Pilot-Scale Modelling of Aerated Lagoon Technology for the Treatment of Landfill Leachate: Case Study Hrybovychi Plant

Myroslav Malovanyy[1], Volodymyr Zhuk[2], Ivan Tymchuk[1*], Ruslan Grechanik[1], Vira Sliusar[1], Nataliya Vronska[1], Anastasiya Marakhovska[1], and Andriy Sereda[1]

[1]*Viacheslav Chornovil Institute of Sustainable Development, Lviv Polytechnic National University, S. Bandera Str. 12, Lviv 79013, Ukraine*
[2]*Institute of Civil Engineering and Building Systems, Lviv Polytechnic National University, S. Bandera Str. 12, Lviv 79013, Ukraine*

ARTICLE INFO

Received: 26 Apr 2022
Received in revised: 11 Aug 2022
Accepted: 22 Aug 2022
Published online: 12 Oct 2022
DOI: 10.32526/ennrj/21/202200103

Keywords:
Aerobic biological treatment/ Leachate/ Pilot-scale treatment unit/ Solid waste landfill

*** Corresponding author:**
E-mail: i.s.tymchuk@gmail.com

ABSTRACT

Results of experimental pilot-scale study of aerobic pre-treatment of the leachate of the Hrybovychi municipal solid waste (MSW) landfill (Ukraine) in batch reactor mode and in semi-continuous mode are presented. The dependencies of key pollution indicators, namely biological oxygen demand, chemical oxygen demand, pH, suspended solids, and total Kjeldahl nitrogen (TKN), during a 30-day periodical aeration process were obtained. The first 15 days treatment was in the batch reactor mode treating an initial volume of raw leachate. The second 15 days treatment was in a semi-continuous reactor mode: 400 L of aerobically pre-treated leachate were pumped to the next treatment stage and consequently the same volume of raw leachate was added in the bioreactor tank. Aerobic biological treatment of Hrybovychi landfill leachate using the developed method achieved significant treatment effects, namely 55.3% of the total Kjeldahl nitrogen, 27% of COD, 70.2% of BOD_5 and 66.5% of BOD_{tot}. Time dependences of TKN, COD, BOD_5, and BOD_{tot} are well fitted by simple exponential trends, which correspond to first-order reactions. Landfill leachate, aerobically pre-treated in the pilot-scale treatment unit, can be discharged for final treatment to the bio-plateau or to the wastewater treatment plant.

1. INTRODUCTION

Municipal solid waste (MSW) landfills are big sources of chemical and biological environmental pollution (Degtyar and Galkina, 2019; Grynchyshyn, 2019). MSW landfills are particularly dangerous in terms of their impact on the surface water bodies and groundwater in the area of influence of these environmentally hazardous objects (Samoylik and Molchanova, 2017; Vaverková et al., 2020). According to expert estimations, more than 99% of Ukrainian MSW landfills do not meet European requirements, and the volume of household waste tends to increase (National Strategy for Waste Management in Ukraine Until 2030, 2017).

Leachate is the most harmful impact of landfills and dumps on the environment. Leachate is actively formed in the landfill body when moisture content of deposited solid waste is more than 55%, and due to precipitation that exceeds the evaporation from the landfill surface (Municipal Solid Waste Landfills, 2005). Landfill leachates are highly concentrated water solutions of various toxic organic and inorganic substances (Melnyk et al., 2014; Popovych et al., 2020; Teng et al., 2021). In the absence of strict control of hydrosphere pollution (Iurchenko et al., 2016; Tulaydan et al., 2017), and due to problems with monitoring of this pollution (Odnorih et al., 2020), development of effective methods to prevent contamination of surface waters and aquifers by leachates is especially important.

The most common technologies for leachate treatment are biological anaerobic and aerobic methods and membrane processes, continuing with a final stage of secondary treatment at municipal wastewater treatment plants (WWTP) (Dereli et al., 2020; Malovanyy et al., 2018) or artificial wetlands (Popovych et al., 2020; Malovanyy et al., 2021). Membrane treatments, including the most widespread

Citation: Malovanyy M, Zhuk V, Tymchuk I, Grechanik R, Sliusar V, Vronska N, Marakhovska A, Sereda A. Pilot-scale modelling of aerated lagoon technology for the treatment of landfill leachate: Case study Hrybovychi Plant. Environ. Nat. Resour. J. 2023;21(1):1-8. (https://doi.org/10.32526/ennrj/21/202200103)

reverse osmosis, are energy-expensive, and implementation of these processes requires significant capital and operating costs (Dushkyn et al., 2011). It is also advisable to use different energy-saving systems (Shchur et al., 2021). Anaerobic biological treatment of leachate (Mojiri et al., 2021; Zamri et al., 2017) could be economical due to the obtaining of biogas, a renewable energy source (Voytovych et al., 2020). However, its implementation on an industrial scale requires strict adherence to the process parameters, and since the leachate composition can vary widely upon time, this technology is challenging to implement.

