Geosciences and Engineering, Vol. 10, No. 15 (2022), pp. 224–232.
https://doi.org/10.33030/geosciences.2022.15.224

ANALYSIS OF TOC VALUES OF MIXED SEWAGE SLUDGE FOLLOWING THE HYDRODYNAMIC TREATMENT, IN COURSE OF PILOT EXPERIMENT IN THE FRAMEWORK OF R&D GINOP ONGOING PROJECT

ÁKOS PINTÉR-MÓRICZ[2], SELLY AYU JANETASARI[3], LJUDMILLA BOKÁNYI[1]

[1]*Institute of Raw Material Preparation and Environmental Processing, Department of Bioprocessing and Reaction Techniques, University of Miskolc, Hungary*
ljudmilla.bokanyi@uni-miskolc.hu, https://orcid.gov/0000-0003-2038-6556
[2]*Institute of Applied Earth Science, University of Miskolc, Hungary*
akos.pinter-moricz@uni-miskolc.hu, https://orcid.gov/0000-0002-1174-5302
[3]*Ph.D. student, University of Miskolc, Hungary, Research Institute of Applied Earth Sciences*
janetasari.selly.ayu@student.uni-miskolc.hu, https://orcid.gov/0009-0005-8282-6379

Abstract: The primary and secondary stages in wastewater treatment generate a large amount of sewage sludge consisting of 90% water, mineral components, nutrients and also a variety of organic and inorganic contaminants. The contaminants do not degrade completely during these processes, thus an additional degradation is needed to stabilize the sewage sludge. The innovative technology is proposed consisting of hydrodynamic cavitation process along with the addition of Bakony brown coal as adsorbent. Hydrodynamic cavitation is known as an effective tool improving sewage sludge stabilization via aerobic degradation, while adsorbent, besides the adsorption ability, has microbial cells disintegration ability as well, further enhancing the biodegradation process. The changes in total organic carbon (TOC) values of sewage sludge after hydrodynamic treatment for various retention times (0, 5, 10, 15, and 25 minutes) was traced and interpreted.

Keywords: *sewage sludge; hydrodynamic cavitation; adsorbent; aerobic degradation, total organic carbon*

1. Introduction

The removal of biodegradable compounds and organic or inorganic particulate matters in municipal wastewater treatment plants (WWTPs) by settling (primary treatment stage) and biological treatment (secondary stage) generates large amounts of sewage sludge. Sewage sludge consists of water (>90%) and solids (<10%), 50–70% of dry matter is organic, while 30–50% are mineral components (including 1 - 4% of inorganic carbon), 3.4–4.0% N, 0.5–2.5% P and other nutrients, including micronutrients [1]. Nevertheless, sewage sludge also contains a variety of contaminants, both inorganic (such as metabolic heavy metals) and organic, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, surfactants, hormones, pharmaceuticals, and many other substances [2]. For this reason, sewage sludge needs to be treated properly prior its further utilization. The aims of sewage sludge treatment are to reduce the waste disposal amount by up to 90% and to reduce transportation costs and accompanying environmental pollution. With the stabilization of sewage sludge, it is possible to gain the new income streams from recovered resources for agriculture (fertilizer, compost) and energy production (burning, pyrolysis or gasification of RDF).

However, the pollutants containing in sewage sludge during wastewater treatment could not fully degrade, thus an additional degradation is needed to stabilize the sewage sludge. Sludge also consists of biological flocks matrices of microorganisms, nonliving organic matter, and inorganic materials. These flocks are highly hydrated colloidal structures of microbial aggregate which make sewage sludge difficult to degrade [3]. To reduce the amount of sludge, as well as to stabilize it, different technologies have been applied in the sludge treatment including physicochemical treatment by hydrodynamic cavitation.

The hydrodynamic cavitation is assumed to have a prominent role in the field of sewage sludge treatment, due to its ease of operation, low energy consumption, flexibility, and ability to vary the required intensities of cavitational conditions [4].

Cavitation is the process of creating, growing, and collapsing bubbles in a liquid because of a local pressure drop. The collapse of cavitation bubbles during the cavitation process can result in a variety of physicochemical effects [5]. Water molecules can be decomposed into a variety of species with high oxidation potential under extreme cavitation conditions, including hydroxyl radicals ($OH^{\bullet}$), $OOH^{\bullet}$, and H_2O_2, which can react with organic compounds in wastewater by enhancing the sludge biodegradability and its reuse in other biological processes [6].

