POSSIBLE APPLICATIONS OF THE BIOCHAR OBTAINED FROM SEWAGE SLUDGE

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Abstract: *The present review has in attention the valorisation of the sewage sledge from the wastewater treatment plants, as this represents a major concern for the public health and the environment. Its processing for the obtaining of the sludge-based biochar can be further used for the removal of some pollutants from the environment. The possibility to use the sludge-based biochar for the removal of heavy metals and of organic pollutants is presented.*

Keywords: wastewater, sewage sludge, biochar, heavy metals

INTRODUCTION

The wastewater treatment plants (WWTPs) are receiving the sewage from different sources and might comprise water that carries wastes discharged from the residential, industrial and commercial establishments. The by-product of the WWTPs is the sewage sludge a biosolid (Turek et al., 2019) that is covered by a number of European legal acts that are focusing on the environmental and water protection, waste management and soil fertilization (E.C. Directive).

As a result of the population growth, the amount of produced sewage sludge is in a continuous increase, and as a consequence the efficiency of the treatment processes in the WWTPs is in a permanent improvement (Spanos et al., 2016; Tytła, 2018).

The composition of the sludge may consist of high concentrations of hazardous components. The main sources of heavy metals in the wastewaters are industrial and domestic activities, including the pharmaceuticals and cleaning products that are intentionally or accidentally discharged (Duan et al., 2018; Rizzardini and Goi, 2014).

Depending on the chemical composition of the wastewater and processes that are used in the WWTPs, the quality of the sewage sludge might differ. In general, the sludge from the residential wastewater might be rich in heavy metals and metalloids (Houhou et al., 2009; Vardhan et al., 2019).

The accumulated heavy metals in the sewage sludge are representing a serious problem for the environment because of their accumulation in the soil, and as a consequence the surface and groundwater can be subsequently contaminated. Ultimately, the crops and the food chain might be containing amounts of heavy metals that might have a negative impact on the animal and human health (Feizi et al., 2019; Tytła et al., 2016).

A report elaborated for the European Commission shows that by 2020 the total amount of produced sewage sludge at the level of EU27 is going to be around 13047000 tonnes of dry solid. Out of this amount about 44% is going to be recycled to the land, 32% will be incinerated and about 7% for landfill (Milieu Ltd, 2008).

As the biggest amount of the sewage sludge is intended for the use of land fertilization, the composition plays an important role. The highest concentration is represented by the organic matter and biogenic compounds, which play a special role in the growth of the plants (Zhang et al., 2017). Unfortunately, beside the necessary compounds, the content in heavy metals (chromium, copper, lead, nickel, mercury, and zinc) (Tytła et al., 2016) might have a negative impact on the environment and on the animal and human health.

CONTENT OF HEAVY METALS IN THE SEWAGE SLUDGE

Considering the provenience of the wastewater and the various anthropogenic activities the load in heavy metals of the sewage sludge is high. According to the work of Gawlik (Gawlik, 2012), the results are presented in Table 1.

Table 1. The range of heavy metals contained by the sewage sludge from the European Union countries (Gawlik, 2012).

Trace metal	Range of determined values in EU countries	Unit
Al	0.1-60	%
Ag	0.1-14.7	mg/kg DM
As	5.6-56.1	mg/kg DM
Ba	41.5-579.9	mg/kg DM
Cd	0.3-5.1	mg/kg DM
Co	1.5-16.7	mg/kg DM
Cr	10.8-1542.2	mg/kg DM
Cu	27.3-578.1	mg/kg DM
Fe	0.2-14.9	%
Hg	0.1-1.1	mg/kg DM
Mn	75.2-959.7	mg/kg DM
Mo	1.7-12.5	mg/kg DM
Ni	8.6-310.0	mg/kg DM
Pb	4.0-429.8	mg/kg DM
Se	3.4-53.6	mg/kg DM
Ti	65.2-1070.9	mg/kg DM
V	2.3-135.4	mg/kg DM
Zn	0.0-0.1	%

*DM-dry matter

The presence of heavy metals in the sewage sludge might be an inconvenient, but for the obtaining of the sewage sludge biochar their negative impact on the environment can be reduced if the combustion is performed at low temperatures, cases when some of the metals are transformed in stable forms and their leaching from the biochar is prevented (Ahmad and Alam, 2016).

