

Ozonation of Activated Sludge in Periodic Reactors

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Abstract: Combining ozonation with aerobic wastewater treatment by using pre- and post-ozonation or other schemes is a known method for improving purification of industrial wastewaters. The application of mentioned methods is usually restricted due to the need of high ozone doses that significantly increases the cost of the purification process. The method of combining of ozonation and aerobic bio-oxidation into single integrated process, described in the current paper, has been found to improve wastewater purification efficiency when small ozone doses are applied. It is demonstrated how small ozone doses improve the performance of the aerobic bio-oxidation process over the conventional aerobic bio-oxidation process. Results revealed that the measurement of mixed liquor suspended solids (MLSS) is not suitable for evaluation of the activated sludge concentration in bioreactor. The measurement of ATP concentration proved to be superior over the MLSS concentration, as its response to ozone attack was immediate.

Keywords: Ozone, Aerobic Bio-oxidation, Activated Sludge, Integrated process, Viability of Micro-organisms, Adenosine-5'-triphosphate

I. INTRODUCTION

Aerobic biochemical (aerobic bio-oxidation) wastewater treatment is an inexpensive and the most widely used primary treatment method used in purification of industrial wastewaters. Industrial wastewaters are often characterized by high total organic carbon content, low biodegradability, high toxicity and colour – these properties may cause great problems in biochemical treatment process.

Ozonation in combination with aerobic biochemical wastewater treatment has been considered to be an effective way to reduce several problems arising in treatment of industrial wastewaters. Earlier studies focused mainly on biochemical wastewater treatment combined with pre- and post-ozonation. Although biodegradability of the wastewater and effluent water quality were improved, those methods were found to increase remarkably the costs of the purification process. To overcome the mentioned drawback, an integrated process – introduction of ozone into activated sludge – was proposed.

There are two possible ways, sited in literature, used for introduction of ozone into activated sludge: ozonation of recycled sludge stream (1) and direct introduction of ozone into bioreactor (2). The main goal of the first method is the reduction of excess sludge production with possible improvement in sludge settling properties. The goal is usually achieved by the cost of slightly reduced effluent water quality [1]. The aim of the second method is to improve the effluent water quality (improved colour removal, reduction of chemical oxygen demand – COD) and, if possible, to reduce

the excess sludge generation without adversely affecting the micro-organisms population in activated sludge (AS) responsible for the purification effect i.e. viable micro-organisms. Due to these effects of the two methods, it would be reasonable to implement the first method in municipal wastewater treatment, as the main problem there is the generation of excess sludge, while the second method (direct introduction of ozone into bioreactor) could be used in purification of industrial wastewaters.

Several works, carried out recently [2, 3, 4], have shown that combining aerobic bio-oxidation (ABO) and ozonation into a single integrated process is an efficient way to improve the purification efficiency of industrial wastewaters. Although, in a lab-scale plant, the integrated process looks promising, there are several problems that have prevented the implementation of the process in a real, large-scale plant:

- selection of ozone dose – it has to be sufficient to improve the purification process efficiency, but low enough, so that it would not inhibit the biological activity,
- micro-organisms, imposed on low ozone dose, may develop improved ozone resistance.

For example, van Leeuwen et al. [3] conducted a study where ozone doses of 45 and 30 mg·L⁻¹ were used. They concluded, based on evolution of COD removal efficiency, that ozone dose of 45 mg·L⁻¹, was too high and caused inactivation of micro-organisms. The authors of the present article have studied the following processes for the purification of phenolic wastewater: ABO, ABO with activated carbon (AC) treatment and ABO with AC treatment and direct introduction of ozone into ABO process [5]. The results of the study showed that small ozone doses almost immediately increased COD and BOD removal efficiencies. A longer period of biomass ozonation led to a disturbance of the bioprocess and to the formation of soluble COD and BOD that reduced effluent water quality. Thereby it is reasonable to ask, how do find the right dose and what parameters need to be considered when choosing it?

Performance of AS system is usually evaluated by determining different values – chemical oxygen demand (COD), biochemical oxygen demand (BOD), sludge concentration, sludge yield, sludge decay rate etc. The evaluation of the impact of ozone on AS system is usually based on the same values. In most of the works dedicated to combinations of ozone and ABO, the effect of ozone on AS have been evaluated by measuring changes in sludge concentration, expressed as the concentration of mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS) [4, 6, 7].