Aerobic methods of biological leachate treatment have a number of advantages compared to anaerobic methods: flexibility of use, convenience of an output to a steady mode of maintenance, and quick adaptation to variable leachate composition and flow rate (Miao et al., 2019; Wang et al., 2018). Aerobic reactors are much simpler in design and less expensive than anaerobic ones, they can be automated and operated much easier. It is interesting to note the study on leachate treatment from Pulau Burung Landfill Site (PBLS), located in Bayram Forest Reserve, Malaysia (Zamri et al., 2017). The researchers selected this site because it is semi-aerobic and recirculates the leachate. PBLS has been in operation for over 20 years and the resulting leachate is mature, with a high COD and concentration of ammonium nitrogen and a low BOD_5/COD ratio. However, the use of adsorbent material, in this case, ion exchange resin, as a second stage after aeration requires the development of methods for its processing or disposal, which involves additional costs.

An effective way to increase the effect of biological treatment of landfill leachate is the use of sequencing batch reactors SBR (Jagaba et al., 2021; Tałałaj et al., 2021), SBR with carriers (Koc-Jurczyk and Jurczyk, 2020), microaeration (Wei et al., 2021), etc. A combination of aerobic and anaerobic methods of leachate treatment is both promising and effective (El-Gohary and Kamel, 2016; Sun et al., 2015). However, treating solid waste landfill leachate in this coordinated manner is energy-intensive and more expensive than aerobic treatment. Treatment using the aeration method with higher plants is interesting (Chen et al., 2022). However, this method is more suitable for domestic wastewater treatment, as it has a more predictable chemical composition.

The main deficiency of aerobic and anaerobic biological methods of landfill leachate treatment is the need for additional stages for more deep treatment to meet the requirements for discharge into open water courses (Lebron et al., 2021; Malovanyy et al., 2018). The most common solution is the use of combined multi-stage treatment methods, where biological methods are combined with reverse osmosis (Tałałaj et al., 2021), treatment with strong oxidants, including ozonation (Yang et al., 2022), and Fenton process (El Mrabet et al., 2020), followed by precipitation enhanced by coagulation and flocculation (De et al., 2019; Malovanyy et al., 2018). Oxidation and sorption are especially necessary and effective for the treatment of mature leachate and for the removal of heavy metal ions (Taghavi et al., 2021).

Aerated lagoons is a simple, economic and effective method for aerobic biological treatment of landfill leachate from organic contaminants and ammonium nitrogen (Broughton and Shilton, 2012; Malovanyy et al., 2018). A typical example of the long-time treatment of mature leachate in aerated lagoons is the Bell House landfill (England), where leachate was treated in four aerated lagoons connected in series (Mehmood et al., 2009). The average COD of raw leachate was equal to 1,740 mg/L, whereas COD decreased to 620 mg/L after the first lagoon, 510 mg/L after the second, 492 mg/L after the third, and 426 mg/L after the fourth, corresponding to a total treatment effect of 75.5%. The average ammonium nitrogen concentration in the raw leachate was 965.2 mg/L, and total treatment effect in the four lagoons was 99.0%.

Technology of biological aerobic treatment of landfill leachate in laboratory conditions, simulating the process in an aerated lagoon, was studied by Malovanyy et al. (2018). The information on its successful application predicts the prospects for its application as a pre-treatment stage in the complex technology of leachate treatment at Hrybovychi MSW landfill (Lviv Region, Ukraine). The purpose of the paper was an experimental pilot-scale study of aerobic treatment of the leachate of the Hrybovychi MSW landfill in the batch reactor mode and in semi-continuous mode.

2. METHODOLOGY

2.1 Materials

Hrybovychi MSW landfill leachate was used in this study as tested leachate. Hrybovychi MSW landfill with a total area of about 38 ha is located in the west part of Ukraine, 2 km to the north from Lviv city (49.90N; 24.04E). It served as the main MSW landfill of Lviv city from 1958 until 2016, and now it is under technical remediation process. The main parameters of raw Hrybovychi MSW landfill leachate, sampled in November 2021, are presented in Table 1.

Thus, significantly excessive concentrations of contaminants were detected in the Hrybovychi MSW landfill leachate. The study of biological leachate treatment under aeration conditions was aimed to find the treatment effects using BOD_5, COD and TKN as key pollutant indicators.