OBTAINING BIOCHAR FROM SEEWAGE SLUDGE

For the mitigation of the risks associated with the presence of the heavy metals in the sewage sludge used as fertilizer in the agriculture were proposed a number of methods (Frišták et al., 2018; Hei et al., 2016; Herzel et al., 2016; Kominko et al., 2019; Meng et al., 2018; Suciu et al., 2015; Thomsen et al., 2017; Vogel et al., 2020; Wang et al., 2019c).

Recently, a huge interest was paid to the obtaining of the biochar based on the sewage sludge (Barry et al., 2019; Yin et al., 2019). An important advantage of using the biochar obtained from this raw material is that the heavy metals that are present in the sewage sludge will be in a stable form in the biochar, fact that will make the use of the biochar less aggressive in environmental application (Zielińska and Oleszczuk, 2015). Biochar can be described as a porous carbonaceous solid material that is obtained from residual biomass through slow pyrolysis (temperature range 450-650°C) under limited oxygen conditions (Colantoni et al., 2016; Mian et al., 2019; Thomsen et al., 2017; Xue et al., 2019). The main advantage of the biochar is that is an efficient adsorbent which is low-cost and can be produced from a large variety of biomass materials, including the sewage sludge. The sludge-based biochar was proven to have chemical stability with low metal leaching, that has the advantage to be recyclable and cost-effective (Mian et al., 2019; Wang et al., 2019b). The steps for the production of biochar are schematically represented in Figure 1.

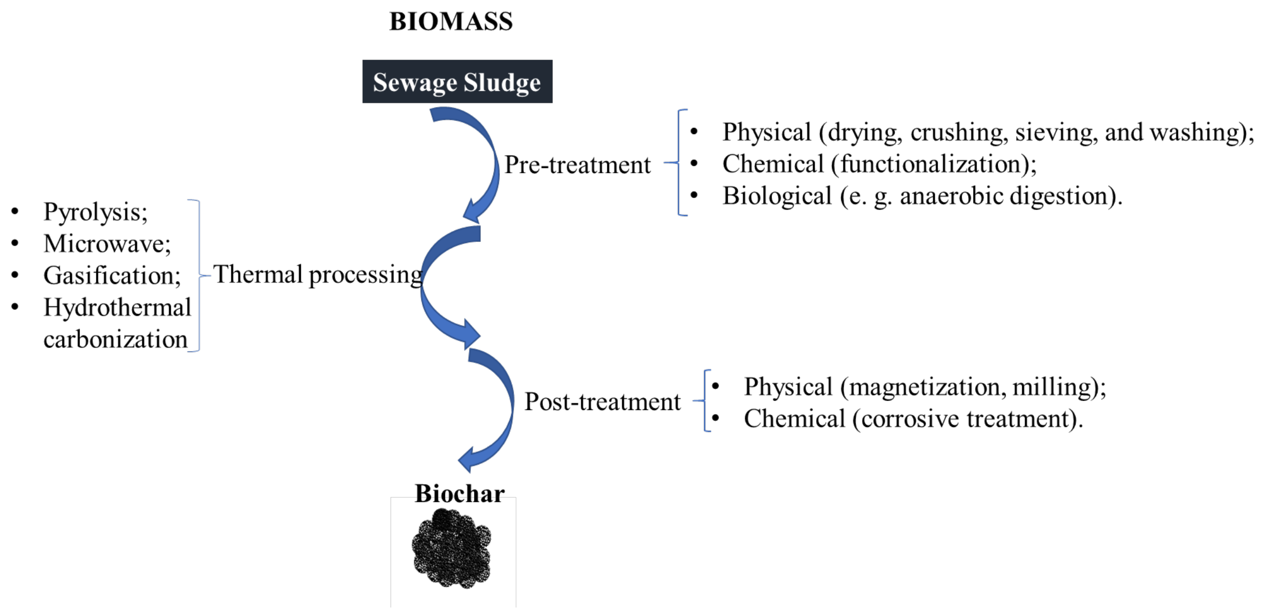

Figure 1. Steps for biochar production from sewage sludge.

Regarding the thermal processing of the pre-treated biomass, the most used methods are: pyrolysis, microwave digestion and hydrothermal carbonization.