The immense collapse force can break the molecular bonds of organic pollutants and destroy microorganism cell walls. Microorganism disintegration leads to the release of intercellular substances, first of all enzymes which are easily accessible to a subsequent biological degradation process and expand the biological degradation phenomenon [7]. By breaking up the filamentous structure and larger flocs, disintegrated sludge can also be used to reduce sludge bulking and foaming in sludge treatment process [8].

Given the positive role played by hydrodynamic cavitation, it has received more attention in scientific research and publications. For example, Lucia Umberto et al, 2009 [9] reviewed experimental approaches to hydrodynamic cavitation, Ilgyu Lee and Jong In Han, 2003 [10] studied the effects of pretreatment of activated sludge with hydrodynamic cavitation on methane production. In 2015, Dular Matevz et al. [11] also gave a review on the use of hydrodynamics in wastewater treatment. The same study was authored by Randhavane Shrikant, 2016 [12] which found that hydrodynamic cavitation has several positive effects on wastewater treatment. Based on the previous research data, it can be concluded that hydrodynamic cavitation as a sole treatment is an effective and efficient technique for sewage sludge treatment. Nevertheless, creation of a novel process and equipment is required. The idea of this research is to combine hydrodynamic treatment with the addition of solid adsorbent, namely Bakony brown coal to enhance the secondary biodegradation process of sewage sludge.

2. SCIENTIFIC AND INNOVATION IDEA

The concept idea of the R&D GINOP project is to bring innovative technology based on intensive mechanical impact by cavitation and adsorption phenomena which is showed in following diagram:

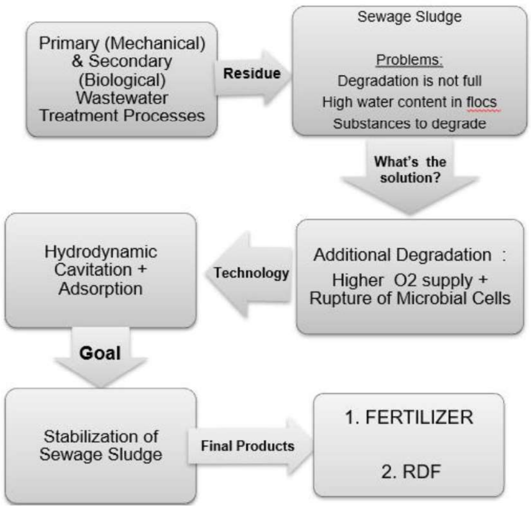

Figure 1
The Concept of Sewage Sludge Treatment in the GINOP Project

3. PILOT EXPERIMENTS IN SIÓFOK, DRV COMPANY

The pilot experiments were carried out within the framework of GINOP-2.2.1-15-2017-00069 R&D Project with the consortium consisting of Transdanubian Regional Water Works (DRV) LTD and the Institute of Raw Materials Preparation and Environmental Processing, University of Miskolc. The experimental set up, first hydrodynamic parameter measurements, preliminary laboratory work and the first industrial experiment has been done [14][15]. The experimental set up as shown in Figure 2 consisted of an open storage tank with a volume of 1.86 m^3, centrifugal pump, cavitation chamber and pipelines with different diameters. This part of the research was the second stage of the experimental program, the experiment was conducted on the site of Wastewater Treatment Plant in Siófok. The real sewage sludge was used, hydrodynamic cavitation with various retention times (0, 5, 10, 15, and 25 minutes) was conducted with adsorbent addition, namely 8% of Bakony brown coal or 8% of natural zeolite for comparison. Bakony brown coal has high porosity, high surface area and high humic acids content, as well as high adsorption potential. Natural zeolite has been chosen due to the high performance in adsorption in aqueous solution such as ammonium and heavy metals. The effect of hydrodynamic cavitation along with adsorbent addition on sewage sludge degradation was traced and interpreted by the change of Total Organic Carbon (TOC).

Figure 2
Hydrodynamic Cavitation Set Up

4. Results and discussion

In the field of sewage sludge treatment, hydrodynamic cavitation has become widely used. HC usually used to treat aqueous effluents polluted by organic, toxic, and bio-refractory contaminants due to its oxidative capability [16]. Hydrodynamic cavitation was investigated in order to accelerate the digestion of sewage sludge, increase the degree of degradation, and thus reduce the amount of sludge to be disposed of.

To monitor the stabilization of sewage sludge, the change Total Organic Carbon (TOC) values due to the combination of hydrodynamic cavitation process along with adsorbent addition has been investigated.

