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Pyrolysis and gasification in the process of sewage sludge treatment

ABSTRACT

Pyrolysis and gasification represent a thermo-chemical process of solid mass conversion and the products obtained are: liquidity (pyrolytic oil), gases and coke residue. In modern society, there is a growing need for the use of ecological systems and renewable energy sources. As a potential and renewable energy resource we can consider sewage sludge. Sewage sludge is mostly disposed of in nature, while a very small part of the treats. Due to the non-adequate treatment of sewage sludge there is a high risk of impacts of harmful substances on humans and animals. Apart from the fact that the sewage sludge can be a major energy potential, thermal treatment allows to solve the problem of disposal of sewage sludge in nature and environmental pollution. Utilizing the sewage sludge as an energy source would generate large fossil fuels, neutralize sewage sludge landfills and reduce the risk of developing and spreading the disease due to the presence of harmful substances.

Keywords: *gasification, sewage sludge, pyrolysis, thermal processes.*

1. INTRODUCTION

Energy efficiency and environmental protection are of great importance to the planet. To prevent global warming, it is need to promote the use of biomass and communal waste as a new energy source. It is believed that their use will results in a reduction in the effect of greenhouse gases. In order to utilize energy from biomass, energy producers must find a way to meet the needs of the company. The most important thing is to maintain economic efficiency, stable supply and proper fuel control. The use of biomass for energy purposes is one of the tasks of implanting energy efficiency. Parallel to this, there are attempts to solve the problem of the treatment and disposal of large quantities of sewage sludge. Some companies have developed technology that is excellent in sterilization of sludge, and also recycles sewage sludge as fuel and produces electricity and heat energy. The new system can meet the needs for effective treatment of sewage sludge, reducing greenhouse gas emissions and make use of sludge as a fuel in power plants and heating plants. This type of use of energy, gives hope that it is possible to use sewage sludge as fuel without carbon [1].

Thermal treatment of sewage sludge proved to be most effective when it comes to the impact on global warming, aquatic and terrestrial eco toxicity, acidification of land and agricultural products [2].

2. THERMAL TREATMENT OF SEWAGE SLUDGE

The composition of sewage sludge is one of the most important factors in the proper method of choice for the treatment of sludge. For this reason, it is necessary to pay attention to the technical and an elementary analysis from which we get the energy value and composition of the sludge. The advantage of using sludge as fuel in cement kilns is often mentioned in literature [3]. The dry matter, lower heating value and composition of the sludge are important factors to be used as fuel. In this paper data on the composition of sewage sludge from 17 different locations in the world were collected. The results are shown in Table 1.

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Table 1. Technical and elemental analysis of sewage sludge in the world (literature data) [from 4 to 21]

Tabela 1. Tehnička i elementarna analiza kanlizacionog mulja u svetu (literaturni podaci) [od 4 do 21]

Literature data [from 4 to 21]	Mass fraction (%)							H_g (MJ / kg)
	C	H	N	S	O	Ash	W	
China-Jiangsu	7,6	2,53	0,37	0,91	34,09	54,5	77,9	--------
Poland- Krakow	30,8	3,9	4,3	1,4	18,3	36,4	4,9	12,57
China-Guangzhou	38,96	5,3	3,51	0,27	35,18	8,67	8,32	13,51
Korea	32,59	6,08	3,08	1,27	56,97	13,33	72,13	1,37
Turkey	38,97	5,10	4,11	0,81	50,99	36,54	5,14	16,18
Poland-Gliwice	32,1	5,26	4,7	1,56	23,64	34,29	55,11	14,42
China-Beijing	33,98	6,02	6,24	0,92	52,84	30,76	57,78	13,17
Greece	35,00	6,1	4,5	1,9	19,8	32,7	-------	14,80
Spain	29,5	4,8	4,1	1,6	18,3	41,7	8,7	13,1
Singapore	39,9	6,2	6,0	5,6	29,1	21,8	82,5	18,00
Hawaii	37,7	5,22	7,05	3,58	14,6	31,9	-------	-------
France	54,9	7,3	9,3	0,8	22,2	-------	-------	17,6
China-Shandong	27,69	4,89	4,36	1,37	61,69	43,11	-------	8,27
Malesia	68,96	9,78	3,14	0,27	54,8	8	4	33,97
China-Hunan Province	51,05	5,97	0,73	0,12	-------	4,98	-------	--------
EU	9,30	8,13	5,32	0,552	76,7	-------	28,5	--------
India	15,24	1,30	1,02	0,81	22,44	60,00	-------	--------