Pyrolysis can be performed at temperatures between 100°C and 800°C in the presence of argon or nitrogen as control gases of the pyrolysis. Thereafter, the solid residues can be treated with acidic solutions for the increase of the specific surface area and porosity (Tu et al., 2014).

Use of the microwave digestion it usually implies three sequential steps: (i) impregnation of the sewage sludge with an acidic solution; (ii) chemical activation with a solution of KOH/KCl, and (iii) post-calcination (Gu et al., 2017).

Hydrothermal carbonization is performed at temperatures in the range of 150-250°C, and a pressure of 1.5-2.5 Ba for a retention time that might vary between 1 and 24 h (Zhang et al., 2018).

In comparison with the physicochemical properties of the sewage sludge, the properties of the sludge-based biochar need improvements that can be obtained by improving the carbonization conditions and/or by a post-treatment (chemical or physical)

In general, for improved characteristics of the surface and catalytically active sites of the engineered biochar, are used advanced synthesis methods (Mian and Liu, 2019).

APPLICATIONS OF SEWAGE SLUDGE BASED BIOCHAR

Most of the applications that are using the sludge-based biochar are focusing on the removal of some pollutants from the environment (Mian et al., 2019; Regkouzas and Diamadopoulos, 2019; Wang and Wang, 2019; Wang et al., 2019a; Xue et al., 2019; Zhang et al., 2019). Some environmental applications of the sludge-based biochar are presented in Table 2.

Table 2. Applications of the sludge-based biochar for the removal of some contaminants.

Contaminant	Adsorption capacity	Method for biochar preparation	Reference
Heavy metals			
Lead	51.20 mg/g	anaerobic digestion sludge under pyrolysis temperature of 600°C	(Ho et al., 2017)
	126.40 mg/g		(Ni et al., 2019)
	116.20 mg/g	pyrolysis of sewage sludge by electromagnetic induction, at 500°C	(Xue et al., 2019)
Cadmium	0.44 mmol/g	anaerobic digestion sludge under pyrolysis temperature of 600°C	(Ni et al., 2019)
	97.30 mg/g	pyrolysis of sewage sludge by electromagnetic induction, at 500°C	(Xue et al., 2019)
Organic pollutants			
2,4-Dichlorophenol	3.88 mg/g	Anaerobic pyrolysis of sewage sludge at 500°C	(Regkouzas and Diamadopoulos, 2019)
2,3,4-Trichlorophenol	1.32 mg/g		
Bisphenol A	24.89 mg/g		
Carbamazepine	761.10 mg/g		
Androsterone	0.006 mg/g		
Estrone	92.21 mg/g		
17a-Ethinylestradiol	0.011 mg/g		
Methylene blue	376.9 mg/L	Thermal decomposition at 800°C of sewage sludge (SS) and different ratios of nanoparticles (NPs: Fe and Ti) impregnated with chitosan	(Mian and Liu, 2019)

As shown in Table 2, the biochar obtained through different methods from the sewage sludge can be successfully used for the removal of some contaminants from the environment. Nevertheless, the efficiency of using the sludge-based biochar for the removal of some contaminants is promising and can be further considered for real environmental samples.

CONCLUSIONS

The biochar obtained from the sewage sludge is proving to be a good candidate for the removal of some pollutants from the environment. It was shown that the pyrolysis of the sewage sludge it will lead to biochars that can be used for the adsorption of some heavy metals or organic pollutants from different samples.

Future work should consider the optimization of the pyrolysis temperature, as this parameter plays an important role in the physical properties of the biochar as well as on the number of catalytic sites that allow a better adsorption capacity.

A special attention should be also paid to the use of other materials mixed with the sewage sludge for the obtaining of a biochar with improved properties as promising materials for environmental remediation.

Unfortunately, most of the studies were performed under laboratory conditions, so that further studies should be considered for the extension of the sludge-based biochar for in-field use.

REFERENCES

Ahmad, T.A.K., Alam, M., 2016. Sustainable management of water treatment sludge through 3‘R’ concept. J Clean Prod 124, 1-13.

Barry, D., Barbiero, C., Briens, C., Berruti, F., 2019. Pyrolysis as an economical and ecological treatment option for municipal sewage sludge. Biomass Bioenergy 122, 472–480.