Figure 3 shows the TOC values for mixed sewage sludge without addition of Bakony brown coal adsorbent at different retention times. The TOC values for mixed sewage sludge without addition of adsorbent decreased significantly from 955 mg/L to 674 mg/l already at 4 minutes retention time. At 8 minutes retention time, the TOC value increased until 1328.15 mg/L and then decreased slightly until the end of treatment in 24 minutes of retention time. It means that the optimal retention time for hydrodynamic cavitation is below 15 min.

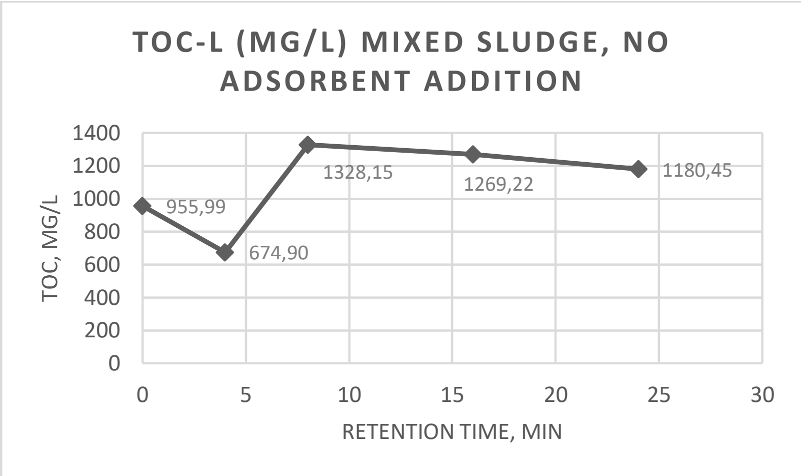

Figure 3
TOC Values due to Hydrodynamic Cavitation without Adsorbent Addition

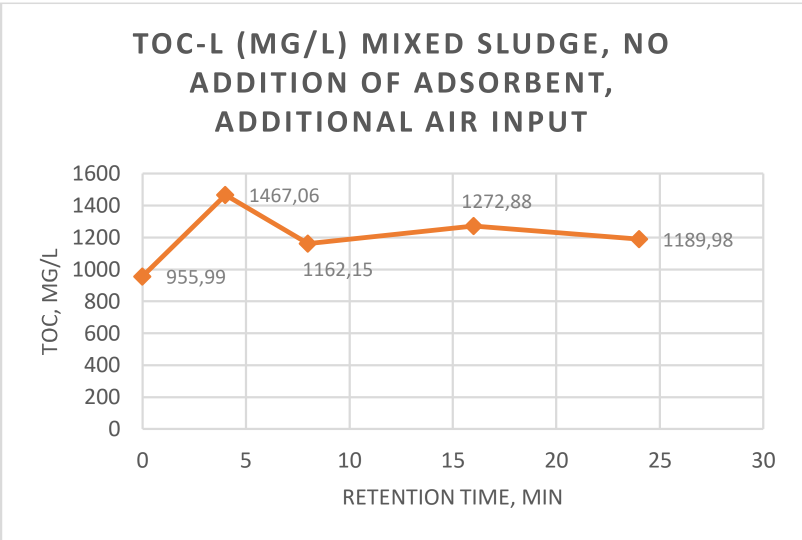

Figure 4
TOC Values Due to Hydrodynamic Cavitation with Additional Air Input

The change of TOC values also occurred in the mixed sewage sludge without adsorbent but with additional air input, as shown in *Figure 4*. TOC values increased from 955.99 mg/L to 1467.06 mg/L or 53.45% after only 4 minutes of retention time, then decreased slightly to 1162, 15 mg/L at 8 minutes of retention time [17].

