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RESEARCH OF CHARACTERISTICS SEWAGE SLUDGE AS THE FOUNDATION FOR THERMAL PROCESSING AND EVALUATION OF ITS ENERGY EFFICIENCY

ABSTRACT
This paper presents research on the preparation of sewage sludge for thermal treatment. Sampling of sewage sludge was carried out in Doboj (Bosnia and Herzegovina). The sewerage system in Doboj has no sewage sludge treatment plant and no wastewater treatment plant. Wastewater and sewage sludge is extracted from booster stations they directly discharged into the river Bosna. One of the potential solutions for sewage sludge disposal and environmental protection is the preparation of sludge for thermal processing such as pyrolysis, gasification or burning. Technical and elemental analysis of the sewage sludge from Doboj indicates increased mass of coal (C=26.76%) and oxygen (O=67.48%) reduced to the burning mass, which justifies the possibility of applying this sludge for thermal purposes. Sampled sewage sludge mass of 3000 g was dried in a laboratory drier at a temperature of 105ºC and the drying time of 420 min. After the drying process, the mass of an absolutely dry sludge was 2130 g or 71%. The characteristics of the sewage sludge (technical and elemental analysis) and the mass obtained by an absolutely dry sludge indicate the possibility of using energy and matter by thermal processing. During the process of sludge drying in the exhaust gas from the dryer there are no registered values of the volume concentrations CO, CO_2 and NO_x.
Keywords: sewage sludge, characteristics, drying, thermal treatment

SAŽETAK
U radu su prikazana istraživanja pripreme kanalizacionog mulja za termički tretman. Uzorkovanje kanalizacionog mulja sprovedeno je u gradu Doboju (Bosna i Hercegovina). Kanalizacioni sistem u Doboju nema postrojenje za prečišćavanje otpadnih voda i postrojenja za tretman kanalizacionog mulja. Otpadne vode i kanalizacioni mulj se iz precrpnih stanica direktno ispuštaju u reku Bosnu. Kao jedno od potencijalnih rešenja zbrinjavanja kanalizacionog mulja i zaštite životne sredine jeste priprema mulja za termičku preradu kao što su: piroliza, gasifikacija ili sagorevanje. Tehnička i elementarna analiza kanalizacionog mulja iz Doboja ukazuje na povećani maseni udeo ugljenika (C=26.76%) i kiseonika (O=67.48%) svedeno na sagorljivu masu, što opravdava mogućnost primene ovog mulja u termičke svrhe. Uzorkovani kanalizacioni mulj mase 3000 g sušen je u laboratorijskoj sušari pri temperaturi od 105ºC i vremenu sušenja od 420 min. Posle procesa sušenja masa apsolutno suvog mulja iznosila je 2130g ili 71%. Karakteristike kanalizacionog mulja (tehnička i elementarna analiza) i dobijena masa apsolutno suvog mulja upućuje na mogućnost korišćenja energije i materija termičkim postupcima prerade. Tokom procesa sušenja mulja u izlaznom gasu iz sušare nisu registrovane vrednosti zapreminskih koncentracija CO, CO_2 i NO_x.
Ključne reči: kanalizacioni mulj, karakteristike, sušenje, termički tretman

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1. INTRODUCTION

Sewage sludge is an inevitable byproduct of waste water, which is created in developed environments. Production of sewage sludge is increasingly becoming a concern for human health and the environment [1]. Sewage sludge is rich in nutrients such as nitrogen and phosphorus and contains organic matter that is useful for repairing damaged soil. Because of this, the sewage sludge has long been used as fertilizer. The problem is the presence of pathogenic substances, heavy metals and highly biodegradable organic compounds [2].

Over the past decades there has been rapid development and the amount of sludge has drastically increased, which can have negative effects on the environment. Because of this, the traditional methods of disposal of landfills and agricultural land are less represented. Thermal treatment such as combustion, pyrolysis and gasification of municipal sludge now dominate [3].

Combustion of sewage sludge is an attractive technology because it allows a reduction in the volume of sewage sludge, destroys the presence of pathogenic substances, replaces fossil fuels, gives access to hidden energy and achieves economic savings.

European regulations on the treatment of sewage sludge [4] are very rigorous, and impose an accelerated development and application of thermal processes for the treatment of sewage sludge.

Environmental protection and EU regulations support the use of renewable energy sources such as biomass and sewage sludge which should be binding on Bosnia and Herzegovina (BiH) in view of a series of agreements signed with the EU on the use of renewable sources. Data on the production of sewage sludge in the world are different. The reason for this is probably the treatment of sewage sludge in the phase of modernization. In order to obtain precise data on the production of sewage sludge, it would be best to carry out the measurement in each case individually. For example, it is estimated that the dry matter production of sewage sludge is 40-50 g per person per day [1].