Table 1. The average chemical composition of Hrybovychi MSW landfill leachate

#	Pollution indicators	Unit	Value	TLV*
1	Ammonium nitrogen	mg/L	548.1	2
2	Total Kjeldahl nitrogen (TKN)	mg/L	889.3	10
3	BOD_5	mg/L	192.0	15
4	COD	mg/L	5,082.0	80
5	Suspended solids (SS)	mg/L	3,011.0	-
6	Iron	mg/L	10.7	0.3
7	Cadmium	mg/L	0.005	0.001
8	Cobalt	mg/L	0.028	0.1
9	Manganese	mg/L	0.015	0.1
10	Nickel	mg/L	0.09	0.1
11	Lead	mg/L	0.12	0.03
12	Strontium	mg/L	0.022	7
13	Total dissolved solids (TDS)	mg/L	15,245.0	-
14	Chlorides	mg/L	3,900.0	350

*TLV - threshold limit value for the output in open water courses in Ukraine

2.2 Pilot-scale aeration treatment unit

Biological aerobic treatment of Hrybovychi MSW landfill leachate was studied at the pilot treatment unit with a capacity of 400 L/day. Aeration was carried out in a bioreactor with diameter D=1.6 m, total depth H=1.8 m and leachate depth h=1.4 m, equipped with a jet pump aerator (P=2.2 kW), as shown in Figure 1. Standard oxygen transfer rate was equal to 0.9±0.1 kg O_2/h.

The optimal aeration parameters (timing and intensity) were determined during the research. Previous laboratory studies have shown that the optimal duration of the non-stationary period for the start of the process of aerobic biological treatment is 7-15 days (Malovanyy et al., 2018). Pilot studies have confirmed these figures. Microbiocenosis was gradually self-inoculated in the bioreactor in the process of aeration (Dos Santos et al., 2022; Malovanyy et al., 2018), which resulted in a gradual biological treatment of leachate.

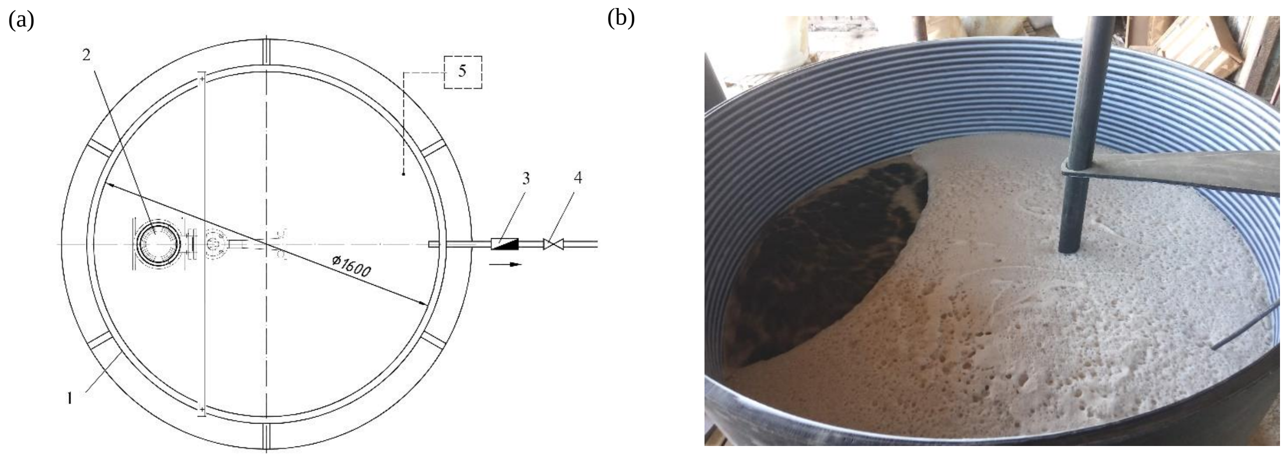

Figure 1. Pilot-scale bioreactor treatment unit: Principal scheme (a); leachate aeration process (b); 1-reservoir, 2-jet aerator, 3-water meter, 4-valve, 5-oximeter/pH meter/TDS meter

Periodical aeration process was used, with 12 h of aeration per day. Control samples of leachate were taken for laboratory analysis every 24 h. Previously published methods (Baird et al., 2017) were used for the analysis of key pollutant indicators, namely BOD_5, BOD_{tot}, COD, SS, TKN, and pH.

Dependencies of key pollution indicators during the 30-day periodical aeration process were obtained experimentally. The first 15 days treatment in the batch reactor mode treating the same initial volume of raw leachate. Another 15 days treatment in the continuous reactor mode and 400 L of aerobically pre-treated leachate were pumped to the next treatment stage, and consequently the same volume of raw leachate was added in the bioreactor tank, thus in continuous mode hydraulic retention time (HRT) was equal to seven days.

