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SIMULATION OF AEROBIC STABILISATION OF MUNICIPAL LANDFILLS IN LYSIMETERS

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ABSTRACT

Results of experimental studies of simulation of the aerobic stabilisation of municipal landfills in lysimeters are discussed in the paper. It was found that due to the aeration, intensive leachate circulation and enhancement of organic substance degradation by advanced oxidation processes (ozonation), waste bed stabilisation was reached in a very short time. After 20 days since the beginning of lysimeter aeration, a reduction of both nitrogen compounds ($N\text{-}NH_4^+$ by around 70%), and easily biodegradable organic substances (ca. 90%) was achieved.

Key words: lysimeters, landfills, aerobic stabilisation, leachates, ozonation

INTRODUCTION

Methane, the main component of a landfill gas, is after carbon dioxide the second greenhouse gas with GWP (Global Warming Potential) being 20 times higher than that of CO_2 which greatly contributes to the greenhouse effect. The content of methane in the atmosphere grows continually (from around 0.7 ppmv in the pre-industrial period to ca. 1.8 ppmv at present [2]). The annual methane emission from all sources is estimated at around 500-600 Tg, in this number 200 Tg being of natural origin [11]. The methane emission caused by man’s activity (mainly agriculture, waste disposal in landfills) is almost 3 times higher than that from natural producers.
During anaerobic degradation of wastes disposed in landfills, a landfill gas (LFG) is produced. It contains 55-60% v/v methane, 40-45% v/v carbon dioxide and up to around 5% v/v numerous trace components coming from different hazardous materials disposed in the landfills or formed as a result of biological/chemical degradation [9].

Although the existing municipal landfills are often equipped with the systems of landfill gas collection that is flared or used as an energy source, still great quantities of this gas escape to the atmosphere. At methane concentration in the landfill gas below 30% v/v, flaring is difficult or even impossible. Gas generated in such conditions is usually diluted by ambient air and released to the atmosphere uselessly [4]. Methane is also emitted from old, smaller landfills where the application of gas collection system is economically unjustified, as well as from many other unauthorised landfills. This constitutes about 20-70 Tg in the annual global methane emission [15,16].

A predominant technology of waste disposal in Poland is landfilling. Predictions of annual methane emission from Polish landfills are as follows: year 2000 – 0.471 Tg; year 2010 – 0.536 Tg; year 2020 – 0.675 Tg; year 2030 – 0.757 Tg [19]. The methane emission from domestic landfills is by half higher than the average world emission, which is on the level from 7% to 20% of global anthropogenic sources of methane emission that contribute to a change of global climate [19,24]. Thus, the technology of landfilling causes the longterm environmental impact. For modern landfill strategies, the sustainability of a landfill represents the main goal to be achieved.

A decrease of methane emission from landfills to the atmosphere and at the same time guaranteeing safety in these landfills can be accomplished in different ways because of microbiological oxidation of methane:

- by using proper upper layers (soil/compost) that cover the landfill, where the process of methane oxidation takes place [4,5,10,13,14],
- due to the application of a system of biofilters combined with a landfill draining system that collects landfill gas [23],
- by using forced aeration of landfills [22].
- in situ flushing of the waste mass [3,8]

The above methods are usually applied in the landfills that are equipped with landfill gas collection systems in the conditions when the quantity of the obtained gas is small or methane concentration too low for efficient gas recovery and combustion. However, the first and third method can be used for both the landfills that are equipped with a degassing installation and those which are not equipped with such systems.

In Poland the number of municipal landfills reaches around 10 000, from which 998 are working as organised landfills, while the others are mostly unauthorised dumping grounds (data of 2000, [20,25]). To decrease the emission of methane from biologically active landfills (when the use of biogas as a source of energy is unprofitable or the application of degassing system too expensive), the most advantageous is the application of a proper upper layer that would cover the deposited wastes; or aeration of the landfill through the existing drainage system or forcing the air under pressure by a “lance”; or a combination of these methods. On the other hand, the application of forced aeration causes a reduction of the landfill methanogenic potential and its aerobic stabilisation. From the point of view of a better landfill neutralisation two problems are important, namely:

- a decrease of the impact of residual biogas emission on the environment by the oxidation of methane in the landfill upper layers, and
- a reduction of the impact of residual biogas emission and leachates on the environment by aerobic biodegradation of unreacted material deposited in anaerobic conditions.

