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APPLICATION OF THE TRIZ METHOD FOR SELECTING THERMAL TREATMENT PROCEDURE AND OBTAINING ENERGY FROM WASTE

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Abstract. *The paper discusses the problem of municipal waste disposal and utilization in the region of Nis. A detailed analysis was carried out of the existing technical solutions thermal treatment and extraction of landfill gas from municipal waste, with an emphasis on energy efficiency. On the basis of accessible data on the quantity, composition and heating power of municipal solid waste, obtained by measurements made in situ, a detailed analysis is carried out of the existing solutions for thermal treatment of waste obtained energy. The basis of the TRIZ methods are given for solving technical contradictions, as well as application of the TRIZ methods for generating innovative ideas. The use of the TRIZ methods is meant to improve the existing procedure for the extraction of landfill gas from municipal solid waste. The preliminary plant design is given for extraction of landfill gas with the impact analysis of suggested improvements for extraction procedure.*

Key words: *Municipal Waste, Incineration, TRIZ, Landfill, Gas Extraction*

1. INTRODUCTION

The conditions of modern business and ever stricter environmental requirements contribute to the fact that the most wanted systems and processes that treat new raw materials are waste materials. The municipal solid waste disposal is one of the serious problems of contemporary urban areas. Despite the innovative technology, modern logistics solutions and marketing strategies aiming at raising environmental awareness of urban environment, waste per capita continues to grow despite the improvements in the process of waste management. Utility companies remove solid waste through three main procedures: composting, incineration and disposal at landfills. Composting is a process that is based on the use of certain strains of bacteria that have the ability to decompose organic waste [1]. With composting it is possible to treat all organic waste, even municipal organic waste, but this procedure is commonly used for plant origin waste treatment, because in addition to the

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effect of reducing the volume of waste, the remains of the composting process are used as organic fertilizers in agriculture. A large number of authors examine the process and parameters of municipal solid waste composting process [2], while some authors deal with the influence of communal waste upon the characteristics of agricultural land [3].

Incineration is the process of thermal treatment of solid waste, which in addition to effectively reducing the volume of waste, releases energy contained in it. The above mentioned energy is used most frequently to produce steam or electricity. Although some authors [4] believe that the process of incineration is more economically justified than the recycling process, during incineration of communal waste, harmful chemical compounds (primarily dioxins) and heavy metals are released into the atmosphere. A large number of authors deals with cases of inhibition of harmful chemical compounds and heavy metals [5,6,7]. Also, the process of incineration is not economically justified at already formed landfill, which reduces the possibilities for its application in the Republic of Serbia. The analysis of composting process and incineration leads to the conclusion that the process of incineration is, economically speaking, more beneficial in comparison to the composting process.

Disposal of waste at landfills is the cheapest way of municipal waste disposal; it is the dominant one in our region. Disposal of waste at landfills is linked to the process of recycling. Municipal waste includes many components, which can be used successfully as high-quality secondary raw materials. The above mentioned raw materials are extracted from municipal waste before its transport to the landfill. Disposal of waste at landfills has far-reaching effects on the environment. In addition to a huge and otherwise useful area it takes up, the process also leads to chemical processes that pollute the atmosphere and can cause their ignition or even an explosion. Today there are technical solutions for extracting harmful and flammable gases from landfills [8], which are used as transmission materials in the production of the electricity. The lack of existing procedures of extraction in relation to the process of incineration is reflected in the fact that in incineration the available energy is released immediately, while at the process of extracting that process takes up to 30 years. The direct consequence of the above-mentioned lack is that with extraction process the remains that are important for the area are used as opposed to the process of incineration.

The paper has given a general idea of the improved extraction procedure, which significantly reduces the duration of the extraction process, and therefore raising the efficiency and economic viability of extraction process of landfill gas. The authors have come upon a new extraction procedure by using TRIZ methods for solving technical contradictions.

2 Analysis of Current Situation in Waste Incineration and Extraction of Landfill Gas

In view of the present situation, two methods have been applied for destruction of municipal waste:

- destruction without exploitation,
- destruction with exploitation.

The thermal waste treatment includes:

Incineration-there are two variants of burning the waste:

- waste incineration without energy recovery,
- waste incineration with energy use.