3. RESULTS AND DISCUSSION

Experimental dependence of the TKN on the duration of biochemical aerobic treatment of leachate is presented in Figure 2. During batch reactor mode of aerobic leachate treatment, the concentration of TKN decreased from 889.3 mg/L to 397.2 mg/L, corresponding to a treatment effect of 55.3%. The high rate of TKN decreasing can be explained by the intensive conversion of ammonium nitrogen from aqueous to gaseous phase at pH higher than pH 7 (Abood et al., 2014). The results obtained in this batch reactor mode can be approximated by a simple exponential dependence, corresponding to the first-order reaction:

$$C_{TKN} = 833.5 \exp\,(-0.551t) \qquad (1)$$

Where; C_{TKN} is the TKN concentration in mg/L; t is time in days; coefficient of determination of the dependence (1) R^2=0.959.

The most relevant factor in the treatment process is COD (Koc-Jurczyk and Jurczyk, 2020). Dependence of the COD of the leachate on the duration of its aerobic biochemical treatment at the pilot-scale treatment unit (Figure 3) shows that in first 15 days of the batch reactor mode the value of COD decreased by about 27%, which is quite typical for medium and mature leachates, containing high levels of hard oxidizing organic substances (Miao et al., 2019). For the batch reactor mode, the approximate equation is:

$$C_{COD} = 5{,}007 \exp\,(-0.0204t) \qquad (2)$$

Where; C_{COD} is the value of COD, mg/L, and coefficient R^2=0.983.

Average treatment effect by COD, obtained in the continuous mode at HRT=7 days, is found to be 26.5%, and this result correlates quite well with the treatment of mature leachate of Bell House landfill (UK) in aerated lagoons, where the average COD at the inlet was 1,740 mg/L and after 56 days of aeration was reduced to 620 mg/L, corresponding to the treatment effect of 64% (Mehmood et al., 2009). Extrapolating the exponential dependence (2) to the value of the (HRT) of 56 days, the estimated treatment effect of Hrybovychi leachate by COD could be about 69%.

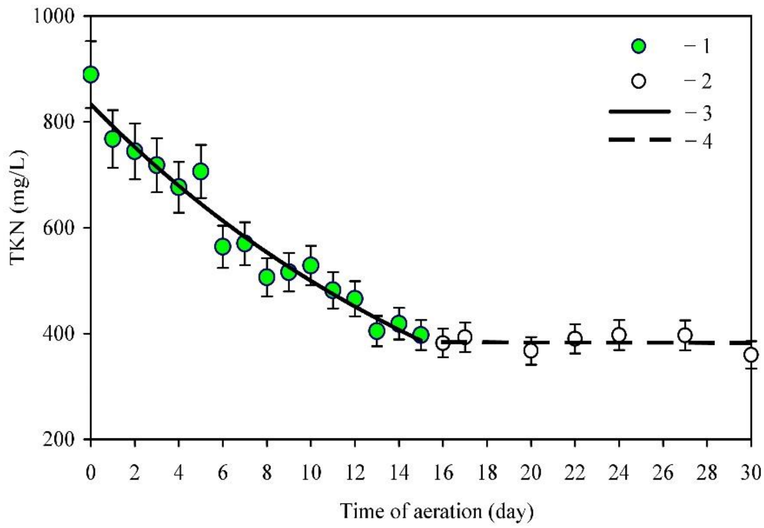

Figure 2. Content of total Kjeldahl nitrogen in Hrybovychi leachate during its aeration in the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (1); 4-average value of 385 mg/L

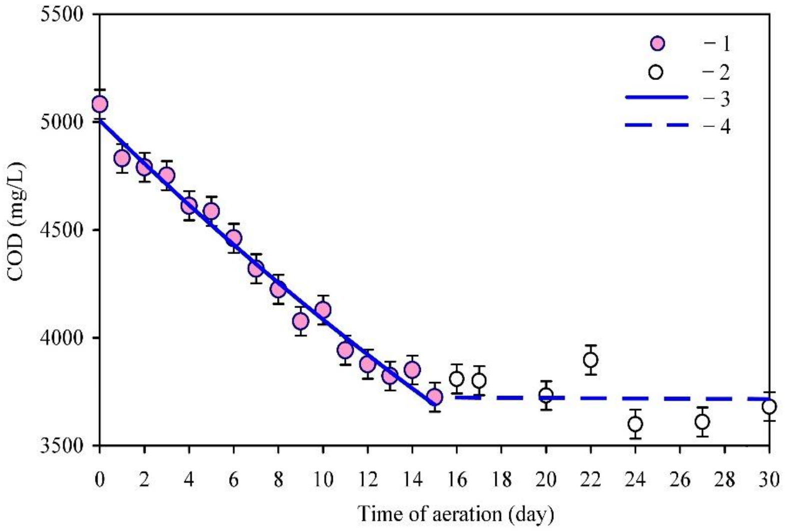

Figure 3. Change of COD in Hrybovychi leachate during the aeration process at the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (2); 4-average value of 3,732 mg/L

The average treatment effect by BOD_5 of Hrybovychi landfill leachate was found to be 70.2% (Figure 4), which is much higher than the treatment effect on COD, and an exponential approximation with R^2=0.849 is obtained:

$$C_{BOD_5} = 176.9 \exp\ (-0.075t) \quad (3)$$

At the same time, slightly less than 74.6% was obtained by (De et al., 2019) after three days of aeration treatment of Kolkata landfill leachate (India), which can be explained by a significantly higher degree of biodegradability of Kolkata leachate with a BOD_5/COD ratio of 0.36.