The aim of this study is an experimental simulation of a landfill aerobic stabilisation that enables reduction of the landfill gas emissions and leachates, and enhanced biodegradation of material deposited under aerobic conditions.

MATERIALS AND METHODS

In landfill processes simulation the lysimeters were filled with alternately laid layers of a waste and compost mixture. The mixture of wastes contained organic waste (a composition typical of kitchen waste in the city of Łódź [17]: vegetable and fruit – 10.9%; potatoes – 21.2%; bread – 2.3%; others – 3.6%) – 38%, paper and cardboard – 25%, plastics – 17%, textiles –5%, other wastes – 15%. The waste was comminuted to the size 20-50 mm.

Compost used in the experiments was obtained from the Green Waste Composting Plant in Lodz, Poland, and stabilised fermented sewage sludge – from the Group Wastewater Treatment Plant in Lodz, Poland.

Experimental set-up and process parameters

Experiments were carried out in 4 laboratory lysimeters of working capacity 15 dm^3. The lysimeters consisted of a glass cylinder of inner diameter 150 mm and height 850 mm, closed on top and bottom with stainless steel covers, equipped with pipes for leachates recirculation, taking samples for analysis, supply and collect of gases. After mixing, the comminuted waste was placed in the lysimeters in layers, alternatively with a compost layer and wetted with tap water. A month after charging, around 200 ml of stabilised fermented sewage sludge was added to the lysimeters in order to initiate methane fermentation. The process of anaerobic stabilisation in the lysimeters lasted for the next 8 months. Then, studies on aerobic stabilisation started by supplying air to the lysimeters in a continuous way at the volumetric flow rate 10 dm^3/h. Leachates taken from the lysimeters were recirculated and subjected to advanced oxidation processes, i.e. ozonation and UV radiation with the addition of H_2O_2. One of the lysimeters was treated as a control device. Processes in the lysimeters were carried out at room temperature (around 20°C).

Analytical methods

In the leachates taken from lysimeters, pH, redox potential, BOD_5 (by the dilution method, APHA Standard Methods [1]), COD (by the dichromate method, APHA Standard Methods [1]), the content of volatile fatty acids – VFA (according to the Polish Standard PN-75C-04616 using Büchi – Distillation Unit B-324), N-NH_4^+ (by the method of distillation in the Büchi device), total N (by Kjeldahl method according to the Polish Standard PN-75-C-04576-17 in the Büchi device), total organic carbon - TOC (in Coulomat 702 Li/C, Strohlein Instruments, Germany) were analysed. The composition of gas being formed in this way was regularly controlled (gas analyser, LMS GasData).

RESULTS AND DISCUSSION

The simulation of aerobic landfill processes was carried out in lysimeters with a bed stabilised during 250 days under anaerobic conditions [18]. Fig. 1 shows changes of basic indices of organic load in leachates from lysimeters. The final values of organic load index were relatively low and pH was neutral (Table 1). After starting the aeration, the intensive aerobic processes in the lysimeters caused an increase of pH to around 8.9 and a rapid change of redox potential from negative to positive values (Fig. 2a, b). In one of the lysimeters (R1) that was treated as a control one, leachates were recirculated twice a day. In the other two lysimeters (R2 and R3) the leachates recirculated twice a day were subjected to advanced oxidation processes (ozonation and UV radiation with the addition of H_2O_2). In the fourth lysimeter (R4) the recirculation was more frequent, i.e. four times a day.

Fig. 1. Changes in basic organic load indices in leachates during anaerobic biodegradation