Waste incineration is applied in order to reduce their quantity and utilization of obtained energy. With waste incineration, the available chemical energy, defined with thermal power, is translated into the physical energy of flue gases, defined with gas temperature. However, there are positive and negative sides of incinerators: energy use from flue gases after combustion, combustion process destroying all microorganisms including pathogens, effective problem solving of hazardous waste, reduction of the volume of waste, water pollution, air and soil.

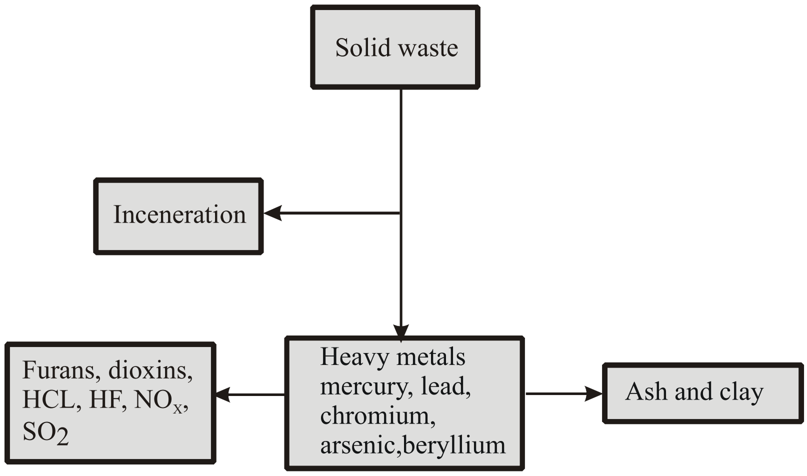

Fig. 1 Product of waste combustion

Pyrolysis-represents the thermal decomposition of organic waste components without presence of oxygen, whereby gases are formed while condensed products and solid carbon remain. Pyrolysis of organic part occurs at two levels:

- Primary decomposition: forming H_2O, CO_2, NH_3, HCI, H_2S, CH_4 and other aliphatic.
- Secondary supporting reactions as polymerization of primary products of decomposition in ter.

Advantages of pyrolysis in relation to incineration: lower temperature level at pyrolysis process and thus a slight separation of heavy metals and chlorine hydrocarbons, less production of flue gases, flexible process management in changeable composition of waste, less elimination of harmful substances into the environment.

Disadvantages pyrolysis in relation to the burning: need grinding and homogenization of waste, a slight reduction of weight (about 400 kg of solid residue per ton of waste), poor energy efficiency due to soot content (15%) in coke and inflammable carbon, increased content of heavy metals and toxic organic substances in solid pyrolytic residue, due to lower temperature reactions with poor level of bonding.

Gasification-waste refers to waste heat which contains air in the presence of air or steam in order to obtain fuel gases. According to heat source the gasification process are divided to:

- alotermne- heat is provided by external sources of heat,
- autotermne- heat required for gasification is provided by oxidation a certain quantity of fuel in circulating air or oxygen.

Plasma-using technology plasma burner waste can be translated into carbon rich gases and hydrogen and small clay rich with metals. Metals from the slag may be regenerated with appropriate treatment and gases can be used as fuel.

Decomposition of waste at place of its deposit is carried out through physical, chemical and biological processes which operate at the same time, until the biodegradable part of municipal waste is not degraded, or is not stabilized.

Generation of methane occurs in the methanogenic anaerobic stage of waste decomposition. At this stage the organisms convert the organic substances present in the delayed municipal waste into methane and carbon dioxide. Research has confirmed that this phase, as a rule, established after a period of time from 3 to 9 months after the deposit of waste.

Landfill gas, particularly its methane component, has an energy value of the order of 38 MJ/ m^3, which makes it a sufficient fuel for gas-powered engine, or for obtaining electricity. Landfill gas can be used for obtaining heat through its combustion in a variety of technical systems or heating pipe systems, and as fuel for landfill leachate treatment in the process of evaporation. In addition, with further purification of landfill gas and its improvement, its delivery is made possible within the existing network for distribute natural gas, and there are several locations where the refined and compressed landfill gas is used to drive landfill hatchback, refuse collection trucks, buses and cars.

With the extraction of landfill gas the air pollution would be reduced, as well as the spread of odors from the landfill. Exploitation of landfill gas for leachate treatment directly affects the reduction of negative impacts on groundwater.