For example, in sewage treatment plants in Poland, the sewage sludge production is 0.25 kg/m^3 of treated wastewater [4]. Estimated sewage sludge production in Spain is about 0.2-0.3 kg per capita [5]. According to literature data it is estimated that the production of sewage sludge varies from 16 to 94 g per person per day.

In underdeveloped countries, such as Bosnia and Herzegovina, a very small number of cities have wastewater treatment plant, while most cities sewage sludge without treatment is directly discharged into rivers, lakes or seas. One such case is the town of Doboj, where wastewater and sewage sludge have been discharged into the river without treatment, which poses a direct threat to health and the environment.

A positive example of wastewater treatment in the Balkans was carried out as a pilot project in Kikinda (Republic of Serbia). In this project, a drinking water dispenser was introduced. The capacity of this unit is about 700 l/h of processed wastewater [6].

2. EXPERIMENTAL TESTING OF THE SEWAGE SLUDGE PREPARATION PROCESS

2.1.Sampling of sewage sludge

Sampling of the sewage sludge was carried out in the drainage collector in the city of Doboj (BiH), where there are pumps located for sludge pumping into the drainage pipeline in Bosnia. Sampling was done according to the European Standard EN 12880, relating to the characterization of sludge's [7]. Sampling scheme of the sewage sludge is shown in Figure 1.

The filter container for collecting is hung on the rope that is fixed to the manhole cover. When measuring, a precision digital scale is positioned above the lid which is connected by rope with filter container for collecting (TCM, measuring range 0-4000 g, and accuracy class 1g/0.1oz). In the filter vessel precipitated the sewage sludge total mass 3000 g while the rest of the water passes through the filter into the main sewerage pipe. The sludge measurement is performed once a day (M.M.1), five consecutive days at the same time, after which the filter vessel is emptied and washed with clean water. The measurement of the sewage water temperature (M.M.2) is done using a thermometer-DATA LOGERA (Elitech, measuring range from -30 °C to +70 °C, accuracy class +/- 0.5 °C) in a plastic container, hermetically protected, placed at the bottom of the canalization shield. The bowl is secured by a safety rope to the shield lid. The measurement of wastewater temperature is done for testing purpose of waste heat energy, as well as for recuperation options over heat pumps. The average value of the wastewater temperature is about 17 °C.

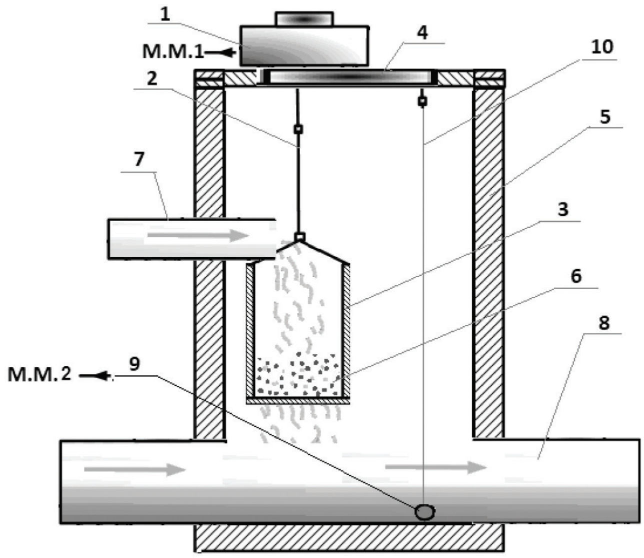

Figure 1. *Scheme sampling of sewage sludge*
1- digital scale, 2- rope, 3 – filter container for collecting, 4 – manhole cover, 5 – sewer manhole, 6 – collected sludge, 7 – sewer pipe, 8 – main sewer pipe, 9 – athermocouple, 10 – safety rope

2.2. Drying of sewage sludge

After sampling the sewage sludge, sludge (3000 g) was introduced into the dryer. Dryer is designed and made in the Laboratory of the Department of Environmental Protection and Occupational Safety Engineering and Department of Energy and Process Engineering of the Faculty of Technical Sciences in Novi Sad. Materials used for building a dryer should be resistant to high temperatures and temperature corrosion. Figure 2 shows measuring site on which the weight change of sample sludge was measured (M.M.1), temperature in the dryer (M.M.2) and the composition of the output gases (M.M.3). Digital precision scales METTLER P1000 was used to measure sludge sample change. Heating of sludge sample in a drying oven was carried out by electric heats, and after reaching a temperature of 105°C, the temperature was maintained at that temperature until the mass of the sample in the reactor had settled. The container with the sample is pointed at the scale by means of a flexible connection between the scale and the container.