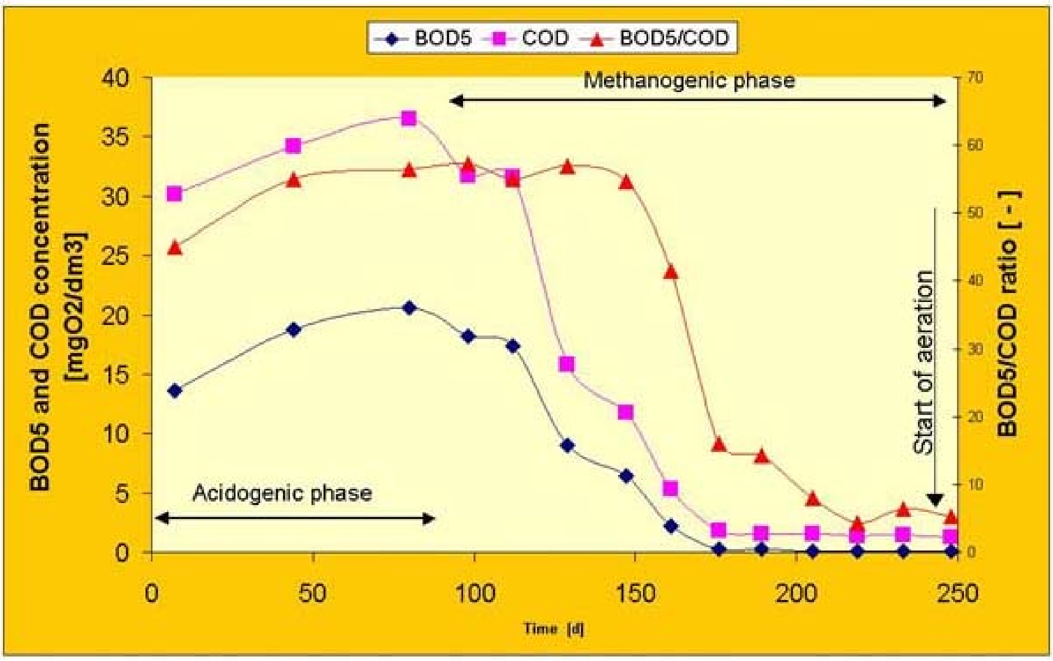
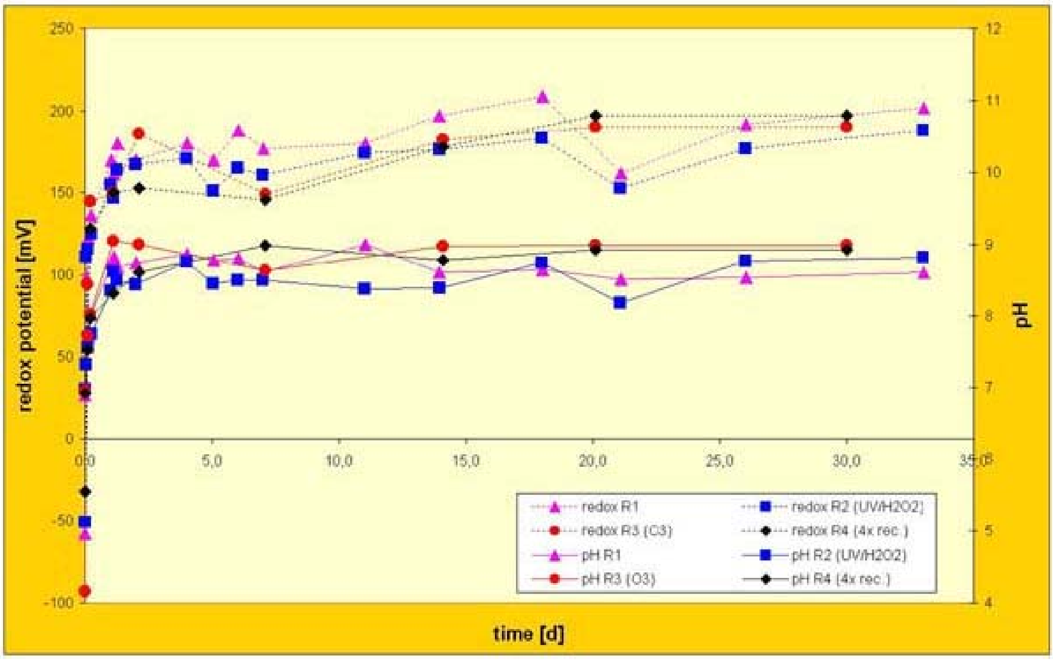