The approach to evaluate the viable micro-organisms in AS by measuring the MLSS concentration is questionable, since

usually the adenosine-5'-triphosphate (ATP) concentration is considered to be the measure of micro-organisms viability. The main reason why it is not correct to use MLSS concentration for monitoring the viability of AS, is a long response time – ozone inactivates sludge and it begins to affect the sludge generation rate. An inverse relationship is valid: the greater the amount of inactivated sludge, the lower is the generation rate of new micro-organisms (sludge yield is assumed to be constant, as it depends of the type of wastewater or substrate). As solids retention time (SRT) of conventional AS system is usually at least 3 days (i.e. particles that enter the bioreactor are retained there for 3 days), a considerably long time is needed before any change in number of viable micro-organisms, detected as MLSS, can be measured. Another problem is the time needed to carry out the MLSS measurement procedure – a portion of sample has to be dried at 105 °C as long as there is no change in mass [8]. Taking into account the shortcomings of MLSS measurement, several other applications are suggested for the measurement of changes of viable micro-organisms in AS. The most appropriate method seems to be the measurement of ATP concentration. The method of ATP measurement is a specific, precise, fast and sensitive way to detect the concentration of all viable micro-organisms in suspension.

The aim of the present study was to determine the effect of ozone on the efficiency of ABO process and on micro-organisms viability in AS.

II. MATERIALS AND METHODS

The effect of small ozone doses on efficiency of ABO process and pollutants (resorcinols) removal kinetics was evaluated using the results of the experimental study, described in [5] and additional experiments. The viability study – ozonation of AS in batch reactor – was performed to evaluate the effect of different ozone doses on viability of AS, detected as ATP, and on MLSS concentration.

A Methods

The previous study of the effect of ozone on the efficiency of ABO process was carried out in a continuous lab-scale plant consisting of two ABO reactors (volume of 10 litres). Integrated processes – ABO with AC treatment and ABO with direct introduction of ozone into ABO reactor and AC treatment – was carried out in one reactor and ABO process in another reactor (control reactor for the reference data) [5]. The results of the two integrated processes were used to evaluate the effect of ozone on ABO process.

The effect of ozone on the viability of micro-organisms in AS, as well as kinetic study was carried out in batch reactors (volume of reactors 1 and 2.6 litres, respectively).

The synthetic resorcinols containing wastewater, corresponding by its composition to the Kiviter oil-shale semicoking process effluent [2], was used in the experiments. In viability study, in order to detect the effect of ozone on pure AS (i.e. there are initially no ozone reactive compounds, other than AS, in suspension), also distilled water (with necessary nutrients – C, N, P, Mg²⁺, Ca²⁺, Fe³⁺, K⁺, Na⁺) was used. The results of the integrated processes were compared to the

results of the ABO process, carried out simultaneously. AS used in experiments was adapted to the wastewater.

For ozone introduction into continuous reactor, distilled water was saturated with ozone and pumped to the reactor – the method was used to simplify the calculation of transferred ozone dose. In kinetic study, distilled water saturated with ozone was injected via syringe. To avoid the apparent improvement of the performance of the integrated process over the ABO process, caused by the addition of distilled water saturated with ozone (effect of dilution), the same amount of distilled water was added to the ABO process at the same time. In viability study, gaseous ozone with the flow rate of 0.5 L·min⁻¹ and inlet concentration of 24 to 26 mgO₃·L⁻¹, was introduced into the activated sludge in batch reactors. Ozone was produced from compressed air by Trailigaz Labo LO ozone generator (batch processes) or from air by Clear Water Tech. Inc. P-2000 ozone generator (continuous process).

B Analyses

Ozone concentration in distilled water was measured by indigo colorimetric method (4500-O₃ B) as described in [8]. In viability study, ozone concentration in the inlet gas was detected with ozone analyzer (Anseros GM-PRO), in the outlet gas by iodometry [8] (2350E).

Determination of COD, and BOD was performed according to [8] (methods 5220 D and 5210 B, respectively). MLSS and MLVSS measurements were performed via porcelain dishes as described in [8] (methods 2540 B and 2540 E).