Temperature in container with a pattern was measured using the Testo 925 digital temperature display the probe type K (NiCr - Ni). After the experiment, solid mass of sample mass was measured. The composition of the gas (CO,CO2,NOx,O2) at the outlet from the dryer was measured using a gas analyzer PROTECH Ipex D.

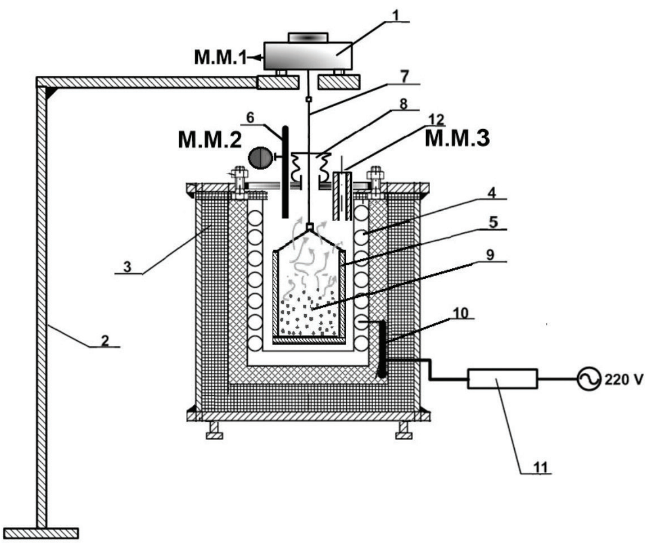

Figure 2. *Scheme drier and metering points*
1 - digital scale, 2 - rack for the scale, 3 - oven, 4 - electric heaters, 5 - dryer, 6 - thermocouple (temperature gauge in an oven), 7 - a flexible connection between the scales and the sludge container, 8 - flexible teflonic wrapper, 9 - sample of sewage sludge, 10 - temperature regulator sensor, 11 - temperature regulator, 12 - gas analyzer

Figure 3 shows the variation of sludge sample mass mWM/m0 as a function of drying time. During the first 10 minutes the sample mass in the dryer remains unchanged (3000 g). Further, during the process of drying the sample, a slight loss of sample mass was recorded. The loss of mass of the sample was recorded up to 420 minutes. After 420 min, the sample mass in the dryer was stabilized (2130 g) and was not recorded further change of the sample mass.

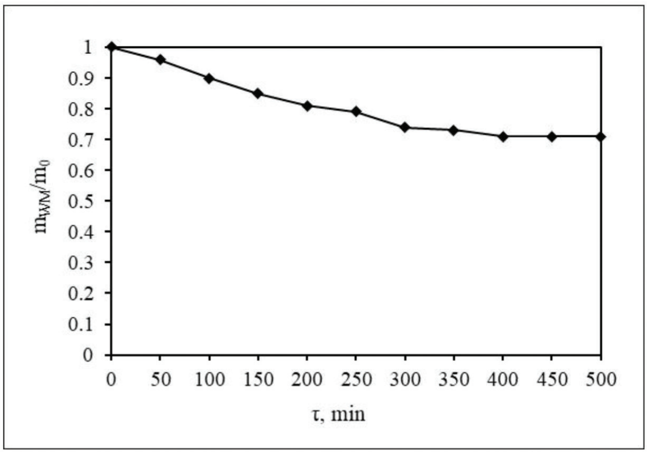

Figure 3. *Change mass of sludge sample by drying depending on time (m_0 - the initial mass of the sludge, m_{WM} – procedural mass of sludge, τ – the time of drying)*

The mass fraction of moisture ($\tilde{x}_{H_2O}$) in the wet sewage sludge during the drying process can be determined by expression :

$$\tilde{x}_{H_2O} = \frac{m_{H_2O}}{m_{SM} + m_{H_2O}} = \frac{m_{H_2O}}{m_{WM}}, \frac{g\,H_2O}{g\,WM} \tag{1}$$

where are:
m_{H_2O} - weight moisture in the wet sludge, g
m_{SM} - mass of an absolutely dry sludge, g
m_{WM} - mass of wet sludge, g.

During the sludge drying process in the exhaust gases no registered concentrations CO, CO2, NOx. Volume fraction Cubical the share of oxygen in the exhaust gas was 20.64%.