There are several options for using energy from sewerage sludge. Depending on the organic compound in the sludge the possibility of utilization of energy can be divided into nine groups [22]:

- Anaerobic digestion of sewage sludge,
- Production of biofuels from sewage sludge,
- Direct production of electricity from sewage sludge in microbial fuel cells,
- Incineration of sewage sludge with energy recovery,
- Co-incineration of sewage sludge in coal-fired power plants,
- Gasification and pyrolysis of sewage sludge,
- Use of sludge as an energy and raw material source in the production of cement and building materials,
- Supercritical wet oxidation of sewage sludge,
- Hydrothermal treatment of sewage sludge.

3. INCINERATION, PYROLYSIS AND GASIFICATION OF SEWAGE SLUDGE

The thermal process makes it possible to burn almost every waste regardless of the type and composition. Incineration of sewage sludge is carried out in rotary kilns. Working temperatures in rotary kilns range from 500°C to 1450°C. The sealing time of the sewage sludge in the kiln is 30 to 90 minutes. In order to improve combustion in the rotary kiln can be added to liquid waste or fuel. The higher the combustion temperature, the greater the possibility of dirt and damage to the furnace [23].

Pyrolysis is a thermo- chemical process of solid mass conversion which takes place in the absence of oxygen, and the products obtained are: liquidity (pyrolytic oil), gases and coke residue [24]. The amount of pyrolysis product depends on the chemical composition of the sewage sludge and the conditions in which pyrolysis takes place. Sewer sludge components are thermally decomposed at different speeds. It is difficult to precisely determine the lower temperature limit at which the thermo-chemical decomposition of the sewage sludge begins. The pyrolysis process takes place in 4 phases [25]:

- Phase 1 (up to 200°C): Removes the moisture and volatile substances are released such as ethanoic (acetic) and methane (formic) acid.
- Phase 2 (from 200°C to 280°C) pyrolysis of the acid release, water and oil pyrolytic gases (CO, CO_2).
- Phase 3 (from 280°C to 500°C): The release of the combustible volatile products, such as CO, CH_4, H_2, Methanal, methanoic acid, ethanoic acid and methanol.
- Phase 4 (above 500 ºC): The carbonization process is complete. If the reaction products are not removed from the reaction zone immediately after formation, secondary reactions and coke reaction with the gas begin.

The process of pyrolysis at low temperatures, high heating rates and a short period of mass residence in the reaction zone achieves the maximum amount of liquid product.

The process of pyrolysis at low temperatures and low heating rates achieves the maximum amount of coke residue.

The process of pyrolysis at high temperatures, low heating rates, and long periods of gas phase in the reactor achieves a high yield of pyrolytic gas [25,26].