C Determination of adenosin-5'-triphosphate (ATP)

ATP was extracted from the samples (2 ml) with an equal volume of TCA/EDTA solution (10%/4 mM) (TCA – trichloroacetic acid). The fixed samples were frozen at -18°C and analysed within four weeks. For ATP analysis samples were thawed, mixed, and MLSS was allowed to settle. Prior to assay, samples were diluted 50-fold with Tris-EDTA buffer (0.1 M/2 mM; the pH of the buffer was adjusted to 7.75 with acetic acid). ATP concentration was determined using firefly luciferin-luciferase reaction mixture (ViaLight@MDA Plus, Lonza, USA). Internal calibration with known ATP concentration was used throughout the procedure. 100 µL of diluted sample was pipetted to a cuvette, background light emission was measured; 100 µL of luciferine-luciferase enzyme mixture was added, sample was rapidly mixed and light emission was measured with 1253 luminometer (ThermoLabsystem, Finland); subsequently 10 µL of ATP internal standard (1.65·10⁻⁶ mol ATP·mL⁻¹, Sigma, USA) was added, sample was mixed and light emission was measured.

D. Determination of resorcinols (kinetic study)

The concentration of resorcinols in the batch reactors was measured by gas chromatography using Thermo Electron Corporation Focus GC system with a flame ionisation detector. Resorcinols were extracted with diethyl ether (3 times), which was then exchanged with chloroform. 2 µL of sample was manually injected to split-splitless injector (300 °C, splitless time 0.5 min). The sample was carried by carrier gas (N₂, flow rate 1 mL/min) to Restek Rtx-1 (fused silica)

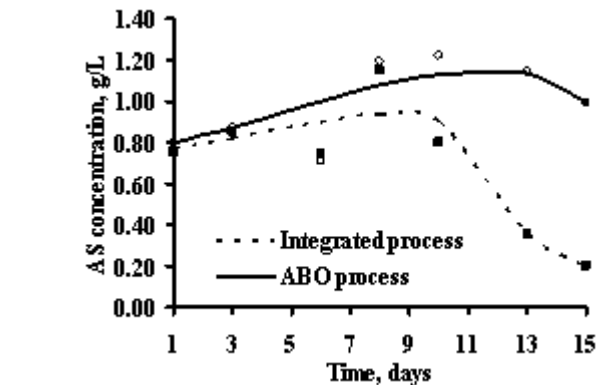
capillary column (30 m×0.32 mm×0.25 μm) where it was separated. Total resorcinols concentration was measured.

III. DISCUSSION

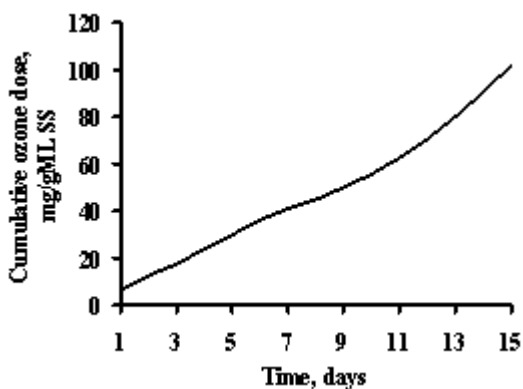
A Effect of ozone on the efficiency of ABO process

The evaluation of the effect of small ozone doses on ABO process was carried out on the basis of the results of the continuous integrated processes. An average ozone dose was 2.45 mgO₃·L⁻¹ (mg ozone per litre of treated water).

The concentration of viable micro-organisms was estimated by measuring the concentration of AS (as MLSS) (Figure 1a). Performance of the integrated process (direct introduction of ozone into activated sludge) was characterized by effluent water quality (as COD and BOD) (Figure 2).



a)



b)

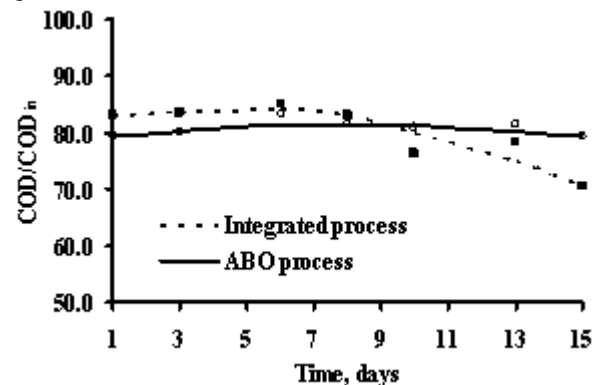
Fig. 1. Activated sludge concentration in studied processes. Lines show the trend of the concentration of AS (a). Calculated cumulative ozone doses (b)