3. COMPARATIVE ANALYSIS OF ACQUIRED CHARACTERISTICS OF SEWAGE SLUDGE WITH DATA FROM LITERATURE

The technical and elemental analysis of the sewage sludge is shown in Table 1. The analysis was carried out in a laboratory for water, hydrocarbons and materials testing in the INA d.d. from Zagreb (Republic of Croatia) [8].

Table 2 shows the characteristics of the EU sludge sludge and some other countries. Mass components of individual components refer to burnable mass (a base without moisture and ashes).

For comparison of the characteristics of the sewage sludge from Doboj (BiH) with the sewage sludge of some other countries and EU (Table 2) in Figures 4 and 5, the dependence of the upper heat power of sludge, coal and size

$$M = \frac{\left| H_g - O_g / 8 \right| \cdot 12}{C_g}$$

reduced on a burnable mass (base without moisture and ash). It can be noticed that there is a linear correlation

Technical and elemental analysis (dry basis, mass fraction, %)							Upper heat power - H^g MJ/kg
Carbon C_S	Hydrogen H_S	Nitrogen N_S	Sulfur S_S	Oxygen O_S	Ash A_S	**Moisture W**	
14.92	2.16	0.55	0.51	37.63	44.24	30.90	1.73

Table 1. *Characteristics of the sewage sludge in the city of Doboj*

Country	Combustible mass (mass percentage, %)							Hg (MJ/ kg)
	C_g	H_g	N_g	S_g	O_g	A	W	
China [9]	16.70	5.56	0.82	2.00	74.92	54.50	77.90	1.30
Korea [10]	32.59	6.08	3.08	1.27	56.97	13.33	72.13	9,92
Turkey [11]	38.97	5.10	4.11	0.81	50.99	36.54	5.14	11.75
India [12]	38.10	3.25	2.55	2.02	56.10	60.00	-	8.56
European Union [13]	9.30	8.13	5.32	0.55	76.7	-	28.50	1.44
Bosnia and Herzegovina (Doboj)	26.76	3.87	0.99	0.91	67.48	30.57	30.90	3.62

Table 2. *Comparative characteristics of sewage sludge in some countries with BiH (Doboj)*

between the characteristics of the sewage sludge from Doboj (BiH) with the characteristics of the sewerage sludge of the EU and some other states. Graphics (Figure 4 and Figure 5) show that there is a high degree of stacking between variable C_g i H^g (the coefficient of correlation amounts R=0.91, and the regression equation is H^g=0.35·Cg-3.37) and variable M i H^g (the coefficient of correlation amounts R=0.96, and the regression equation is H^g=4.61·M+12.74). With the increase in oxygen content in the sewage sludge (lower value of indicator M), the value of the upper heat sludge power decreases, which is understandable since the oxygen is present ballast because it is not gratifying. In addition, with the rise of oxygen in the sludge the value of the mass fraction of fixed carbon (C_{fix}) in the sludge is also reduced. From the point of combustion of sludge it is more suitable for sludge with smaller C_{fix} content. The obtained results can be used as a starting point for determining the material and thermal balance of the thermal treatment plant of sludge both in BiH and in some other countries and in the EU.

2. CONCLUSION

Exploration of sewage sludge characteristics on samples from Doboj (BiH) indicates increased oxygen content (Og = 67.48%) and carbon (Cg = 26.76%) reduced to the combustible mass (base without moisture and ash). By comparing the characteristics of the sewage sludge from this study as a reference for BiH with the characteristics of the sewage sludge from the EU and other countries, it indicates a high degree of correlation. A higher degree of connection between the characteristics of the sludge from Doboj was noted with sludge characteristics from the EU and China. Drying sewage sludge in laboratory drier at 105ºC was obtained 71% (2130 g) an absolutely dry sludge compared to the initial mass of a wet sludge. Characteristics of the sewage sludge from Doboj and the obtained amounts of absolutely dry sludge point out the justification for applying sludge to thermal processing such as: combustion, pyrolysis and gasification. Heat energy, fuel gas and a solid residue are

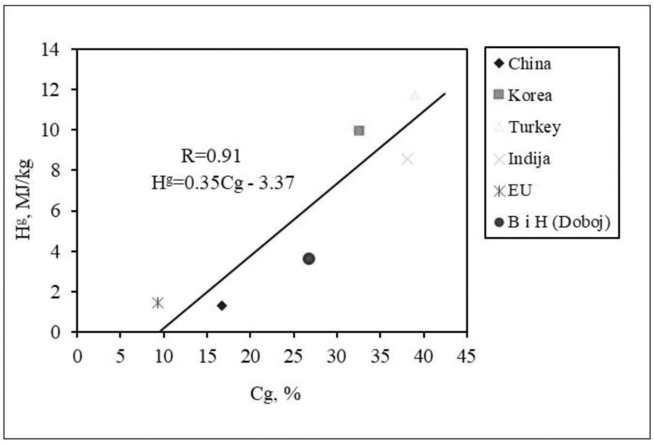

Figure 4. *The dependence of the thermal power of sewage sludge and carbon reduced to a burning mass*