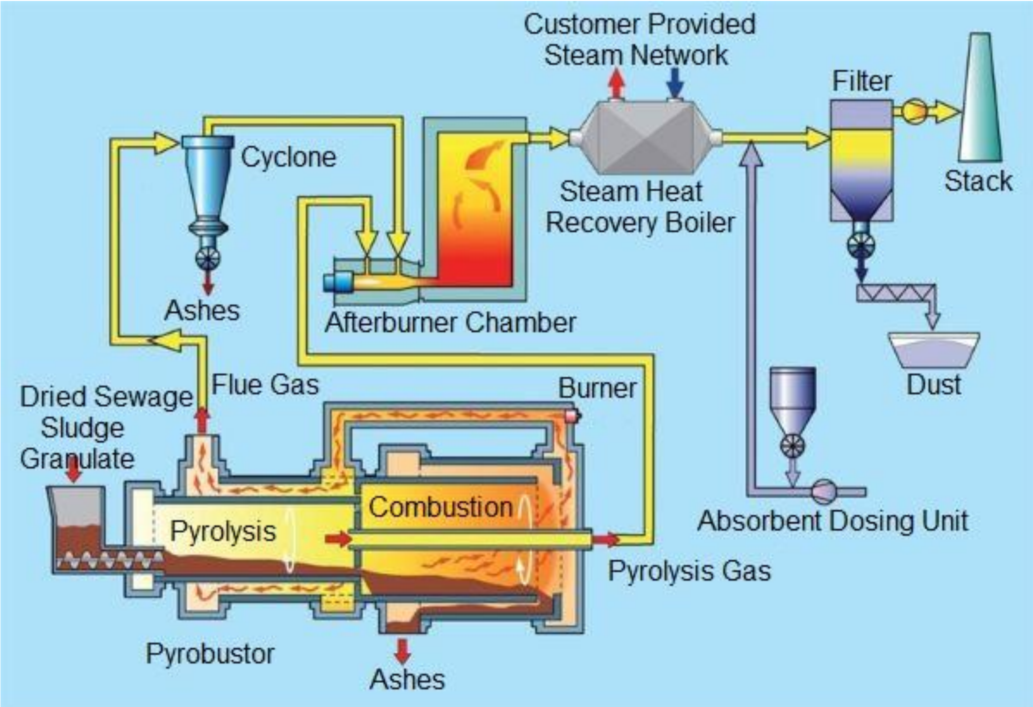


Figure 1. The process of pyrolysis of sewage sludge [27].
Slika 1. Postupak pirolize kanalizacionog mulja [27].

Gasification can be seen as a continuation of the pyrolysis process. After pyrolysis, during the gasification process, gas, pyrolytic oil and coke residue are further reacted. In comparison to pyrolysis, a certain amount of oxygen is added to the gasification process. [28]

The gasification process takes place at high temperatures (700-1000°C). The main gas components generated by the gasification process are: CO, CO_2, H_2O, H_2, CH_4 and other hydrocarbons [29].

The gasification process takes place in 2 phases after completion of the pyrolysis process: [30]:

- Phase 1 (above 500ºC): volatile matter and part of the solid residue react with oxygen and form CO_2 and small amounts of CO.
- Phase 2 (combustion-zone reduction): income-plete combustion products (H_2O, CO_2 and unsaturated pyrolysis products) react with water vapor, thereby reducing the temperature of the resulting gasification products (CO, CO_2, CH_4, H_2 and N_2). The reduction temperature is (~ 700-950 °C).

Pyrolytic oil has a wide application and can be used as [28]:

- fuel for combustion in boilers, furnaces and energy production,
- fuel or component for blending with fossil diesel fuel for diesel engines and
- raw material for the preparation of chemical compounds, adhesion agents, anhydrous sugar.

The coke residue can be used:

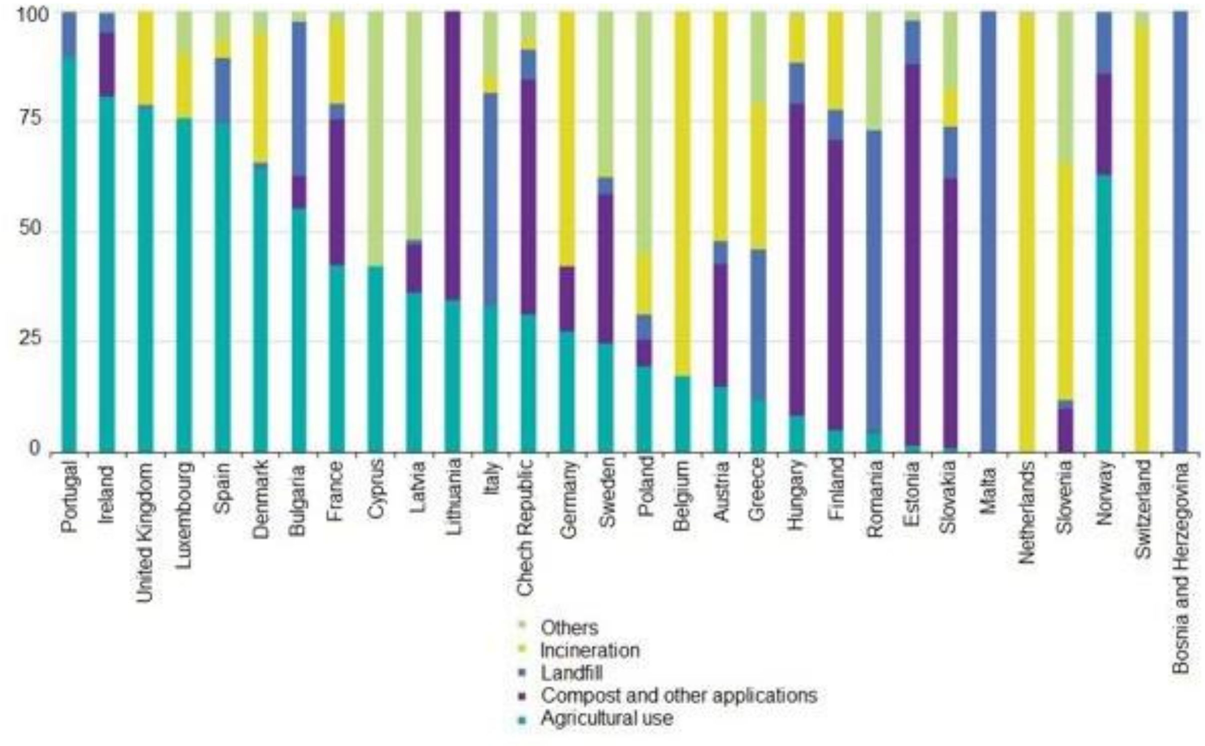
- Solid fuel in boilers, either alone or in combination with biomass, to obtain activated carbon and
- Gasification processes for obtaining hydrogen-rich gas.