Similar results were obtained for BOD_{tot} (Figure 5):

$$C_{BOD_{tot}} = 586 \exp\ (-0.076t) \quad (4)$$

Where; C_{BODtot} is the value of BOD_{tot}, mg/L; R^2=0.9487.

The average effect of leachate treatment on BOD_{tot} is found to be 66.5%. It should be noted the high value of the ratio BOD_{tot}/BOD_5=3.57 when entering the regular semi-continuous operating mode of the aerobic biological treatment, which can be explained by the low rate of biochemical oxidation of biodegradable organics in Hrybovychi leachate, comparing, for instance, the Kolkata leachate (De et al., 2019).

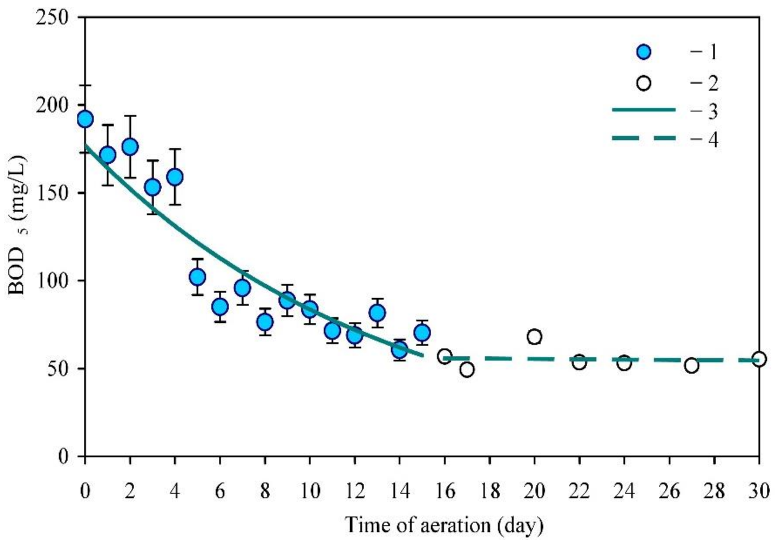

Figure 4. Change of BOD_5 in Hrybovychi leachate during the aeration process at the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (3); 4-average value of 57.3 mg/L

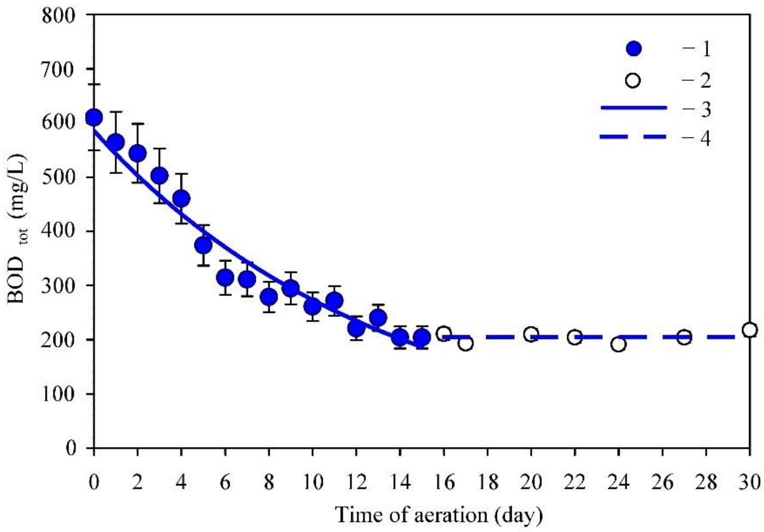

Figure 5. Change of BOD_{tot} in Hrybovychi leachate during the aeration process at the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (4); 4-average value of 204.4 mg/L

Clear trends of relatively rapid increasing of the pH value at the beginning of the aeration and slow asymptotic increasing to the 12-15 days of aeration are obtained (Figure 6). This tendency is analogical to reported by (Mehmood et al., 2009), where mean pH of raw leachate was 7.2, while the mean pH after 4-stage aerated lagoon with HRT=56 days was 8.5. This permanent growth of pH is probably caused by the nature of biochemical processes of the leachate oxidation by aerobic microbiocenosis, and for the first 12 days of aeration of Hrybovychi leachate the exponential association equation is obtained (R^2=0.971):

$$pH = 0.623 \times [15.64 - \exp(-0.536t)] \qquad (5)$$

In the semi-continuous mode of operation pH of leachate was stabilized at an average value of 9.74 with small (±0.05) variations in both directions (Figure 6), which is something above the upper optimal limit for biological treatment process estimated about pH=8.5.