The initial concentration of AS in both processes (integrated and ABO process), was equal (0.74 g·L⁻¹) (Figure 1a). During the first 8 days of operation, the concentration of AS in integrated process increased by 0.39 g·L⁻¹. In ABO process the concentration of AS at day 8 was of 1.19 g·L⁻¹. During the whole experiment period (15 days), the concentration of AS in ABO process, compared to initial concentration, increased, reaching finally approximately to 1 g·L⁻¹. After 8 to 10 days of operation, biomass concentration in integrated process started to drop. By this time, as part of AS was discarded from the reactors (approximately 5%) on days 1, 3, 6, 8, 10, 13, and 15, a cumulative ozone dose per 1 gram of MLSS (using an average MLSS concentration) was calculated to be from 45 to

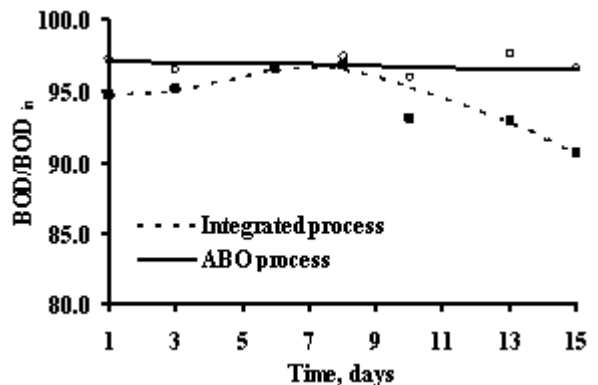
56 mgO₃·gMLSS⁻¹ (Figure 1b). It was concluded that possible reason for the decrease in biomass concentration was too large ozone dose.

The changes in effluent water quality (as COD and BOD), compared to initial values (COD_{in} and BOD_{in}), are presented in Figure 2. It is shown that in the beginning, the COD removal efficiency in integrated process was calculated to be ~3% higher. On the other hand, BOD removal efficiency in integrated process was ~5% lower compared to ABO process. Increased BOD value shows that ozone can oxidise refractory organics into biodegradable oxidation intermediates and at the same time ozone may disturb the biodegradation of organic substances. Possible disturbance was caused by decreased pH (it constantly lowered in integrated process from 7.22 to 5.90 – optimal pH for ABO process is from 6.5 to 8.5) or decreased oxidation capacity (activity) of living micro-organisms. It is also possible, as stated by Kamiya and Hirotsuji [4] that the deterioration of effluent water quality was caused by increased organic loading as a side effect of the reduction of the concentration of AS.

After 8 to 10 days of operation, COD and BOD removal efficiency in integrated process started to drop. It was possibly related to the reduced biomass concentration, although, as one can see from Figure 1a, the reduction of biomass concentration was much faster compared to changes in effluent water quality. In the light of these results, it is justified to ask, what happens to the sludge when it is subjected to ozonation, i.e. how the viable (active) part of the sludge is affected?



a)



b)

Fig. 2. Evolution of COD (a) and BOD (b) removal efficiencies in integrated and ABO processes

B Kinetics of removal of resorcinols

Study of the ABO and the integrated process in batch reactors was carried out to ascertain the kinetics of the processes. An average initial concentration of AS in both process was 1.46 g/L. Ozone dose, used in integrated process, was of 0.57 mgO₃·L⁻¹. At the start up of the study the wastewater was added to the bioreactor so that an average initial COD was of 1250 mg/L and BOD of 646 mg/L.

In Figure 3a and 3b changes in COD and BOD compared to initial values (COD₀ and BOD₀) are presented. The COD and BOD removal in integrated process remained higher compared to ABO process. In fact, in integrated process the same purification level was achieved approximately two times faster than in ABO process.

This finding shows that short-termed ozonation or small ozone doses actually increase biomass activity, as ozone oxidation alone (dose of 0.57 mgO₃·L⁻¹) can not be responsible for such a great increase in COD and BOD removal efficiency.

