MAGNETIC TREATMENT FOR AMELIORATION OF WASTEWATER BIODEGRADATION

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Abstract: Nitrogen removal from wastewaters is highly important for environmental protection and human health. Recent findings about positive effect of a relatively weak magnetic field on microbial and enzymatic activity are opening new research fields, also on amelioration of wastewater biodegradation processes. Different models of magnetic devices were simulated with OPERA 17R1 Vector Fields Software and constructed with adjustable magnetic field strength, for laboratory tests on wastewater biodegradation to find an efficient treatment regime. Total nitrogen removal in lab-bioreactor was enhanced by direct exposure of synthetic wastewater (inoculated with active sludge) to a static magnetic field at strength (30 to 50) mT, indicating positive impact onto ammonium oxidizing bacteria. Similar effect was observed by inducing the recirculation of wastewater through the alternating magnetic field with peak strength 50 mT.

Key words: magnetic devices, simulation, modelling; wastewater; biodegradation

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1. Introduction

Wastewaters need careful treatment before being discharged safely into the environment. A typical municipal sewage treatment plant includes primary treatment to remove solid material, secondary treatment to remove dissolved, suspended organic material, and disinfection. Microbial degradation during the second phase includes anaerobic and aerobic processes using activated sludge. Organic-nitrogen pollutant is converted into ammonium followed by nitrification and de-nitrification, finally released into the air as nitrogen gas; while organic carbon is oxidized gradually into carbon dioxide. Industrial wastewaters need additional treatment for degradation of specific toxic components, such as oil pollutants, phenols (Kriklavova et al. 2014) and formaldehyde (Lebkowska et al., 2011), due to their high persistency within the environment and the food chain (Buzoianu and Coloja, 2012).

Increasing pressure to meet more stringent discharge postulations (i.e. standards for Chemical Oxygen Demand (COD), Total Nitrogen (TN), and specific toxic components) have led to the implementations of a variety of advanced biological treatment processes (Tramsek et al., 2008; Bouskova et al., 2011). There are also new ideas about how to support biodegradation activities by alternative methods, for instance by exposure to a Magnetic Field (MF), which has working principle apart from the simple influence of the magnetic field on dispersed magnetic particles (Ravnik et al., 2017; Zielinski et al., 2018).

A number of studies have already appeared in the literature about the noticeable influences of MF on microorganisms, their viability and metabolism. In general, the potential use is either for preventing or enhancing purposes, depending on the organic species and treatment regime, e.g. strength and type of MF (static, pulsating), and length of exposure. For instance, the growth of *Escherichia coli*, *Leclercia adecarboxylata* and *Staphylococcus aureus* was inhibited by exposure to the pulsating (50 Hz) MF with strength 10 mT (Fojt et al., 2004).

Static magnetic field exposure influenced the aerobic biosynthesis of polyhydroxyalkanoates by activated sludge: When the reactants were mixed or exposed solely to MF, maximal production of poly-3-hydroxybutyrate occurred at 7 mT, and of poly-3-hydroxyvalerate at 21 mT (Chen and Li, 2008). Several cases of increased enzymatic activity have been reported: Cellulase at 1 mT, 50 Hz (Gao et al., 2011); glucose dehydrogenase and hexokinase at 300 mT, glycolytic enzymes at 0.1 mT, 50 Hz (Potenza et al., 2012); and dehydrogenase activity at formaldehyde removal, where biodegradation increased up to 20 % at direct exposure to 7 mT (Lebkowska et al., 2011). The growth of *Escherichia coli* and *Pseudomonas putida*, commonly found in municipal wastewater treatment plants, was inhibited during the exposure to static MF (17 mT) at their optimal growth temperature (28 and 37) °C, while the dehydrogenase activity was increased about 30-times by MF and they viability was reversible shortly after the MF had been terminated (Filipic et al., 2012).

Some studies have already been reported about amelioration of wastewater biodegradation by exposure to a static MF of moderate strength.

An enhancing effect on bacterial growth and metabolic behavior was observed in activated sludge, resulting in increased removal of organic pollutants, especially those containing nitrogen. A biodegradation of synthetic sewage (inoculated with activated sludge from a municipal wastewater treatment plant) increased up to 44 %, attributed to glucose degradation, at direct exposure to 18 mT (Yavuz and Celebi, 2004); similarly, biodegradation of organic compounds in real municipal wastewater increased up to 40 % at 20 mT (Ji et al., 2010). An anaerobic TN removal in synthetic sewage with lab-cultivated anammox microbial population increased up to 50 % at 75 mT (Liu et al., 2008); similarly synthetic sewage with municipal sludge was increased at 48 mT and the enhancement in growth and increased activity of nitrite-oxidizing bacteria was proved (Wang et al., 2012). At lower temperatures (4 to 15) °C, the cold adaptability was enriched by MF, biodegradation of synthetic sewage with lab-cultivated sludge was increased at MF density in the range (20 to 40) mT (Niu et al., 2014). In the case of recirculating of synthetic sewage with municipal sludge through the MF with 40 mT, the biodegradation increased up to 16 % (Tomska and Wolny, 2008).