During the phase of biochemical treatment of the leachate, a monotonic but insignificant increase in the content of suspended solids was observed (Figure 7). This can be explained by the gradual growth of the microbiocenosis biomass involved in the biochemical treatment process. Simple linear trend can be used to approximate the experimental results:

$$C_{SS} = 193 + 1.91t \qquad (6)$$

Where; C_{SS} is suspended solids content, mg/L; R^2=0.8448.

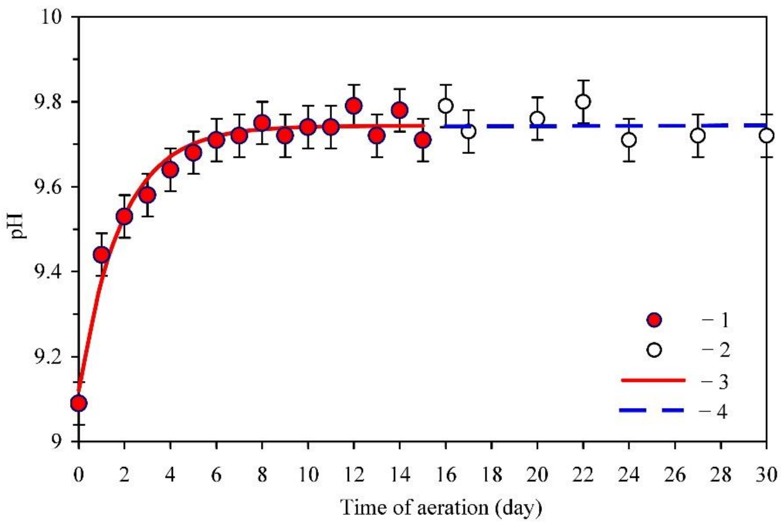

Figure 6. Change of pH in Hrybovychi leachate during the aeration process at the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (5); 4-average value 9.74

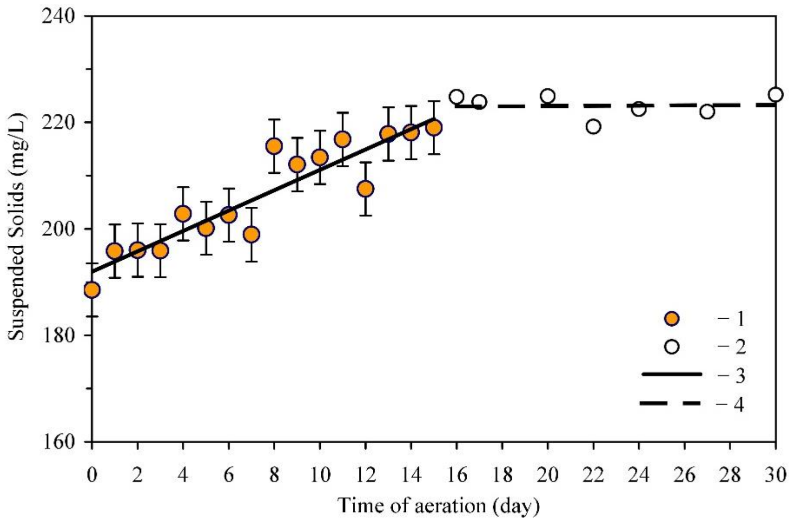

Figure 7. Change of C_{SS} in Hrybovychi leachate during the aeration process at the pilot-scale treatment unit: 1-batch reactor mode; 2-semi-continuous mode; 3-trend line (6); 4-average values 223 mg/L

The average content of suspended solids in the continuous operation mode of the pilot plant C_{SS}=223 mg/L is 31% of the average value of suspended solids of 700 mg/L obtained for full-scale aerated lagoons (Mehmood et al., 2009). Such a low level of suspended solids can be explained by the short duration of the pilot plant study, and over time this value should stabilize at a much higher equilibrium value, similar to (Mehmood et al., 2009).

