown in Figure 2.

**Figure 2** – MSW morphological composition in Nizhnevartovsk

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 [6].

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 (see Figure 3) with the use of the technique reported in [5, 7].

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a) b)

**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 favors 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.

* 1. ***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.

* 1. ***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 at the 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.

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**Выводы.**

Применение эксергетического подхода позволяет проводить комплексную энергоэкологическую оценку и прогнозирование пожарной опасности ТКО. Учет показателей пожарной опасности ТКО через эксергию повышает объективность процедуры классификации опасных грузов железнодорожного транспорта. Дает возможность учитывать реальные условия возникновения и развития горения при транспортировке и захоронении ТКО в Сибирском регионе.

Реализация эксергетического подхода определяет необходимость получения и анализа данных, отражающих объем, морфологию, свойства ТКО и их изменение во времени в процессе сбора, сортировки, перевозки, захоронения отходов с целью оптимизации накопления и перемещения мусора, обеспечения пожарной безопасности. Дает возможность выбора стратегий обращения с отходами.

Предложена аналитическая платформа, применение которой позволяет осуществлять поиск наилучших решений по обеспечению пожарной безопасности железнодорожных перевозок и захоронения ТКО Сибирского региона.

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