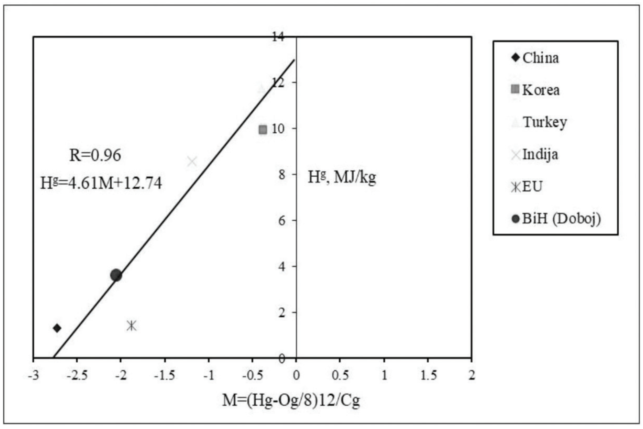

Figure 5. *Dependence of the heat power of the sewage sludge and its size M is reduced to the burning mass*

obtained using the processing procedures and can be used as a fertilizer in agriculture. During the drying process of sewage sludge there were no registered concentrations in the exhaust gas from the dryer CO, CO_2 and NO_x. Such research is of particular importance because the agreement on the Energy Community of South East Europe obliges Bosnia and Herzegovina to increase the use of renewable energy sources, including sewage sludge.

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REFERENCES

[1] Sanchez ME, Lindao E, Margaleff D, Martinez O, Moran A. Bio-fuels and bio-char production from pyrolysis of sewage sludge. J Residuals Sci Tech, 2009: 6(1).

[2] Omer AM. Environmental and socio-economic aspects of possible development in renewable energy use. J Agric Ext Rural Dev, (2010): 2(1): 001-021.

[3] Wang T, Zhang W, Lu X. Preparation and Cu (II) Adsorption Characteristics of Carboxymethyl Cross-Linked Sewage Sludge. PJoES, (2016): 25(2).

[4] Werle S, Wilk RK. A review of methods for the thermal utilization of sewage sludge: The Polish perspective. Renew Energy, (2010): 35(9): 1914-1919.

[5] Font R, Fullana A, Conesa JA, Llavador F. Analysis of the pyrolysis and combustion of different sewage sludges by TG. J Anal Appl Pyrolysis, (2001): 58: 927-941.

[6] Kukučka MĐ, Kukučka NM. Groundwater nanofiltration process efficiency improvement with additional concentrate membrane treatment. Hem Ind. (2016): 56-56.

[7] EUROPEAN STANDARD, Characterization of sludges - Determination of dry residue and water content (HRN EN 12880:2000), February 2005.

[8] INA, Laboratorij za ispitivanje voda, ugljikovodika i materijali, (2017). Zagreb. (in Serbian)

[9] Gong M, Zhu W, Zhang H, Su Y, Fan Y. Polycyclic aromatic hydrocarbon formation from gasification of sewage sludge in supercritical water: The concentration distribution and effect of sludge properties, J Supercrit Fluids. (2016): 113, 112-118.

[10] Lee YJ, Lee DW, Park JH, Bae JS, Kim JG, Kim JH, Choi YC. Two-in-One Fuel Combining Sewage Sludge and Bioliquid, ACS Sustain Chem Eng, (2016): 4(6), 3276-3284.

[11] Özçimen D, Salan T. Removal of reactive dye Remazol Brilliant Blue R from aqueous solutions by using anaerobically digested sewage sludge based adsorbents. Chem Ind Chem Eng Q. (2016): 22(2): 167-179.

[12] Ahuja P, Singh PC, Upadhyay SN, Kumar S. Kinetics of biomass and sewage sludge pyrolysis: Thermogravimetric and sealed reactor studies, NISCAIR-CSIR, India, (1996): 03 (6): 306-312.

[13] Fonts I, Navarro Puyuelo A, Ruiz Gómez N, Atienza Martínez M, Wisniewsky A, Gea G. Assessment of the Production of Value Added Chemical Compounds from Sewage Sludge Pyrolysis Liquids, Energy Technol, (2017): 5(1), 151-171.