Considering industrial pollutants, for enhancing the phenol biodegradation, a higher static MF strength was needed, e.g. by recirculation through static MF (250 to 370) mT the degradation increased by up to 34 % (Kriklavova et al., 2012, 2014); while by inducing a pulsation of at least 50 Hz, much weaker MF (20 mT) also increased the degradation up to 30 %. Promoted growth and activity of *Rhodococcus erythropolis* enhanced the phenol oxidation (Kriklavova et al., 2013).

How magnetic treatment influences the metabolism of microorganisms is not completely clear yet. MF re-orientates the diamagnetic anisotropic organic molecules, such as membrane lipids, changing the permeability of membrane ion channels (Rosen, 2003; Hughes et al., 2005). The explanation may be sought in hypotheses for other similar phenomena of magnetic water treatment that are related to modified hydration of ions and interface surfaces (Oshitani et al., 1999; Ohata et al., 2004).

The aim of the investigation reported here was to find a magnetic regime that would be technologically and financially applicable for bioreactors with higher capacities than the laboratory vessels which were used in most of reported investigations. Different MF models were analyzed with OPERA 17R1 Vector Fields Software using finite-element operations (Lipus et al., 2012; 2015), for real operational data and material characteristics. Two magnetic devices were constructed with adjustable MF strength for laboratory tests, one for static exposure with homogenous MF and another for recirculation through the alternating MF.

2. Magnetic devices for laboratory tests

For experiments with continuous direct exposure of the reactor vessel to the MF, an excitation coil was found to be most suitable (Fig. 1). The excitation coil was composed of a solenoid coil and the Helmholtz coils (around the non-magnetic shell) to yield a homogeneous distribution of magnetic flux density (B) inside the reactor vessel.

In order to produce the static field, a Direct Current (DC) electricity supply was used and the MF strength was chosen differently by adjusting the electric-current strength during the experimental sets. The coil produces semi-homogeneous MF practically in the whole volume of the reactor vessel. Figs. 1.b and 1.c present two examples of B , about 37 mT and about 75 mT, respectively. Fig. 1.d presents the relationship between the applied electric current, I (A), and B (mT) measured inside the homogeneous region.

Fig. 1. Calculated distribution of magnetic flux density B : (a) inside the double-walled vessel produced by the excitation coil (R (mm) are radii measured from the reactor's axis); (b) At 6 A, and (c) At 12 A of DC electricity supply; (d) Measured B inside the reactor vs. DC electric current I .

Fig. 2. Measured distribution of magnetic flux density B along the channel-axis x of alternating magnetic pairs (ferrite transversally magnetized magnets) at different distances inside pair d .

For experiments with short-term magnetic treatment, a simple array of ferrite magnets, with an alternating orientation of MF lines was constructed (Fig. 2). Low-carbonic steel was selected for the material of the magnetic yoke. The casting and the pipe must be non-magnetic. During the experimental sets, the magnetic field peaks were chosen differently by adjusting the distances, d (mm), inside the magnetic pairs.

3. Experimental tests

A batch regime was used for observation of MF influence on nitrogen removal. A lab-reactor was filled up with a mixture of synthetic wastewater (8 g glucose, 0.4 g NH_4HCO_3 , 0.4 g KH_2PO_4 , 0.4 g NaHCO_3 , 5 mg $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 5 mg FeCl_3 , 5 mg CaCl_2 , 5 mg KCl , 5 mg CoCl_2), inoculated with activated sludge freshly taken from an aerated semi-batched basin at a municipal wastewater-treatment plant. Conditions within the basin vary throughout a season, due to city life-trends and weather; therefore, the runs were performed in short periods and simultaneously for comparison with and without magnetic treatment to provide similar viability and composition of microbial sludge. During the experiments, the effluent from the basin had $\text{TN} = (3.5 \pm 1.5) \text{ mg/L}$ and $\text{COD} \approx 25 \text{ mg/L}$; i.e. much better than the European Council Directive 91/271/EEC (since 1991, $\text{COD} < 125 \text{ mg/L}$ and $\text{TN} < 10 \text{ mg/L}$, concerning urban wastewater treatment). No artificial organic-nitrogen components were added to the synthetic solution.