Colantoni, A., Evic, N., Lord, R., Retschitzegger, S., Proto, A.R., Gallucci, F., Monarca, D., 2016. Characterization of biochars produced from pyrolysis of pelletized agricultural residues. Renew. Sustain. Energy Rev. 64, 187e194.

Duan, B., Zhang, W., Zheng, H., Wu, C., Zhang, Q., Bu, Y., 2018. Disposal Situation of Sewage Sludge from MunicipalWastewater Treatment Plants (WWTPs) and Assessment of the Ecological Risk of Heavy Metals for Its Land Use in Shanxi, China. Int. J. Environ. Res. Public Health 14, 823.

E.C. Directive, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. pp. 3–30. L312. www.eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF.

Feizi, M., Jalali, M., Renella, G., 2019. Assessment of nutrient and heavy metal content and speciation in sewage sludge from different locations in Iran. Nat. Hazards 95, 657–675.

Frišták, V., Pipíška, M., Soja, G., 2018. Pyrolysis treatment of sewage sludge: A promising way to produce phosphorus fertilizer. Journal of Cleaner Production 172, 1772-1778.

Gawlik, B., 2012. Results of a Pan-European Snapshot of randomly taken sewage sludge sample, Proceedings of Workshop DG ENV and DG JRC.

Gu, L., Li, C., Wen, H., Zhou, P., Zhang, D., Zhu, N., Tao, H., 2017. Facile synthesis of magnetic sludge-based carbons by using Electro-Fenton activation and its performance in dye degradation. Bioresour. Technol. 241, 391–396.

Hei, L., Jin, P., Zhu, X., Ye, W., Yang, Y., 2016. Characteristics of Speciation of Heavy Metals in Municipal Sewage Sludge of Guangzhou as Fertilizer. Procedia Environmental Sciences 31, 232-240.

Herzel, H., Kruger, O., Hermann, L., Adam, C., 2016. Sewage sludge ash--A promising secondary phosphorus source for fertilizer production. Sci Total Environ 542, 1136-1143.

Ho, S.H., Chen, Y.D., Yang, Z.K., Nagarajan, D., Chang, J.S., Ren, N.Q., 2017. High-efficiency removal of lead from wastewater by biochar derived from anaerobic digestion sludge. Bioresour Technol 246, 142-149.

Houhou, J., Lartiges, B.S., Montarges-Pelletier, E., Sieliechi, J., Ghanbaja, J., Kohler, A., 2009. Sources, nature, and fate of heavy metal-bearing particles in the sewer system. Sci Total Environ 407, 6052-6062.

Kominko, H., Gorazda, K., Wzorek, Z., 2019. Potentiality of sewage sludge-based organo-mineral fertilizer production in Poland considering nutrient value, heavy metal content and phytotoxicity for rapeseed crops. J Environ Manage 248, 109283.

Meng, X., Huang, Q., Gao, H., Tay, K., Yan, J., 2018. Improved utilization of phosphorous from sewage sludge (as Fertilizer) after treatment by Low-Temperature combustion. Waste Manag 80, 349-358.

Mian, M.M., Liu, G., 2019. Sewage sludge-derived TiO2/Fe/Fe3C-biochar composite as an efficient heterogeneous catalyst for degradation of methylene blue. Chemosphere 215, 101–114.

Mian, M.M., Liu, G., Fu, B., 2019. Conversion of sewage sludge into environmental catalyst and microbial fuel cell electrode material: A review. Sci Total Environ 666, 525-539.

Milieu Ltd, W.a.R., 2008. Environmental, economic and social impacts of the use of sewage sludge on land. European Commission.

Ni, B.J., Huang, Q.S., Wang, C., Ni, T.Y., Sun, J., Wei, W., 2019. Competitive adsorption of heavy metals in aqueous solution onto biochar derived from anaerobically digested sludge. Chemosphere 219, 351-357.

Regkouzas, P., Diamadopoulos, E., 2019. Adsorption of selected organic micro-pollutants on sewage sludge biochar. Chemosphere 224, 840-851.

Rizzardini, C.B., Goi, D., 2014. Sustainability of domestic sewage sludge disposal. Sustainability 6, 2424–2434.

Spanos, T., Ene, A., Styliani Patronidou, C., Xatzixristou, C., 2016. Temporal variability of sewage sludge heavy metal content from Greek wastewater treatment plants. Ecol. Chem. Eng. S 23, 271–283.