4. CONCLUSION

Based on the analysis of the pilot-scale results optimal parameters for the aerobic biological treatment of leachates of typical Ukrainian MSW landfills are obtained. Initial batch reactor mode should continue about 15 days to reach sufficiently high treatment effects on baseline pollution indicators. Aerobic biological treatment of landfill leachate using the developed method allows achieving treatment effect of 55.3% on the total Kjeldahl nitrogen, 27% on COD and 63.3% on BOD. Time dependences of TKN, COD, BOD_5, and BOD_{tot} with sufficiently high accuracy can be described by simple exponential dependences, respectively (1)-(4), which correspond to first-order reactions. The peculiarities of the change of pH and suspended solids at the batch reactor mode of the treatment process are explained by the self-inoculation of the activated sludge microbiocenosis. Landfill leachate, aerobically pre-treated in the pilot-scale treatment unit, can be discharged for the final treatment to the bio-plateau or to the wastewater treatment plant.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Education and Science of Ukraine, grant DZ/107-2021 “Development of the Technology for Preliminary Treatment of Municipal Solid Waste Landfill Leachates”.

REFERENCES

Abood AR, Bao J, Du J, Zheng D, Luo Y. Non-biodegradable landfill leachate treatment by combined process of agitation, coagulation, SBR and filtration. Waste Management 2014; 34(2):439-47.

Baird RB, Eaton AD, Rice EW. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC, USA: American Public Health Association, American Water Works Association, Water Environment Federation; 2017.

Broughton A, Shilton A. Tracer studies on an aerated lagoon. Water Science Technology 2012;65(4):611-7.

Chen X, Zhong F, Chen Y, Wu J, Cheng S. The interaction effects of aeration and plant on the purification performance of horizontal subsurface flow constructed wetland. International Journal of Environmental Research and Public Health 2022;19(3):1583-93.

De S, Hazra T, Dutta A. Sustainable treatment of municipal landfill leachate by combined association of air stripping, fenton oxidation, and enhanced coagulation. Environmental Monitoring and Assessment 2019;191(2):1-14.

Degtyar M, Galkina H. Research of main factors affecting the efficiency leachate treatment. Scientific Notes of Taurida National V.I. Vernadsky University, Series: Technical Sciences 2019;69(5):62-8. (in Ukrainian).

Dereli RK, Giberti M, Liu Q, Flynn D, Casey E. Benchmarking leachate co-treatment strategies in municipal wastewater treatment plants under dynamic conditions and energy prices. Journal of Environmental Management 2020;260:Article No. 110129.

dos Santos VHJM, de Medeiros Engelmann P, Marconatto L, dos Anjos Borgea LG, de Lara Palhano P, Augustin AH, et al.

Exploratory analysis of the microbial community profile of the municipal solid waste leachate treatment system: A case study. Waste Management 2022;141:125-35.

Dushkyn S, Kovalenko A, Dehtyar M, Shevchenko T. Resource-Saving Wastewater Treatment Technologies. Kharkiv, Ukraine: KNAME; 2011. (in Russian).

El-Gohary FA, Kamel G. Characterization and biological treatment of pre-treated landfill leachate. Ecological Engineering 2016;94:268-74.

El Mrabet I, Benzina M, Valdés H, Zaitan H. Treatment of landfill leachates from Fez City (Morocco) using a sequence of aerobic and fenton processes. Scientific African 2020;8:e00434.

Grynchyshyn N. Properties of the filtrate formed after termination of the operation of the landfill. Bulletin of Lviv State University of Life Safety 2019;19:122-7. (in Ukrainian).

Iurchenko V, Lebedeva E, Brigada E. Environmental safety of the sewage disposal by the sewerage pipelines. Procedia Engineering 2016;134:181-6.

Jagaba AH, Kutty SRM, Lawal IM, Abubakar S, Hassan I, Zubairu I, et al. Sequencing batch reactor technology for landfill leachate treatment: A state-of-the-art review. Journal of Environmental Management 2021;282:Article No. 111946.

Koc-Jurczyk J, Jurczyk Ł. The characteristics of organic compounds in landfill leachate biologically treated under different technological conditions. Journal of Ecological Engineering 2020;21(3):104-11.

Lebron YA, Moreira VR, Brasil YL, Silva AF, de Souza Santos LV, Lange LC, et al. A survey on experiences in leachate treatment: common practices, differences worldwide and future perspectives. Journal of Environmental Management 2021;288:Article No. 112475.

Malovanyy M, Moroz O, Popovich V, Kopiy M, Tymchuk I, Sereda A, et al. The perspective of using the “open biological conveyor” method for purifying landfill filtrates. Environmental Nanotechnology, Monitoring and Management 2021;16:Article No. 100611.

Malovanyy M, Zhuk V, Sliusar V, Sereda A. Two stage treatment of solid waste leachates in aerated lagoons and at municipal wastewater treatment plants. Eastern-European Journal of Enterprise Technologies 2018;1(10):23-30.

Mehmood M, Adetutu E, Nedwell D, Ball AS. In situ microbial treatment of landfill leachate using aerated lagoons. Bioresource Technology 2009;100(10):2741-4.