Fig. 2 (a,b). Changes in pH and redox potential in leachates from lysimeters



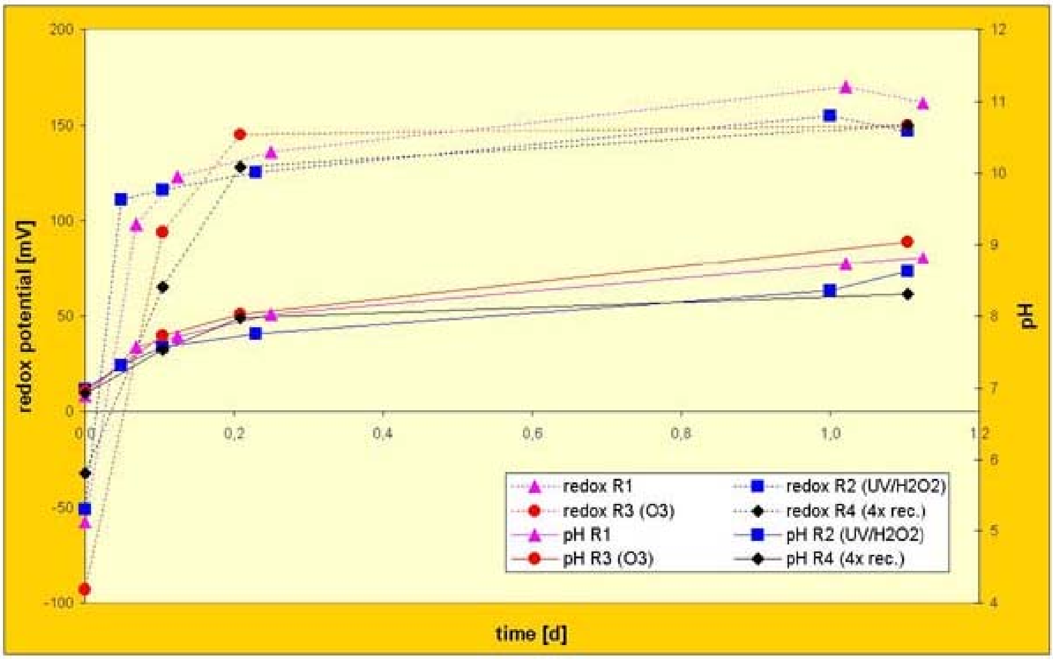


Table 1. Changes in basic organic load indices in leachates from lysimeters (R1 – R4) after 33 days of aerobic stabilisation

Index	R1 (control)		R2 (UV/H_2O_2)		R3 (O_3)		R4 (4x recirculated)	
Time [days]	250/0	33	250/0	33	250/0	33	250/0	33
BOD_5 [mg O_2/dm^3]	40.6	25.8	98.6	48.3	168	23.5	128	16.5
COD [mg O_2/dm^3]	857	1052	1292	1260	1444	1744	1228	1158
Total N [mg N/dm^3]	32.97	41.5	42.70	53.27	77.73	79.15	59.15	49.63
N-NH_4^+ [mg N/dm^3]	2.36	2.00	2.68	4.32	25.1	6.35	11.4	4.17
VFA [mg acetic acid/dm^3]	318	219	446	148	425	99.1	244	365
TOC [mg C/dm^3]	278	330	432	340	523	636	425	456
pH	6.89	8.60	6.98	8.81	6.96	8.98	6.92	8.92
Redox potential [mV]	-58	202	-51	188	-93	190	-32	197

The aerobic stabilisation of municipal waste was a very fast process. During only a month the bed was stabilised completely. At the beginning of the aerobic processes of biodegradation, in the leachates from lysimeters an increase of most organic load indices was observed, i.e. biochemical (BOD_5) and chemical oxygen demand (COD), total and ammonia nitrogen content, total organic carbon (TOC). That was induced by an intensive biodegradation of substances that can be easily degradable in the presence of oxygen. This substantial increase of organic load indices (COD, BOD_5, etc.) in the leachates after aerobic stabilization indicates that not all easily biodegradable material were degraded under anaerobic conditions. The change from anaerobic into aerobic conditions stopped completely anaerobic digestion and initiated aerobic biodegradation of wastes. Then, after 5-7 days, in reactors R1, R2 and R3 and after 2 days in reactor R4, a decrease of most indices was observed (BOD_5, COD, volatile fatty acids-VFA, ammonia and total nitrogen). A high degree of BOD_5 (in all reactors), N-NH_4^+ (in reactors R3 and R4), VFA (in reactors R1, R2 and R3), and a low degree of COD, total N and TOC reduction was observed. Typical time profiles for the main pollutants are shown in Fig. 3. Biodegradability of the leachates expressed as BOD_5 to COD ratio first increased and then was reduced significantly in all lysimeters to the level of around 0.03, as is shown in Fig. 4. Similarly, the oxidability of leachates expressed as COD to TOC ratio remains at the level about 3 mg O_2/mg C, Fig. 5. This means that these leachates are hardly degradable. In studies on the simulation of aerobic stabilisation of municipal landfills carried out in the reactors with leachates aeration and recirculation, (filled with drillings from an old landfill) starting on the 20th day of the process, Ritzkowski et al. [21] observed a significant reduction of the concentration of nitrogen compounds (N-NH_4^+, NO_2). On the other hand, the reduction of COD and TOC after around 80-100 days was not high and was due mainly to the exchange of leachates and their elution, because degradable organic components were very quickly used (in the case of BOD_5 around 10 mg/dm^3 was found already on the 20th day of aeration).