First system of thermal waste treatment has been developed in Switzerland between 1985 and 1992, where the test facility, capacity 110 tons per day, was built in Italy [4]. Larger commercial institution, with a larger capacity of 792 tons per day, was built in Karlsruhe, Germany 1999 [4]. During nineties in the 20th century the Japanese were interested in the waste treating process and in 1999 began building the first factory in Japan, in the city of Chiba. There is a tendency to increase the capacity of such factories, the capacity achieved up to date is 2000 tons per day [9] to enable the treatment of increased amounts of waste as a result of the increasing population and economic development. The tendency of capacity growth of existing factories and future ones needs to increase by 7.5%, until 2030 [9]. Due to increasing population and economic growth, emission will also significantly increase.

The first plant for the methane extraction was built in 2002 in Spartanburg. Extracted methane is used to produce steam, whose energy is transformed into electric energy. In this way, 60% of electricity is obtained in the BMW fabric, located in nearby of Spartanburg. Since the beginning of methane extracting process savings were made of five million dollars a year in the cost of electricity required for operation in the factory.

The analysis in Fig. 2 clearly shows that the systems thermal waste treatment is in the phase of three technological S curves, where it can be concluded that further development of these systems is associated with significant costs.

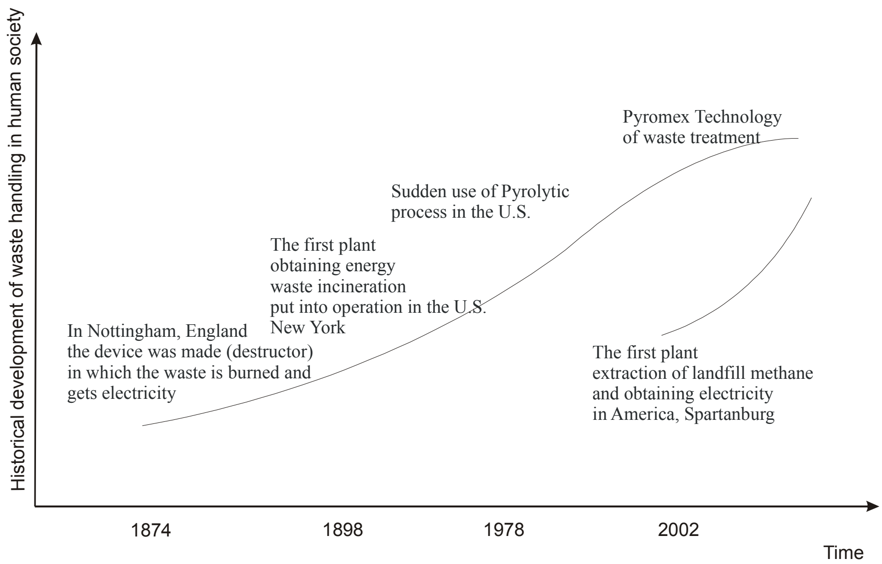

Fig. 2 Curve of the historical development of landfill gas extraction and thermal treatment of waste

3 Analysis of Possibilities of Application of Thermal Treatment and Landfill Gas Extraction of Municipal Waste in the City Of Niš

The daily amount of waste generated by households from one resident in the city of Niš is 0.386 kg. On annual basis this amounts to 140.89 kg. In the springtime, the amount per capita is 0.418 kg, while in the autumn it is 0.354 kg [9].

Table 1 The amount of generated waste in kilograms

Type of waste	The amount per day /resident	The amount per year /resident	The amount per day /city	The amount per year/city [×103]
Total waste	0.386	140.89	105378	38462.97
Organic part	0.280	102.2	76440	27900.6
Inorganic part	0.106	38.69	28938	10562.37
Plastic	0.036	13.14	9828	3587.22
Paper	0.034	12.41	9282	3387.93
Glass	0.012	4.38	3276	1195.74
Metal	0.0024	0.876	655	239.148
Rest	0.022	8.03	6006	2192.19

The collected data lead to the fact that the daily content of organic waste is 0.280 kg per capita, and inorganic 0.106 kg. In percentages, this is 72.54% for the organic part of waste and 27.46% for the inorganic part of waste. This is followed by plastic with 9.32% in total quantity of waste, and then paper with 8.80% and glass with 3.11%. The amount of metal in the total waste is very small and it is 0.62%.