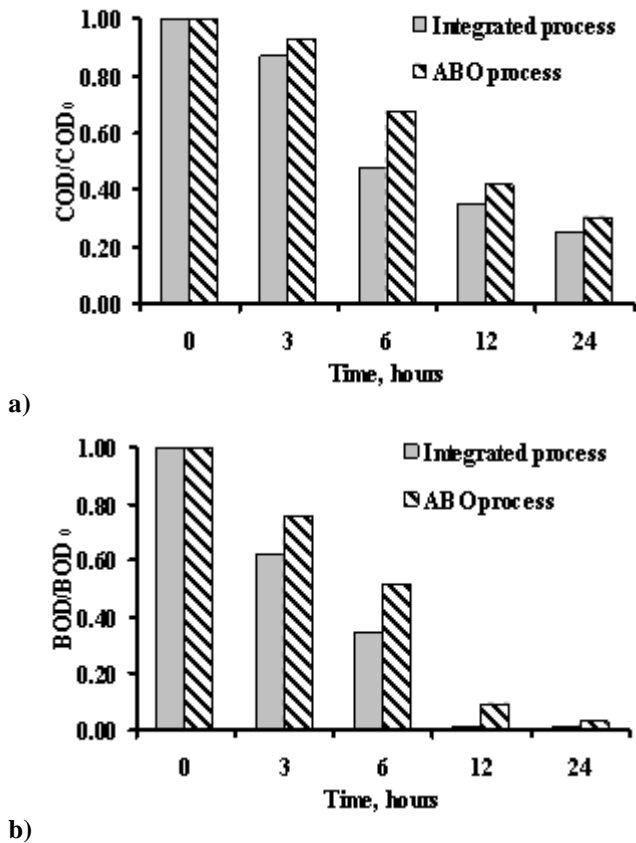


Fig. 3. Relative COD (a) and BOD (b) in batch reactors during the study of kinetics of processes

Target pollutants that were monitored during kinetic study, were resorcinols. As depicted in Figure 4, the concentration of resorcinols in integrated process decreased rapidly. Within 24 hours both processes were capable of reducing the concentration of resorcinols well below the maximum permissible concentration of 15 mg·L⁻¹ for dibasic phenols, as stated in Estonian Water Act.

Effect of ozone on micro-organisms

According to the data, it is clear that small ozone doses have positive influence on ABO process, but it is still unclear,

how to choose ozone dose that gives maximum increase in purification efficiency. In the following experiments carried out in batch reactors, an attempt to use the concentration of ATP as an indicator of concentration of viable micro-organisms in AS, is described.

In order to evaluate the effect of ozone on the ATP in AS, two different systems were subjected to batch ozonation:

1. AS in wastewater;
2. AS in distilled water (with necessary nutrients).

The results of ozonation of AS in wastewater (samples from continuous reactor) showed that transferred ozone doses up to a dose of ~30 mgO₃·gMLSS⁻¹ were not sufficiently large to reduce the concentration of viable micro-organisms in AS. When AS was re-suspended in distilled water, ozone started to reduce its viability almost immediately (Figure 5), whereas MLSS concentration was not changed (or the change was too small to detect). These results clearly indicate the importance of the detection of viability, as a measure of the concentration of AS, instead of MLSS concentration in ozonation of AS.

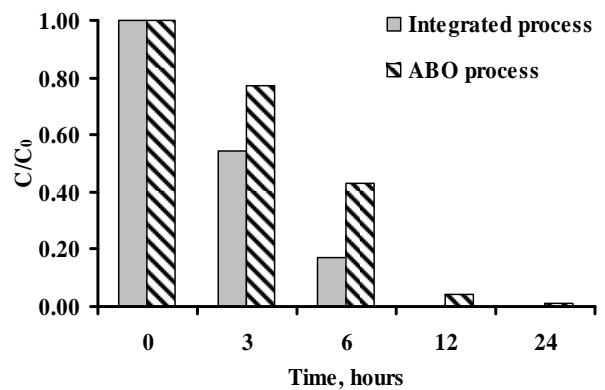


Fig. 4. Relative concentration of resorcinols in batch reactors

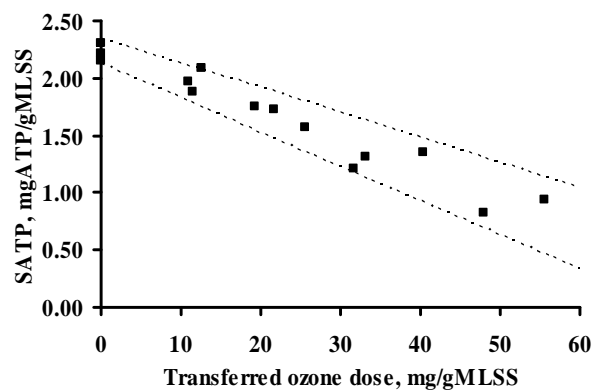


Fig. 5. Effect of transferred ozone doses on relative SATP of AS re-suspended in distilled water. Dotted lines represent upper and lower 95% confidence limit (obtained using regression data analysis tool in MS Excel)