Treatment of sewage sludge incineration, pyrolysis and gasification is different in many ways. Incineration, pyrolysis and gasification have the ability to convert sewage sludge to simple nonhazardous byproducts. However, the mechanisms of conversion and the nature of the side effects vary considerably. Each of these processes must be consistent with environmental protection and economy. Based on the collected data, incineration, pyrolysis and gasification can be compared in four categories: sludge preparation and feeding, operation, gas cleanup and byproducts handling [31].

Based on the various technologies used to treat sewage sludge, advantages and disadvantages can be defined. All technologies have the advantage of reducing the volume and weight of silt and less landfilling. Lack of incineration in relation to pyrolysis and gasification are the costs associated with air pollution. While pyrolysis and gasification are assumed to meet all environmental protection requirements. The process of preparing sewage sludge for all technologies is the same. The first step is drying and then the water is removed. The thermal process in all cases is different. At the incineration, ashes appear as a byproduct disposed on landfills, while slag is the primary product in pyrolysis and gasification. Pyrolysis and gasification of sewage sludge are relatively new technologies and there is not much information about them. The assumption is that more attention will be devoted to researching and delivering more quality data over the next period. [31].

4. REVIEW OF THE TREATMENT OF SEWAGE SLUDGE IN EUROPE

The residual of wastewater treatment is sewage sludge. In Europe, production of sewage sludge per inhabitant is about 90 g/person per day and is derived from primary, secondary and tertiary wastewater treatment. Annual production in 1992 was about 5.5 million dry matter, this amount has increased to about 9 million tones until the end of 2005 [27]. This increase is a result of the practical implementation of the Directive on the treatment of urban waste water (91/271EEC) [32], as well as the increased number of households connected to the sewage system and a larger share of tertiary treatment of waste water through which nutrients are being removed. In Germany, in 2002, 10 million tons of sludge has been produced, 30% of which is dry matter. This amount is approximately equal to 3.5 times the volume of the pyramid Giseh [33].



(') Belgium, Denmark, Greece, Spain, Cyprus, Lithuania, Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden and the UK:2012
Italy: 2010. Croatia: not available.
Source: Eurostat (online data code: env_ww_spd)

Figure 2. Sewage sludge disposal from urban wastewater treatment, by type of treatment, 2013. in percentage (%) [34]
Slika 2. Tretman otpadnog mulja iz prečišćenih komunalnih otpadnih voda, prema vrsti obrade, 2013. u procentu (%) [34]

While the amount of sludge generated per inhabitant depends on many factors and hence is quite variable, the nature of this sludge – rich in nutrients, but also often loaded with high concentrations of pollutants such as heavy metals – has led countries to seek different pathways for its disposal, as illustrated in Fig. 2.