Melnyk A, Kuklinska K, Wolska L, Namiesnik J. Chemical pollution and toxicity of water samples from stream receiving leachate from controlled municipal solid waste (MSW) landfill. Environmental Research 2014;135:253-61.

Miao L, Yang G, Tao T, Peng Y. Recent advances in nitrogen removal from landfill leachate using biological treatments: A review. Journal of Environmental Management 2019;235:178-85.

Mojiri A, Zhou J, Ratnaweera H, Ohashi A, Ozaki N, Kindaichi T, et al. Treatment of landfill leachate with different techniques: An overview. Water Reuse 2021;11(1):66-96.

Municipal Solid Waste Landfills. Basic Design Points: DBN V.2.4-2-2005. Kyiv, Ukraine: State Committee of Ukraine on Construction and Architecture; 2005. (in Ukrainian).

National Strategy for Waste Management in Ukraine Until 2030. Order of the Cabinet of Ministers of Ukraine dated November 8, 2017 No. 820-p. Kyiv, Ukraine: Cabinet of Ministers of Ukraine [Internet]. 2017 [cited 2022 Aug 15]. Available from: https://zakon.rada.gov.ua/laws/show/820-2017-p. (in Ukrainian).

Odnorih Z, Manko R, Malovanyy M, Soloviy K. Results of surface water quality monitoring of the western bug river Basin in Lviv Region. Journal of Ecological Engineering 2020;21(3):18-26.

Popovych V, Telak J, Telak O, Malovanyy M, Yakovchuk R, Popovych N. Migration of hazardous components of municipal landfill leachates into the environment. Journal of Ecological Engineering 2020;21(1):52-62.

Samoylik M, Molchanova A. Ecological aspects of influence of solid domestic wastes on the environment. Filtrate. Bulletin of Poltava State Agrarian Academy 2017;1-2:88-91. (in Ukrainian).

Shchur I, Lis M, Biletskyi Y. Passivity-based control of water pumping system using BLDC motor drive fed by solar PV array with battery storage system. Energies 2021;14(23):67-84.

Sun H, Peng Y, Shi X. Advanced treatment of landfill leachate using anaerobic-aerobic process: Organic removal by simultaneous denitritation and methanogenesis and nitrogen removal via nitrite. Bioresource Technology 2015;177:337-45.

Taghavi K, Naghipour D, Ashrafi SD, Salehi M. The removal of heavy metals from the leachate of aged landfill: The application of the Fenton process and nanosilica absorbent. Environment and Natural Resources Journal 2021;19(6):427-34.

Tałałaj IA, Bartkowska I, Biedka P. Treatment of young and stabilized landfill leachate by integrated sequencing batch reactor (SBR) and reverse osmosis (RO) process. Environmental Nanotechnology, Monitoring and Management 2021;16:Article No. 100502.

Teng C, Zhou K, Peng C, Chen W. Characterization and treatment of landfill leachate: A review. Water Research 2021;203: Article No. 117525.

Tulaydan Y, Malovanyy M, Kochubei V, Sakalova H. Treatment of high-strength wastewater from ammonium and phosphate ions with the obtaining of struvite. Chemistry and Chemical Technology 2017;11(4):463-8.

Vaverková M, Elbl J, Koda E, Adamcová D, Bilgin A, Lukas V, et al. Chemical composition and hazardous effects of leachate from the active municipal solid waste landfill surrounded by farmlands. Sustainable Chemical Engineering and Technology, Sustainability 2020;12(11):4531-51.

Voytovych I, Malovanyy M, Zhuk V, Mukha O. Facilities and problems of processing organic wastes by family-type biogas plants in Ukraine. Journal of Water and Land Development 2020;45(4-6):185-9.

Wang K, Li L, Tan F, Wu D. Treatment of landfill leachate using activated sludge technology: A review. Archaea 2018;2018: Article No. 1039453.

Wei M, Zhang R, Zhou M, Yuan Z, Yuan H, Zhu N. Treatment of fresh leachate by microaeration pretreatment combined with IC-AO^2 process: Performance and mechanistic insight. Science of the Total Environment 2021;789:Article No. 147939.

Yang Y, Ricoveri A, Demeestere K, Van Hulle S. Advanced treatment of landfill leachate through combined Anammox-based biotreatment, O_3/H_2O_2 oxidation, and activated carbon adsorption: Technical performance, surrogate-based control strategy, and operational cost analysis. Journal of Hazardous Materials 2022;430:Article No. 128481.

Zamri M, Kamaruddin M, Yusoff M, Aziz H, Foo K. Semi-aerobic stabilized landfill leachate treatment by ion exchange resin: Isotherm and kinetic study. Applied Water Science 2017;7(2):581-90.