An important factor always considered in wastewater treatment is the effluent water quality. It is usually expressed in terms of COD and BOD. In current study, during ozonation of the two systems, only changes in COD were monitored. The results of COD measurements are presented in Figure 6. An important difference between the two systems can be seen. In case of ozonation of AS only – there are no ozone reactive compounds in water that could deplete ozone before it reacts

with AS – ozone attacks AS and increases the COD of effluent water (Figure 6a). When ozone reactive compounds are present, AS is not affected and ozone is used for oxidizing soluble compounds in wastewater. This decreases the COD of effluent water i.e. improves effluent water quality (Figure 6b).

The results are in good agreement with the results of the study of integrated process in continuous reactors and kinetic study. Thus the following conclusions can be made:

1. viability of AS or MLSS concentration in wastewater is not affected when ozone dose is under some specific critical value (Figure 1);
2. direct introduction of small ozone doses into ABO process may enhance the purification efficiency compared to conventional ABO process (Figures 2, 3, and 4);

when AS is attacked by ozone, it is solubilized (the concentration of ATP is decreased) and effluent water quality is deteriorated (Figure 2).

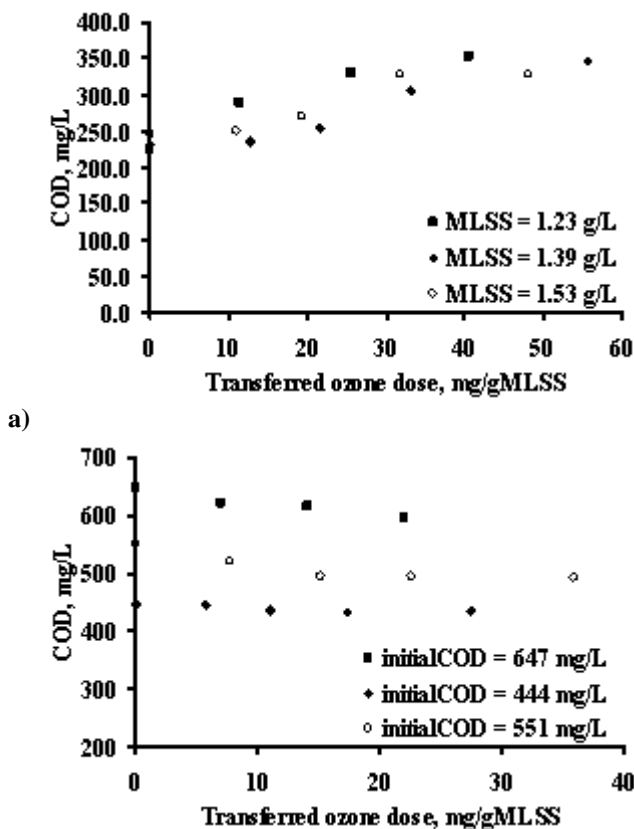


Fig. 6. Changes in effluent water quality, in terms of COD, during ozonation of AS in distilled water (a) and ozonation of AS in wastewater (b)

Thus, the direct ozonation of an activated sludge system is a complex process. Based on the results of the present study, it is clear that the optimisation of ozone dose in integrated process should be based on the experimental measurement of the ATP rather than MLSS concentration. A crucial factor to take into account is also the COD or more specifically the composition of water in bioreactor, as it may or may not

contain enough solubilized compounds that react with ozone before it comes into contact with AS.

IV. CONCLUSIONS

Present study showed that small ozone doses introduced directly into bioreactor improved the COD removal efficiency of ABO of phenolic wastewater. Also, the pollutants (resorcinols) removal rate was improved in integrated process: the concentration of resorcinols was reduced approximately two times faster than in ABO process. This finding shows that short-termed ozonation or small ozone doses actually increase biomass activity and viability of micro-organisms is not affected. At higher ozone doses the performance of the process will deteriorate. This is caused by the reduced concentration of viable micro-organisms, as well as increased solubilization of micro-organisms. The optimal ozone dose depends on wastewater and activated sludge composition and should be experimentally determined.

The experiments of AS ozonation in batch reactors showed that ATP measurements are valuable, giving the precise amount of viable micro-organisms and enable to detect changes in viability.