Fig. 3. Time profiles of basic organic load indices in lysimeter R1

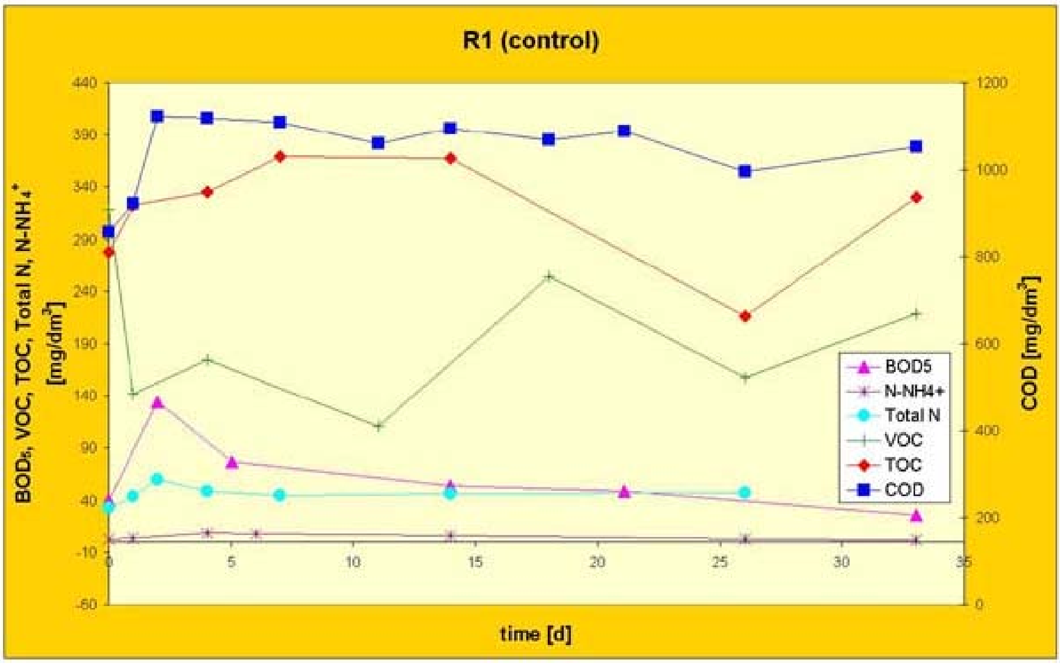


Fig. 4. Changes in biodegradability of leachates from lysimeters

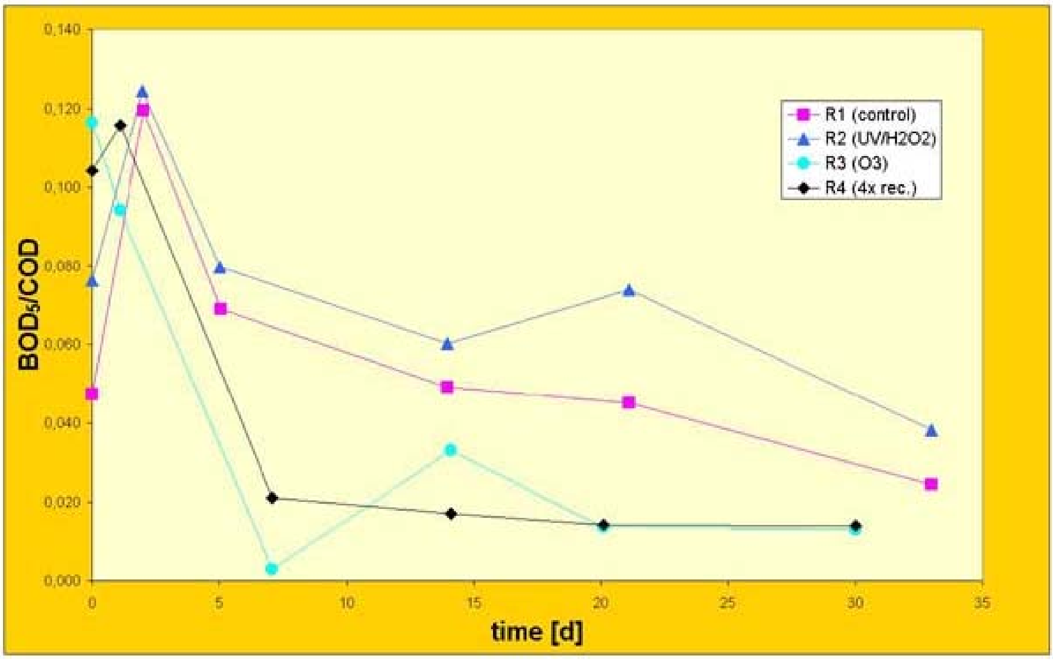
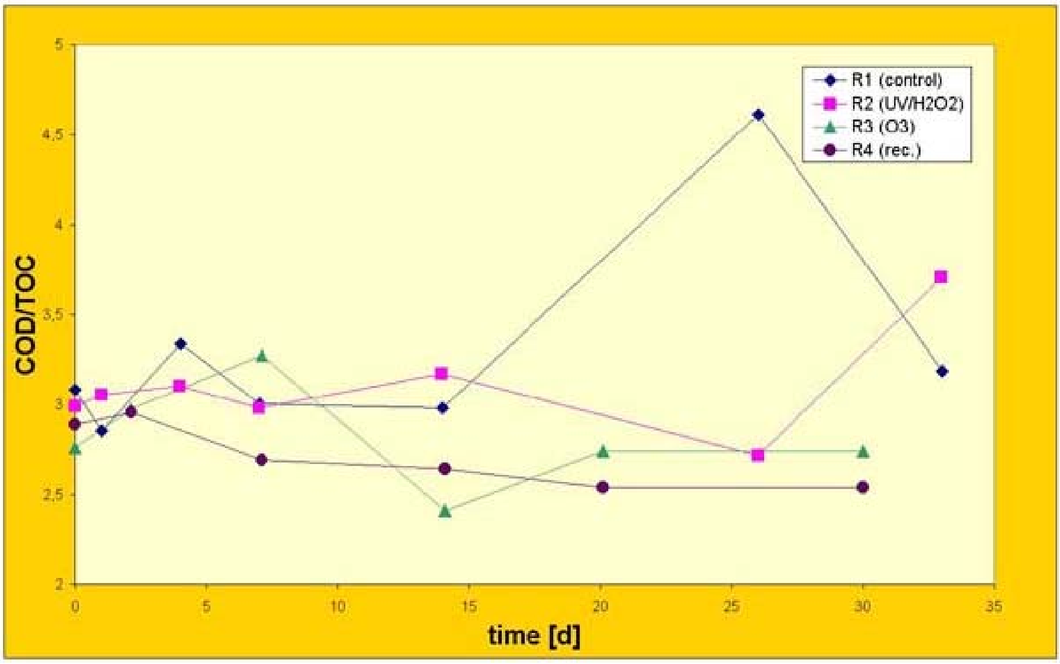


Fig. 5. Changes in oxidizability of leachates from lysimeters