The value of waste heat can vary greatly from town where it came from. In Western Europe the value of waste heat can be between 3000-10000 kJ/kg while in the U.S. it is between 6000 and 14000 kJ/kg [9]. The average value of thermal power waste from cities in Germany is 9200kJ/kg and in Switzerland 10000kJ/kg [9]. According to data obtained in Subotica the lower heat value of municipal solid waste power for that region is approximately 8400 kJ/kg. Thermal power of the collected waste in Niš is larger than Europe and rest of Serbia and it is approximately the size of our lignite thermal power (13.5-20.0MJ/kg) [9]. The acquisition of reliable data on waste characteristics (quantitative, qualitative analysis) is ensured by the years of research done by the established methodology using the current standards. In the Republic of Serbia, such tests have not been carried out yet.

Thermal energy that would be given by complete combustion of solid waste generated in one day, in the territory of Niš is:

$$105378\,kg\,x14297\,KJ\,/\,kg \approx 1506589266 \approx 1506589{,}266\,MJ \quad (1)$$

Based on this analysis, it can be concluded that this waste can be effectively used as fuel (e.g. in the cement industry), or destroyed by burning in which the received thermal energy would be used.

The average daily amount of crude oil in winter time for the heat plant at the Faculty of Mechanical Engineering is 5500 kg. Thermal power of the crude oil is 44000 kJ/kg. Daily amount of heat for heat plant is:

$$5500kg \times 44000KJ\,/\,kg \approx 242000000 \approx 242000MJ \quad (2)$$

Table 2 Thermal power of solid waste

Components	Daily amount [kg/city]	Mass share of components [%]	Thermal power of components [MJ/kg]
Organic materials	76440	75.27	14.7
Plastic	9828	9.68	15.0
Paper	9282	9.14	15.0
Rest (textiles, rubber, leather)	6006	5.91	16.3
Total	101556	100	14.851

The above-mentioned analysis shows that the thermal energy obtained by combustion of waste is nearly six times higher than the combustion of fuel oil. However, complete combustion is difficult to achieve, the efficiency is lower than with crude oil combustion. If we take into account cost of raw materials, in spite of the inaccuracies in the analysis, it can be concluded that with the combustion of municipal waste a considerable amount of energy is released by multiple lower cost compared to the classic fossil fuels.

4 SOLVING TECHNICAL CONTRADICTIONS

The introduction of innovative products, processes and services is a very complex procedure that requires the application of integrated development strategies that are based on modern systems, methods and processes [10].

TRIZ method is a modern method which is used for solving technical problems and contradictions, developed by Altsulera (G. Altshuller) in the USSR [11].

Construction of the model function and the correct formulation of the problem are the first steps towards the solution of technical problems using the TRIZ. After the formulation of technical problems and contradictions arising from technical problems with Altshuller`s matrix, which contains 39 principles for solving technical contradictions, the contradiction solutions are obtained. (Example: increase the volume and structure without increasing the weight of structure). Responses to the contradiction are offered by the principles which differ depending on the contradictions.

Table 3 Technical contradictions

	Power, capacity (21)
17-Temperature	2
	14
	17
	25
	Material losses (23)
17-Temperature	21
	36
	39
	31
	Adverse factors that are induced in the object (31)
26-The amount of material	3
	35
	40
	39

17-Temperature
Undesirable changes which increase:
21- Power, capacity (2, 14, 17, 25),
23- Material losses (21, 36, 39, 31).
26-The amount of material
Undesirable changes which increase:
31- Adverse factors that are induced in the object (3, 35, 40,39).

On the basis of the principles for resolving technical contradictions 2b, 3c, 25b and 36, the conclusion is that the methane and other gases are, which are the products of biochemical reactions and are a potential source of explosion, to be used as desirable fuel. The optimal temperature for conducting biochemical reactions according to (2) is 41^{o}C, where it should be remembered that at temperature higher than 50^{o}C all biochemical processes cease.

5 THE SOLUTION OF EXISTING LANDFILL

Given the high price of pyrolysis plant and capacity occupancy at the landfill in Niš and energetic potential which it contains, we will take into consideration the potential use of the existing landfill.

At the existing landfills gases are released of which 50% is methane. These gases have high thermal power and can be used as fuel. At landfill in Niš there is no adequate system for the utilization of these gases. By observing other landfills in the world which use the system for methane extraction and other gases of high thermal power, it is evident that after long time interval (on the order of ten years), using that gases the landfill is becoming self payable.