The problem of the treatment of sewage sludge exists in most European countries. This problem is best to solved in Malta, where, with the construction of the plant for waste water treatment in 2011, coverage has reached 100%. Apart from Malta, the highest rate of treatment of sewage sludge has been reported in Belgium, Hungary, Poland, Bulgaria and Slovenia. In 2013, the highest percentage of treatment of sewage sludge was recorded in Malta (100%), the UK (99.5%), the Netherlands (99.4%), Luxembourg (98.2%), Spain (97.8%), and Germany (96.4%). In the 14 EU Member States, the share of the population that is attached to the wastewater treatment system has increased by more than 80% compared to other countries [35]. Observed from the other side, less than 2% of households are connected to the system for the wastewater treatment plant in Romania, Croatia, Turkey, Albania, Serbia, Bosnia and Herzegovina and Kosovo. In five EU countries: Portugal, Ireland, Italy, Luxembourg and Spain, at least three-quarters of sewage sludge is used as fertilizer in agriculture. On the other hand, about two-thirds of sewage sludge is composted in Lithuania and Finland. As an alternative form of disposal of sewage sludge and possibilities for expansion of pollution in agriculture, thermal form and disposal can be used. According to available data from 2010 in Europe, the incineration of sewage sludge is performed in 17 countries.

In percentages: Luxembourg 5%, Hungary 5%, Poland 5%, Romania 5%, Slovakia 5%, Spain 10%, France 15%, Italy 20%, UK 20%, Chech Rep. 25%, Slovenia 25%, Portugal 30%, Austria 40%, Denmark 45%, Germany 50%, Belgium 90%, Netherlands 100% [36]. Treatment of sewage sludge by pyrolysis and gasification is still under development and can be considered as a technology of the future. Many researches on the potential for pyrolysis and gasification are being conducted in Europe, while commercial applications are small. From the available data it can be seen that in Germany there are two treatment plants for sewage sludge treatment by gasification. The first demonstration plant was built in Balingen in 2002 at a flow rate of around 1100 t / d. After several years of experience, it was built where the flow increased to 1950 t/d. The sewage sludge is sprung from six surrounding systems. The system has about 250000 inhabitants. Installed power is 720 kW of heat energy. The second gasification plant is located in Manheim. It was built in 2010. Based on the experience gained, this system has been upgraded and its flow is around 5000 t/d. The system is about 600,000 inhabitants. Installed power is 2.2 MW of heat energy [37].

Although sewage sludge is produced per citizen, its composition depends on many factors. Sewage sludge contains many nutrients, but often contain high concentrations of harmful substances such as heavy metals, and many countries use different methods for its removal. Fig. 3 shows the production and wastewater treatment in Bosnia and Herzegovina in the period of several years.