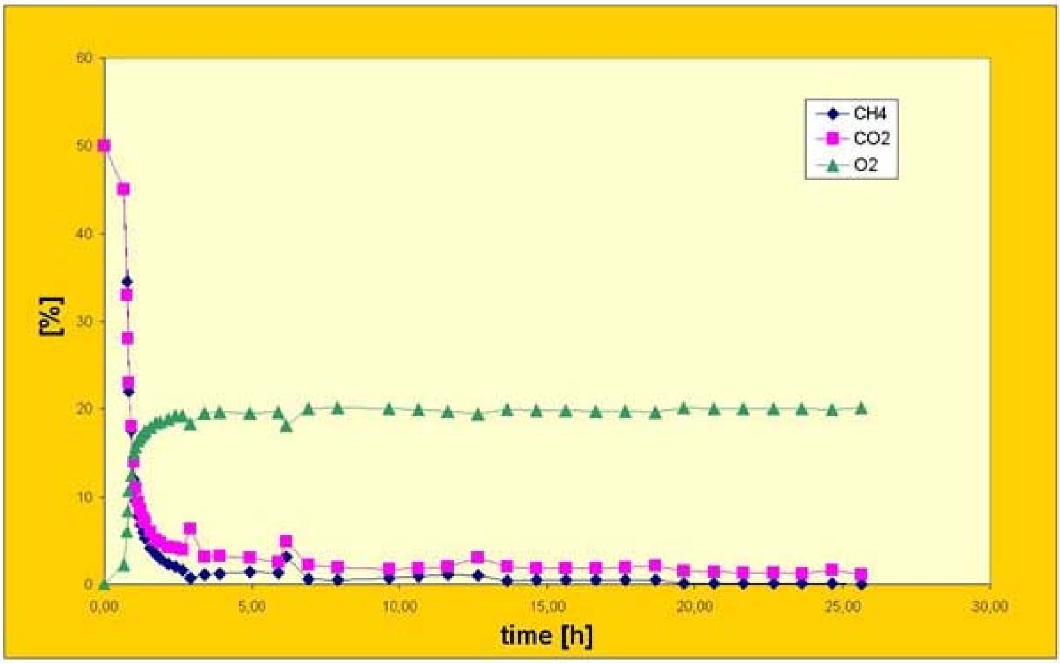
A more frequent recirculation of leachates (four times a day) enhanced greatly the degradation of organic substance. In comparison to the control lysimeter, a higher degree of organic substance degradation was observed. A comparison of results obtained is given in Tables 1 and 2.