Since the biochemical processes are at issue here, under the environmental conditions, it is logical to assume that increasing the temperature of biochemical processes in the trash accelerates its decomposition.

Extraction of methane can be expressed by following equation:

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0,1}^{1} k \quad L_0 M_i (e^{-k\ t_{ij}}) \tag{3}$$

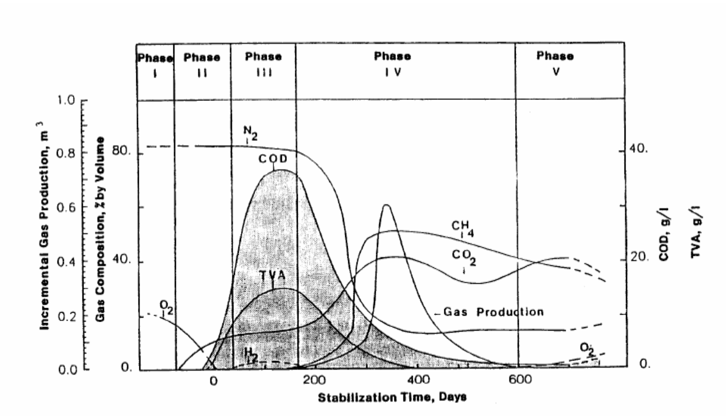

Fig. 3 Graphical description of the changes characteristic of the landfill with age [20]

The temperature has a significant effect on micro-biological degradation and destruction. The most commonly used equation which gives the speed to dependence of methane extraction in the function of temperature is Van't Hoff-Arrhenius's equation [21]:

$$k_t = k_{20} \times \theta^{(t-20)} \tag{4}$$

From this dependence it can be seen that the increase of the temperature from 20 to 30°C constant k is increasing from value 0,23 to 0,4. With this it can be concluded that speed separation of methane according to equation (3) is increasing for 30%.

5.1 Economic Analysis

Investments into the system for the landfill gas extraction depend on the amount of energy and distance to which the generated energy can be delivered. The system consists of two subsystems: a system for gathering and evacuation systems.

A system for landfill gas collection, which consists of the vertical tubes placed after the deposit of waste, or horizontal wells, which are set during deposit of waste. The average level of investment for both variants of the system, for the dump of average depth 10 meters is 15 000 - 30 000 USD per hectare.

A system for evacuation of landfill gas is composed of vacuum pumps. Price depends on the system of control and management and volume of landfill gas which will be evacuated. The average investment price for the landfill of 10 meters depth is from 7 000 to 30 000 euro.

The landfill in Nis has an area of 31 ha. Since from that is the store space 350 m of width and 750 m in length, and 21 ha, and the average depth is 16 m. Total investment into these two systems at landfill in Nis is around 1.5 million.

By increasing the medium temperature of landfill to 30 °C, and coefficient k of value from 0.23 to 0.4, it is possible to form expression (3) to calculate a relative increase in the amount of the extracted methane:

$$\frac{Q_{CH430^oC}}{Q_{CH420^oC}} = \frac{\sum_{i=1}^{n}\sum_{j=0,1}^{1} 0,23 \;\; L_0 M_i (e^{-0,23\, t_{ij}})}{\sum_{i=1}^{n}\sum_{j=0,1}^{1} 0,4 \;\; L_0 M_i (e^{-0,4\, t_{ij}})} \tag{5}$$

If we assume that coefficients k and L_0 are constant, the relative ratio of methane extraction can be easily calculated from relation (5). The results are shown in Table (5).

Table 4 Relationship between the amounts of extracted methane in years

Time in years	The relative ratio amounts of the extracted methane
1	1,42
2	1,345
3	1,286
4	1,231
5	1,184
6	1,143

Since the results in Table 4 are obtained from exponential expression (3) i.e. (5), exponential extrapolation of the results is given, for a better view, in Table (5).

$$R_{CH4} = 1{,}471e^{-0{,}043t} \qquad (6)$$

On the basis of expression (6) it can be concluded that the relative extraction of methane after a period of 9 years is equal to one, as well as the middle value of relative methane extraction after a period of 20 years is equal to one.

From the above mentioned it can be seen that it is necessary to increase the temperature of the landfill in order to speed up the process of the landfill gas extraction. Bringing to the optimum temperature can be achieved by using solar energy that would heat working fluid, which in the heat exchanger via a closed pipe system flows through the landfill and warms the waste. The solar energy use can help avoiding additional energy consumption, which is necessary for the process development at optimum conditions.