REFERENCES

1. Minimization of excess sludge production for biological wastewater treatment / Wei, Y., Van Houten, R. T., Borger, A. R., Eikelboom, D. H., Fan, Y. // *Water Research*. – Elsevier, 2003. – [37], P.4453-4467.
2. Wastewater treatment in oil shale industry / Kamenev, I., Munter, R., Pikkov, L., Kekisheva, L. // *Oil Shale – Estonian Academy Publishers*, 2003 – [20:4], P.443-457.
3. Ozonation within an Activated Sludge System for Azo Dye Removal by Partial Oxidation and Biodegradation / van Leeuwen, J. H., Sridhar, A., Esplugas, M., Onuki, S., Cai, L., Koziel, J., A. // *Ozone: Science & Engineering*. – Taylor & Francis, 2009. – [31], P.279-286.
4. Kamiya, T., Hirotsuji, J. / New combined system of biological process and intermittent ozonation for advanced wastewater treatment // *Water Science and Technology – IWA Publishing*, 1998 – [38 (8-9)], P.145-153.
5. Purification of phenolic wastewater using aerobic bio-oxidation combined with activated carbon treatment and ozonation / Järviok, O., Kamenev, I., Viiraja, A., Kallas, J. // *Proceedings of the EA3G International Conference OZONE & RELATED OXIDANTS IN ADVANCED TREATMENT OF WATER FOR HUMAN HEALTH AND ENVIRONMENT PROTECTION. Disinfection, elimination of persistent pollutants and control of by-products*, 15 May 2008.
6. Yasui, H., Shibata, M. / An innovative approach to reduce excess sludge production in the activated sludge process // *Water Science and Technology – IWA Publishing*, 1994 – [30:9], P.11-20.
7. Minimization of sludge production in biological processes: an alternative solution for the problem of sludge disposal / Deleris, S., Geaugey, V., Camacho, P., Debellefontaine, H., Paul, E. // *Water Science and Technology – IWA Publishing*, 2002. – [46:10], P.63-70.
8. *Standard Methods for the Examination of Water and Wastewater*, 19th ed, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

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Olivers Jarviks, Inna Kameneva. Aktīvo dūņu ozonēšana periodiskās darbības reaktorā

Rūpniecisko un sadzīves notekūdeņu attīrīšanai plaši tiek lietota aerobā bioloģiskā oksidēšanās. Rūpnieciskie notekūdeņi bieži satur dažādas krāsvielas, toksiskas vielas, kuru biodegradēšana ir apgrūtināta.

Tādu problemātisko notekūdeņu attīrīšanai ir izstrādātas dažādas metodes, kas iekļauj sevī aerobās oksidēšanās un ozonēšanas kombināciju.

Dotās metodes ļauj samazināt notekūdeņu toksicitāti, uzlabot to biodegradāciju un kvalitāti, tomēr būtiski palielina procesa izmaksas, īpaši pie augstām ozona devām. Minēto trūkumu ir iespējams pārvarēt, izmantojot integrētu procesu, kad ozona ievadīšana notiek tieši bioreaktorā ar mērķi daļēji oksidēt bioloģiski grūti degradējošas un mikroorganismiem toksiskas vielas. Svarīga problēma ir ozona nepieciešamās dozas noteikšana, kas būtu pietiekša attīrīšanas procesa efektivitātes palielināšanai, bet lai vienlaikus nenotiktu bioloģisko procesu inhibēšana.

Šī darba mērķis bija noteikt ozona dažādu devu ietekmi uz fenolu saturošu notekūdeņu bioloģiskās attīrīšanas efektivitāti (pēc KSP , BSP un rezorcīnu koncentrācijas) un uz dzīvo mikroorganismu daudzumu aktīvās dūņās. (pēc ATF daudzuma). Eksperimenti tika veikti kā nepārtrauktās darbības reaktorā (ozona deva $2,45 \text{ mg O}_3/\text{l}$), tā arī periodiskās darbības reaktoros (ozona deva $58 \text{ mg O}_3/\text{g}$ aktīvo dūņu, kas aptuveni ir $80 \text{ mg O}_3/\text{l}$).

Eksperimentāli tika noteikts, ka nepārtrauktās darbības reaktorā nelielu ozona devu ievadīšana palielina fenolu saturošu notekūdeņu bioloģiskās attīrīšanas efektivitāti pēc KSP (aptuveni par 3%), taču kumulatīvi ievadītā ozona devas pieaugums no 45 līdz $56 \text{ mg O}_3/\text{g}$ aktīvo dūņu izsauc aktīvo dūņu koncentrācijas samazināšanos, vienlaicīgi samazinājās procesa pH un tā kopējā efektivitāte.