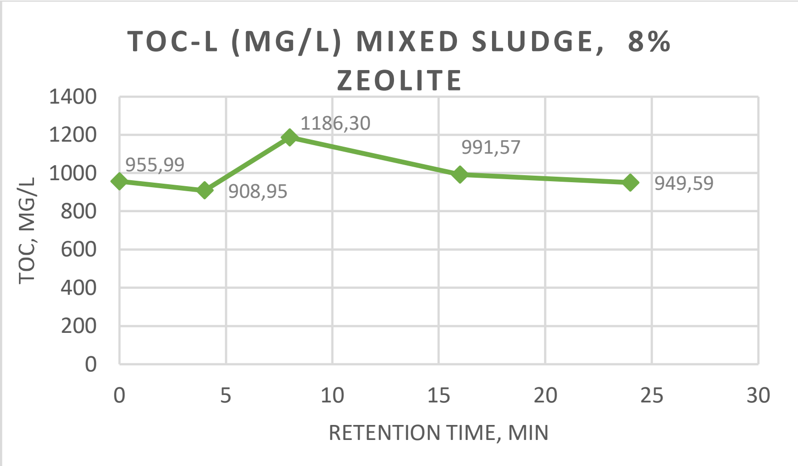

Figure 5
TOC Values Due to Hydrodynamic Cavitation with Addition of 8% Zeolite

The change in TOC value of mixed sewage sludge after hydrodynamic cavitation with adsorbents addition is shown in *Figure 5* and *Figure 6*. In the case of 8% zeolite, the TOC values of the mixed sludge with addition of 8% zeolite decreased slightly in the beginning of the treatment, then increased from 908.95 mg/L to 1186.30 mg/L at 8 minutes retention time. From that point until the end of process, the TOC values decreased continuously.

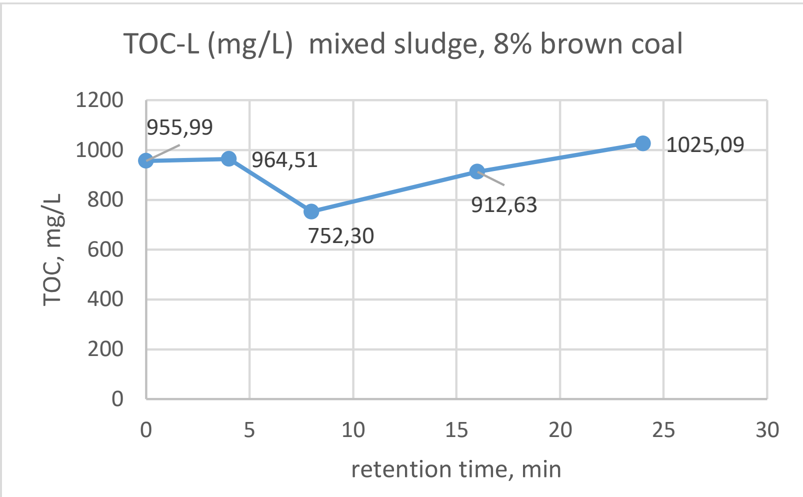

Figure 6
TOC Values Due to Hydrodynamic Cavitation with Addition of 8% Bakony Brown Coal

In contrast to zeolite, the TOC value for the 8% of Bakony brown coal addition as shown in *Figure 6*, decreased significantly at 8 minutes retention time from 964.51 mg/L to 752.30 mg/L. In the 16 minutes retention time, the TOC value then increased continuously until the end of treatment.

All the results indicate that application of hydrodynamic cavitation along with the addition of adsorbent resulted the change of TOC values. This effect could be caused due to the following phenomena: (i) liberation of water inclusions in flocks; (ii) the increase of contact surface leading to the raise of mass transfer and exposure of the free radicals; (iii) fragmentation of microbial cells, release of free enzymes into aqueous environment; (iv) achievement of a high oxygen concentration gradient, for intense additional aerobic degradation; (v) the addition of adsorbents (fossil coal and zeolite) to adsorb various species of vapour/gas and solute.

The physical effects of hydrodynamic cavitation include the production of shear forces of solid particles, dissolution of soluble compounds into fluid phase, as well as release of intracellular organic matter and enzymes present in cells' cytosol, results in the increased dissolved organic matter concentration in the liquid [19]. This phenomenon can increase the TOC values as can be seen in the treatment.

The decrease of TOC value could be caused by the intense additional aerobic degradation. When the cavitation bubble burst, there is an increase of oxygen concentration gradient, so the additional aerobic degradation takes place. Moreover, under cavitation conditions, water molecules can be decomposed into a variety of species with a high oxidation potential, including hydroxyl radicals (·OH), ·OOH, and H_2O_2, which can react with organic compounds and reduce the TOC values.

Beside the high adsorption ability towards contaminants, the addition of Bakony brown coal adsorbent may contribute to the cells rupture along with hydrodynamic cavitation, causing the TOC values increase. In the case of the mixed sludge treatment with the brown coal addition the growth in TOC is related to the coal itself as well. However, it is not easy to uncover all the reasons for the behavior, because in the system of the cell rupture due to cavitation is accompanied by an adsorption process makes the whole system very complex.

The addition of brown coal increases the added value of sewage sludge. Brown coal of Dudar is becoming a valuable fertilizer constituent because of the high content of humic acids, its calorific value is also remarkable.