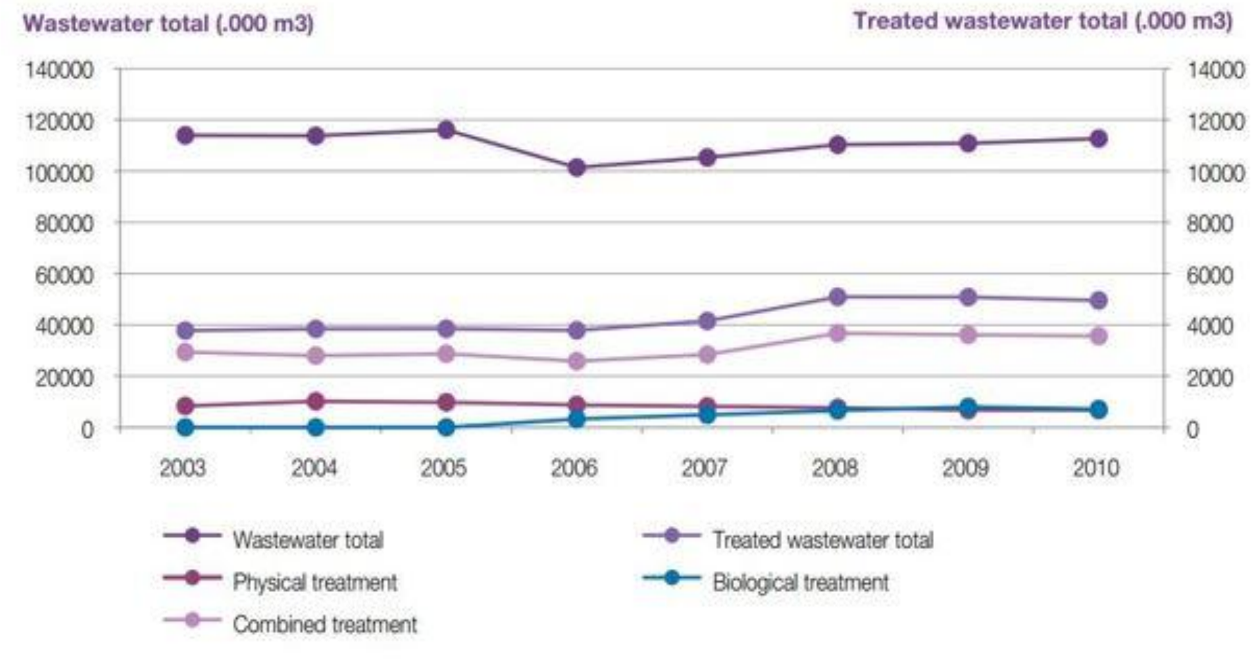


Figure 3. Wastewater treatment in Bosnia and Herzegovina [35]

Slika 3. Obrada otpadnih voda u Bosni i Hercegovini [35]

Since 2003, in Bosnia and Herzegovina, there was a slight increase in user connection to the waste water treatment system. In the analyzed period (2003-2010) some progress has been achieved, if we take into account the ratio of the amount of water that is purified by a year to the total amount of waste water. In 2009, a positive upward trend in the quality of treatment has continued, as evidenced by the increase in the share of biological methods of treatment while in 2010 there was a slight fall which can be seen in Fig. 3.

In BiH, the problem of inadequate wastewater discharge is pronounced. Only a few municipalities in the Federation (Gradačac, Žepče, Odzak, Srebrenik and Trnovo in the Sava River basin; Ljubuski, Citluk, Grude and Neum in the Adriatic Sea basin) and two in the RS (Trebinje and Bileca in the Adriatic Sea basin) have operational facilities for treatment of sewage water [34].

5. CONCLUSION

The treatment of sewage sludge is currently a big problem. Since there are many ways for the treatment sewage sludge, it is important to choose the most effective. When effective treatment is mentioned, it is understood that the harmful substances are neutralized through treatment, the amount of the treated residue from the disposed sludge is reduced, the potential energy of the composition of the sludge is used and that the treatment has no effect of environmental pollution or said effect is very small. Most represented treatment of waste water is disposal or use as a fertilizer in agriculture. An important factor in defining the most suitable sludge treatment and final disposal may be a possibility of its re-use. It would be recommended to examine existing methods and to focus more on the possibilities for the thermal treatment of sewage sludge and sludge utilization as fuel to generate electricity and thermal energy. In the thermal treatment, the most effective treatment is a process of pyrolysis and gasification. In this case, the coefficient of utilization is the highest and the environmental impact is minimal. Using the technology of pyrolysis and gasification is much more complicated than conventional thermal treatment, and therefore, more attention should be paid to scientific research and the development of it. The motivation for this is great. Application of the concept of sustainable development, the reduction of greenhouse gas emissions and protecting the environment are just some of the things that can affect the application of sewage sludge treatment process of pyrolysis and gasification.

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IZVOD

PIROLIZA I GASIFIKACIJA U PROCESU TRETMANA KANALIZACIONOG MULJA

Piroliza i gasifikacija predstavljaju termohemijski proces konverzije čvrste mase, a dobijeni proizvodi su: tečnost (pirolitičko ulje), gasovi i koks kao čvrsti ostatak. U modernom društvu se sve više javlja potreba za primenom ekoloških sistema i obnovljivih izvora energije. Kao potencijalni i obnovljivi energetski resurs možemo smatrati kanalizacioni mulj. Kanalizacioni mulj se pretežno odlaže u prirodu, dok se veoma mali deo tretira. Zbog neadekvatnog tretmana kanalizacionog mulja postoji veliki rizik od uticaja štetnih materija na čoveka i životinje. Osim što kanalizacioni mulj može predstavljati veliki energetski potencijal, termički tretman omogućava da se reši problem odlaganja kanalizacionog mulja u prirodu i zagađenje životne sredine. Iskorišćenjem kanalizacionog mulja kao energenta ostvarile bi se velike uštede fosilnog goriva, neutralisala bi se odlagališta kanalizacionog mulja i smanjio bi se rizik od nastanka i širenja bolesti usled prisustva štetnih materija.
Ključne riječi: *gasifikacija, kanalizacioni mulj, piroliza, termički procesi.*

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