The use of advanced oxidation processes somehow enhanced waste biodegradation but not as significantly as one may expected. In the lysimeter in which leachates were exposed to UV radiation with the addition of H_2O_2, the reduction of particular indices was comparable to that in the control reactor. A better result was obtained in the case of ozonation as illustrated in Table 2.

Table 2. Degree of organic load reduction in leachates from lysimeters (R1 – R4) after 33 days of aerobic stabilisation

Index	R1 (control)	R2 (UV/H_2O_2)	R3 (O_3)	R4 (4x recirculated)
BOD_5 [mg O_2/dm^3]	36.5 %	51.0 %	86 %	87.1 %
COD [mg O_2/dm^3]	-22.8 %	2.48 %	-20.8 %	5.70 %
Total N [mg N/dm^3]	-25.9 %	-24.8 %	-1.83 %	16.1 %
$N\text{-}NH_4^+$ [mg N/dm^3]	15.3 %	-61.0 %	74.7 %	63.4 %
VFA [mg acetic acid/dm^3]	31.1 %	66.8 %	76.7 %	-49.6 %
TOC [mg C/dm^3]	-18.8 %	21.3 %	-21.5 %	-7.16 %

Fig. 6. Changes in biogas percentage



The lysimeters were aerated in the moment when they were in the final methanogenic phase, and methane concentration in biogas constituted still a high percent, i.e. around 50%. Since the beginning of the aerobic process, a decrease of methane and carbon dioxide content and an increase of oxygen content was observed. Already after the first day of the process, gas at the outlet from the lysimeter had a composition similar to that of the atmospheric air mostly due to dilution of biogas and stopping the methane fermentation in the presence of oxygen. Curves that illustrate changes in the gas composition shown in Fig. 6, are similar in nature in each lysimeter. Investigations carried out by Heyer et al. [12] during *in situ* aeration of the landfill in Kuhstedt (Germany) after 14 years since it had been closed, revealed that methane content in the landfill gas decreased from around 50% to less than 1.5% during ca. a month since starting the aeration. In biogas samples taken from the landfill gas system installed in the landfill in Modena (Italy), around 10% methane was found after ca. 50 h of periodic aeration [7].

CONCLUSIONS

Simulation of municipal waste biodegradation in lysimeters provides knowledge of main processes that take place in the aerated landfill. From the point of view of minimisation of hazardous impact of old landfills on the environment caused by the leakage of leachates and landfill gas emission, the main aim of aeration for achieving its sustainability is the stabilisation of biodegradable substances and components containing nitrogen.

Experimental studies showed that the aerobic waste stabilisation was a very quick process. During a month the bed was stabilised, reaching a significant reduction of organic load indices. Aeration of the lysimeters caused a quick reduction of mainly degradable organic substance (in terms of BOD_5) and $N\text{-}NH_4^+$ and volatile fatty acids. The reduction of methanogenic potential of the landfill was even faster. The composition of gas at the outlet from the lysimeter changed and after one day already it was similar to atmospheric air.

A more frequent recirculation of leachates enhanced greatly the aerobic biodegradation. It was found that ozonation of leachates contributes to a growing reduction of pollutants in the leachates. On the other hand, UV irradiation with the addition of H_2O_2 did not increase either the degree or the rate of organic substance degradation.