5. Conclusions

Based on the experiments with mixed sewage sludge with and without addition of adsorbent, the following conclusion can be drawn:

- The hydrodynamic cavitation treatment combined with addition of adsorbent have a high potential for sewage sludge stabilization to obtain fertilizer and RDF as the final product.
- The change of TOC values due to the cavitation combined with the adsorption indicates the dissolution of colloidal solid particles into fluid phase, the

increase of dissolved oxygen consumed for fast aerobic degradation, as well as the rupture of the microbial cells.

- In general, the significant changes of TOC values occurred between 4–15 minutes of the treatment, it can be concluded that hydrodynamic cavitation needs a short retention time to work effectively.
- The addition of Bakony brown coal to hydrodynamic cavitation treatment causes the continuous increase of TOC value after 8 min retention time comparing to the addition of zeolite and the treatment without adsorbent addition.

REFERENCES

[1] Fytili, D., Zabaniotou, A. (2008). Utilization of sewage sludge in EU application of old and new methods-a review. *Renew. Sust. Energ. Rev.*, 12, pp. 116–140.

[2] Tyagi, V. K., Lo, S. L. (2013). Sludge: A waste or renewable source for energy and resources recovery? *Renew. Sustain. Energy Rev.*, 25, pp. 708–728.

[3] Yin, X., Han, P., Lu, X., Wang, Y. (2004). A review on the dewaterability of bio-sludge and ultrasound pretreatment Ultrason. *Sonochem*., 11, pp. 337–348.

[4] EU, 1986. EU sludge directive 86/278/EEC (European Commission).

[5] Wu, Z., Yuste-C´ordoba, F. J., Cintas, P., Wu, Z., Boffa, L., Mantegna, S., Cravotto, G. (2018). Effects of ultrasonic and hydrodynamic cavitation on the treatment of cork wastewater by flocculation and Fenton processes. *Ultrason. Sonochem*., 40, pp. 3–8, https://doi.org/10.1016/j.ultsonch.2017.04.016.

[6] Grübel, K., Machnicka, A. (2010). Hydrodynamic disintegration of foam biomass to upgrade of wastewater. *Ecological Chemistry and Engineering S*, Selected Full Texts, 17 (2), pp. 137–148.

[7] Muller, J. (2000). Disintegration as a key-step in sewage sludge treatment *Water Sci. Technol.*, 41, pp. 123–130.

[8] Lehne, G., Moller, A., Schwedes, J. (2001). Mechanical disintegration of sewage sludge. *Water Science and Technology*, pp. 19–26.

[9] Lucia, U. Gervino, G. (2009). Hydrodynamic cavitation: From theory towards a new experimental approach *Cent. Eur. J. Phys.*, 7, pp. 638–644.

[10] Lee, I., Han, J. I. (2013). The effects of waste-activated sludge pretreatment using hydrodynamic cavitation for methane production *Ultrason. Sonochem.*, 20, pp. 1450–1455.

[11] Randhavane Shrikant, B., Khambete, A. K. (2017). Hydrodynamic Cavitation: A Novel Treatment Approach. *Mater. Today Proc.*, 4, pp. 9680–9684.

[12] Chanda, S. K. (2012). *Disintegration Of Sludge Using Ozone-Hydrodynamic*. M.Sc Thesis. The University Of British Columbia, Canada.

[13] Bokányi, L., Krizsán, G., Takács, J., Faitli, J., Abbadi, A., Mádai Üveges, V., Janetasari, S., Pintér, M. Á. (2020). Evaluation of Efficiency of Hydrodynamic Treatment on Sewage Sludge. *Proceedings Of The Miskolc Ipw - Iv. Sustainable Raw Materials International Project.*

[14] Abbadi, Alaa Imad Hasan (2020). An experimental investigation of hydrodynamic cavitation for the sake of sewage sludge treatment. M.Sc. Thesis. University of Miskolc, Supervisors: Dr. Faitli József and Dr. Bokányi Ljudmilla.

[15] Ozonek, J. (2012). *Application of hydrodynamic cavitation in environmental engineering.* CRC Press, Boca Raton. pp. 1–10, 75–76.

[16] Machnicka, A., Grubel, K., Suschka, J. (2009). The use of hydrodynamic disintegration as a means to improve anaerobic digestion of activated sludge *Water* SA, 35, pp. 129–132.

[17] Sorrels, J. L. (1998). Carbon adsorbers. *Metal Finishing*, Vol. 96, p. 76.

[18] Machnicka, A., Grubel, K., Suschka, J. (2009). The use of hydrodynamic disintegration as a means to improve anaerobic digestion of activated sludge *Water SA*, 35, pp. 129–132.