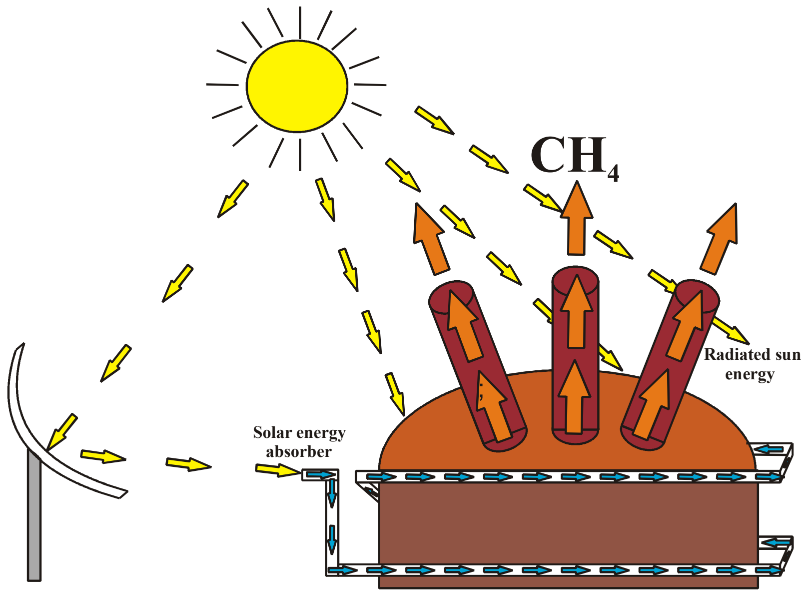

Fig. 4 The accelerated process of methane extraction

The amount of energy that is needed to maintain waste temperatures, at a level of approximately 30°C is:

$$Q_{st} = \alpha \cdot S \cdot \Delta T \qquad (7)$$

Part of this heat is already obtained from solar radiation and it amounts to:

$$\Delta Q = q \cdot S \cdot \eta \cdot \sin\varphi \qquad (8)$$

The difference between the submitted the amount of heat and obtained amount of heat is 13.25 MW. This difference in the amounts of heat can be compensated by increasing coefficient η at value of 0.6. If the heating is done through the exchanger, then we have:

$$\Delta Q = \dot{m} c_w \Delta T_w \tag{9}$$

Required water flow, which would provide for an appropriate amount of heat is 189 kg/s.

11. CONCLUSION

On the basis of above mentioned, it can be concluded:

1. Disposal of communal waste is a major problem of urban environments. The problem can be solved in many ways and the most significant is composting, incineration and extraction of landfill gas.
2. Extraction of landfill gas from energy view is the most efficient process in waste problem resolving.
3. The application of modern methods, processes and systems product development can lead us to innovative solutions to waste problem disposal.
4. Application of the TRIZ methods accelerate the process of landfill gas extraction, which raises the level of utilization facilities for the extraction and reduce the cost and time of extraction.

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PRIMENA TRIZ METODE ZA IZBOR POSTUPKA TERMIČKOG TRETMANA I DOBIJANJE ENERGIJE IZ OTPADA

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U radu je razmatran problem odlaganja i iskorišćenja komunalnog otpada komunalnog otpada u niškom regionu. Izvršena je detaljna analiza postojećih tehničkih rešenja termičnog tretmana i ekstrakcije deponijskog gasa iz komunalnog otpada, sa naglaskom na stepen iskorišćenja energije. Na osnovu raspoloživih podataka o količini, sastavu i toplotnoj moći komunalnog otpada na niškoj deponiji, kao i terenskih ispitivanja, izvršena je uporedna analiza procesa ekstrakcije deponijskog gasa i termičkog tretmana komunalnog otpada. Date su osnove TRIZ metode za rešavanje tehničkih protivurečnosti, kao i primena TRIZ metode za generisanje inovativnih ideja. Primenom TRIZ metode, predloženo je poboljšanje postojećih postipaka za ekstrakciju deponijskog gasa iz komunalnog otpada. Dato je idejno rešenje postrojenja za ekstrakciju deponijskog gasa uz analizu uticaja predloženiih poboljšanja na postupak ekstrakcije.

Ključne reči: *komunalni otpad, inseneracija, TRIZ, deponija, ekstrakcija gasa*