Suciu, N.A., Lamastra, L., Trevisan, M., 2015. PAHs content of sewage sludge in Europe and its use as soil fertilizer. Waste Manag 41, 119-127.

Thomsen, T.P., Hauggaard-Nielsen, H., Gobel, B., Stoholm, P., Ahrenfeldt, J., Henriksen, U.B., Muller-Stover, D.S., 2017. Low temperature circulating fluidized bed gasification and co-gasification of municipal sewage sludge. Part 2:

Evaluation of ash materials as phosphorus fertilizer. Waste Manag 66, 145-154.

Tu, Y., Xiong, Y., Tian, S., Kong, L., Descorme, C., 2014. Catalytic wet air oxidation of 2-chlorophenol over sewage sludge-derived carbon-based catalysts. J. Hazard. Mater. 276, 88–96.

Turek, A., Wieczorek, K., Wolf, W.M., 2019. Digestion Procedure and Determination of Heavy Metals in Sewage Sludge—An Analytical Problem. Sustainability 11, 1753.

Tytła, M., 2018. The Effects of Ultrasonic Disintegration as a Function ofWaste Activated Sludge Characteristics and Technical Conditions of Conducting the Process—Comprehensive Analysis. Int. J. Environ. Res. Public Health 15, 2311.

Tytła, M., Widziewicz, K., Zielewicz, Z., 2016. Heavy metals and its chemical speciation in sewage sludge at different stages of processing. Environ. Technol. 37, 899–908.

Vardhan, K.H., Kumar, P.S., Panda, R.C., 2019. A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. Journal of Molecular Liquids 290.

Vogel, C., Hoffmann, M.C., Taube, M.C., Kruger, O., Baran, R., Adam, C., 2020. Uranium and thorium species in phosphate rock and sewage sludge ash based phosphorus fertilizers. J Hazard Mater 382, 121100.

Wang, J., Wang, S., 2019. Preparation, modification and environmental application of biochar: A review. Journal of Cleaner Production 227, 1002-1022.

Wang, L., Wang, Y., Ma, F., Tankpa, V., Bai, S., Guo, X., Wang, X., 2019a. Mechanisms and reutilization of modified biochar used for removal of heavy metals from wastewater: A review. Sci Total Environ 668, 1298-1309.

Wang, X., Chi, Q., Liu, X., Wang, Y., 2019b. Influence of pyrolysis temperature on characteristics and environmental risk of heavy metals in pyrolyzed biochar made from hydrothermally treated sewage sludge. Chemosphere 216, 698-706.

Wang, X., Zheng, G., Chen, T., Shi, X., Wang, Y., Nie, E., Liu, J., 2019c. Effect of phosphate amendments on improving the fertilizer efficiency and reducing the mobility of heavy metals during sewage sludge composting. J Environ Manage 235, 124-132.

Xue, Y., Wang, C., Hu, Z., Zhou, Y., Xiao, Y., Wang, T., 2019. Pyrolysis of sewage sludge by electromagnetic induction: Biochar properties and application in adsorption removal of Pb(II), Cd(II) from aqueous solution. Waste Manag 89, 48-56.

Yin, Q., Liu, M., Ren, H., 2019. Biochar produced from the co-pyrolysis of sewage sludge and walnut shell for ammonium and phosphate adsorption from water. J Environ Manage 249, 109410.

Zhang, H., Xue, G., Chen, H., Li, X., 2018. Magnetic biochar catalyst derived from biological sludge and ferric sludge using hydrothermal carbonization: preparation, characterization and its circulation in Fenton process for dyeing wastewater treatment. Chemosphere 191, 64–71.

Zhang, X., Wang, X.-Q., Wang, D.-F., 2017. Immobilization of Heavy Metals in Sewage Sludge during Land Application Process in China: A Review. Sustainability 9, 2020.

Zhang, Z., Zhu, Z., Shen, B., Liu, L., 2019. Insights into biochar and hydrochar production and applications: A review. Energy 171, 581-598.

Zielińska, A., Oleszczuk, P., 2015. Evaluation of sewage sludge and slow pyrolyzed sewage sludge-derived biochar for adsorption of phenanthrene and pyrene. Bioresour. Technol. 192, 618–626.