Periodiskās darbības reaktoros veiktie eksperimenti parādīja, ka izmantojot ozona integrēšanas procesu, rezorcīnu koncentrācija samazinājusies aptuveni divas reizes ātrāk, nekā tradicionālajā bioreaktorā. Vienlaikus, pamatojoties uz dzīvo aktīvo dūņu daudzuma noteikšanu (pēc ATF) var secināt, ka ozona ietekme uz dūņu aktivitāti ir atkarīga no to vielu klātbūtnes notekūdeņos, kuras reaģē ar ozonu ātrāk par mikroorganismiem. Ja tādu vielu nav, tad ozons iedarbojas uz mikroorganismiem, kas būtiski samazina kopējo attīrīšanas efektivitāti. ATF koncentrācijas noteikšana (vai jebkāda cita analīzes metode, kas tiek izmantota dzīvu aktīvo dūņu daudzuma noteikšanai) ir ārkārtīgi svarīga ozonēšanas, kā metodes, novērtēšanai. Ozonēšanas ietekme uz notekūdeņu bioloģisko attīrīšanu ir atkarīga no notekūdeņu un aktīvo dūņu sastāva, ko ir iespējams noteikt tikai eksperimentāli.

Оливер Ярвик, Инна Каменева. Озонирование активного ила в реакторе периодического действия.

Для очистки бытовых и промышленных сточных вод широко применяется аэробное биологическое окисление. Однако известно, что некоторые промышленные сточные воды содержат плохо разлагающиеся биологически, токсичные и сильно окрашенные вещества.

Для очистки таких проблемных сточных вод разработаны различные методы, включающие в себя комбинацию аэробного окисления с пред- и постозонированием.

Данные методы позволяют снизить токсичность сточных вод, улучшить их биоразлагаемость и качество, однако существенно увеличивают стоимость процесса, особенно при высоких дозах озона. Указанный недостаток можно преодолеть, используя интегрированный процесс, при котором ввод озона осуществляется непосредственно в биореактор с целью частично окислить биологически трудно разлагаемые и токсичные для микроорганизмов вещества. Одновременно с этим, при правильном дозировании озона, можно добиться заметного снижения количества избыточного активного ила. При этом проблемой является подбор необходимой дозы озона, достаточной для увеличения эффективности процесса очистки, и одновременно с этим недостаточной для ингибирования биологических процессов.

Целью данной работы являлось определить влияние различных доз озона на эффективность биологической очистки фенольных сточных вод (по ХПК, БПК и концентрации резорцинов) и на количество живых микроорганизмов в активном иле (по количеству ATF). Опыты проводились как в реакторе непрерывного действия (доза озона $2,45 \text{ мгO}_3/\text{л}$), так и в периодических реакторах (доза озона $58 \text{ мгO}_3/\text{г}$ активного ила, что приблизительно равно $80 \text{ мгO}_3/\text{л}$).

Опытные данные показали, что введение в реактор непрерывного действия небольших доз озона увеличило эффективность процесса очистки фенольных сточных вод по ХПК (примерно на 3%), однако когда кумулятивно введенная доза озона возросла с 45 до $56 \text{ мгO}_3/\text{г}$ активного ила, концентрация активного ила начала снижаться. Снизилось так же pH процесса и его общая эффективность.

Опыты, проведенные в периодических реакторах показали, что в случае использования интегрированного процесса концентрация резорцинов снижалась примерно в два раза быстрее, чем в традиционном биореакторе. Одновременно с этим, на основе определения количества живого активного ила (по ATF), можно заключить, что влияние озона на активность ила зависит, прежде всего, от наличия в сточных водах веществ, которые реагируют с озоном быстрее, чем микроорганизмы. При отсутствии таких веществ озон атакует микроорганизмы, что ведет за собой значительное снижение результатов. На основе опытных данных можно утверждать, что определение концентрации ATF (или любой другой метод анализа, применяемый для определения количества живого активного ила) является чрезвычайно важным для оценки озонирования на процесс биологической очистки сточных вод. Важно так же то, что влияние озонирования зависит от состава сточных вод и активного ила, что можно определить только экспериментальным путем.