REFERENCES

1. APHA-AWWA-WPCF Standard Methods for the Examination of Water and Wastewater. 17th edition, APHA, Washington, D.C., 1989.
2. Blake D.R., Rowland F.S.: Continuing world-wide increase in tropospheric methane. Science, 239, 1129-1131, 1988.
3. Blakey N.C., Bradshaw K., Reynolds P., Knox, K.: Bio-reactor landfill – a field trial of accelerated waste stabilization. In: Proceedings Sardinia 97, Sixth International Landfill Symposium, vol. I, CISA, Cagliari, 375-386, 1997.
4. Boeckx P., Van Cleemput O., Villaralvo I.: Methane emission from a landfill and the methane oxidation capacity of its covering soil. Soil Biol. Biochem., 28 (10/11), 1397-1405, 1996.

5. Borjesson G., Sundh I., Tunlid A., Svensson H.H: Methane oxidation in landfill cover soils as revealed by potential oxidation measurements and phospholipid fatty acid analyses. Soil Biol. Biochem., 30 (10/11), 1423-1433, 1998.
6. Brosseau J., Heitz M.: Trace gas compound emissions from municipal landfill sanitary sites. Atmospheric Environment, 28,285-293, 1994.
7. Cossu R., Lavagnolo M.C., Raga R.: In situ stabilisation of old landfills: Lab scale and field tests. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. IV, 531-540, 2001.
8. Cossu R., Raga R., Rossetti D.: The PAF model: an integrated approach for landfill sustainability, Waste Management, 23, 37-44, 2003.
9. Dammann B., Streese J., Stegmann R.: Microbial oxidation of methane from landfills in biofilters. In: Christensen T.G., Cossu R., Stegmann R.(eds.): Proceedings Sardinia 99, 7th International Landfill Symposium, CISA, Cagliari, vol. II, 517-524, 1999.
10. Ettala M., Vaisanen P.: New technology to enhance methane oxidation at landfills. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II, 551-554, 2001.
11. Grubler A.: Technology and global change. International Institute for Applied Systems. Analysis Laxenburg Austria, Cambridge University Press, 1998.
12. Heyer K. –U., Hupe K., Ritzkowski M., Stegmann R.: Technical implementation and operation of the low pressure aeration of landfills. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. IV, 521-530, 2001.
13. Hummer M., Lechner P.: Methane oxidation in compost cover layers on landfills. Proceedings Sardinia 1999, Seventh International Waste Management and Landfill Symposium, vol. III, 403-410, 1999.
14. Hummer M., Lechner P.: Design of a landfill cover layer to enhance methane oxidation – results of a two year field investigation. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II , 541-550, 2001.
15. Khalil M.A.K.: Atmospheric Methane. Its role in the global environment. Springer, Berlin, 2000.
16. Khalil M.A.K., Rasmussen R.A.: Climate-induced feedback for the global cycles of methane and nitrous oxide. Tellus, 41B, 554-559, 1989.
17. Ledakowicz S., Kaczorek K.: Biodegradation of leachate from municipal landfill in Lodz enhanced by advanced oxidation processes. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II , 319-328, 2001.
18. Ledakowicz S., Kaczorek K.: Laboratory simulation of anaerobic digestion of municipal solid waste, ISWA Annual Congress, Istanbul, 8 – 12 June 2002.
19. Lewicki R.: Degassing of municipal landfills. Waste management in landfills. Arka Konsorcjum, Poznań, 1993.
20. Main Statistical Office, Environmental Protection 2000, Warsaw, 2000.
21. Ritzkowski M., Heyer K.-U., Stegmann R.: Aerobic in situ stabilization of old landfills with the old landfill in Kuhstedt (Germany) serving as an example. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. IV, 577-586, 2001.
22. Scharff H., Oonk H., Vroon R., van der Sloot H.A., van Zomeren A., Hensen A.: Improved methane oxidation by means of forced aeration under a landfill cover. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II, 555-564, 2001.
23. Streese J., Dammann B., Stegmann R.: Reduction of methane and trace gas emissions from former landfills in biofilters. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II, 575-584, 2001.
24. Thorneloe S.A.: UESPA's global climate change programme – landfill emissions and mitigation research. In: Proceedings Sardinia 91, 3rd International Landfill Symposium, CISA, Cagliari, 1991.
25. Żygadło M.: collective work: Strategy of municipal waste management. Polish Association of Engineers and Technicians, Poznań, 2001.

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