As the TN of the sludge samples was much smaller than in the synthetic solution, initially in the experiments TN was attributed mainly to the initial ammonium nitrogen, while the initial COD was attributed to the glucose. Ammonium removal occurs through the microbial nitrification-denitrification process: It is oxidized into NO_2^- normally by autotrophic *Nitrosomonas* and further into NO_3^- by autotrophic *Nitrobacter*; simultaneously the organic carbon is converted into carbon dioxide gas. Nitrate is then reduced into nitrogen gas by heterotrophic organisms, also releasing carbon dioxide gas using carbon from complex organic compounds. TN was sampled periodically from the vessel and analyzed on a Multi N/C 2100/2100s Analyzer, according to DIN 38409 – H27 and DIN EN 12260 Standards. Furthermore, a MERCK Spectroquant NOVA 60 photometer was used for ammonium determination. Total nitrogen concentration comprises the nitrogen concentration of ammonium, ammonium salts, nitrites, nitrates and organically-fixed nitrogen; while soluble nitrogen is undetected in this analytical method.

The operational conditions in the lab-vessel were maintained close to those in the actual basin during the current season, i.e. the summer. The vessel was double-walled to enable temperature stabilization (21.5 ± 0.5) °C by water-bath circulation; pH was checked periodically, being (7.2 ± 0.2). The oxygen concentration was maintained at (2.3 ± 0.3) mg/L by pumping atmospheric air and dispersing within the vessel by stirrer. Firstly, the lab-reactor was inserted into the electromagnetic coil (Fig. 1), so the microorganisms could be exposed to the static MF continuously. A few preliminary runs with differently adjusted MF strength (Fig. 1.d) were performed to find a

noticeable influence. At 30 mT and 50 mT, an enhancement of TN removal was observed during the first hours (Fig. 3.a), which can be explained by increased viability of ammonium oxidative bacteria (Filipic et al., 2015).

Due to quick response of the activated sludge, a short-term magnetic treatment was induced by recirculation the wastewater mixture, through the array of alternating quadratic pairs of magnets (Fig. 2). A set of four-hour runs for differently adjusted MF strength showed the influence at peaks 50 mT (Fig. 3.b, c). The result complies with the report on a similar treatment regime by Tomska et al., 2008.

Fig. 3. Influence on the ammonium removal (ζ is the mass concentration of nitrogen relative to the initial concentration): (a) Continuous exposure to static MF (30 mT); (b) Recirculation through the alternating MF (peaks 50 mT).

4. Pilot tests

When transferring the required treatment regime from lab- to pilot-level, the model with quadratic transversally magnetized magnets still can produce the required MF for pipe diameters up to 50 mm (Fig. 4), while for higher diameters, a model with hexagonal magnets is applicable (Fig. 5). The capacity can be also increased by the number of parallel arrays of magnets.

The short-term treatment regime by recirculation through the system of alternating quadratic magnets (MF peaks 50mT) was applied for further assessment at MikroChem LKT in the Czech Republic, the company for environmental protection and monitoring, pollution removal and wastewater disposal. Parallel runs (with and without MF) were performed for observation of phenol degradation rate (COD analysis) and of microbial growth (by optical density measurement). With MF, the shortening of lag-phase was observed and the growth rate of microbial population increased approx. 10% within first 3 days of the experiment. Due to positive results, the pilot unit (consisting of 1 m³ stirring reactor, two parallel biofilm-cultivation units, magnetic and control unit) was registered as G (prototype) - Z (verified technology), designated for cultivation of specific microbial populations for water or soil remediation, for removal of specific pollutants, e.g. phenols and petroleum hydrocarbons.

Fig. 4. MF distribution within the gap 50×50 mm, between rows of NdFeB magnets $50 \times 15 \times 5$ mm, on an iron plate, and y - component along the x - axis of the gap, B_y .

Fig. 5. Calculated distribution of MF strength inside the pipe surrounded by hexagonal NdFeB magnets (along the pipe z - axis and along the A-A cross-section: (a) Peaks 30 mT at pipe diameter 100 mm; and (b) Peaks 40 mT at 81 mm diameter.

5. Conclusion

Wastewater biodegradation depends on numerous process factors, such as the wastewater composition, temperature, aeration, flow regime, viability of activated sludge, and eventual presence of toxic components, such as pharmaceuticals. Restrictive criteria for wastewater disposal leads to high interest for implementation of advanced treatment regimes.

Novel methods for improvement of existing biological treatment process shall not require complete reconstruction or crucial changes of present treatment technology. In the view of economic and environmental applicability of the magnetic treatment as an alternative for amelioration of wastewater biodegradation, the capital costs of magnets or electricity consumption for electromagnetic coils shall be compared to savings in operational costs thanks to shorter start-up time and lower electricity consumption for the reactor aeration.

While the biological effects of strong MF, higher than 1 T, have been relatively well studied, fewer reports can be found for effects at weaker MF. Limiting to TN and COD removal by aerobic biodegradation regime, in the majority the positive effects were observed at MF strengths (20 to 50) mT, while 75 mT was found to be effective for anaerobic anammox process. Due to different response of different microbial species, preliminary laboratory experiments are crucial for each individual case, to find the efficient MF strength and proper exposure time regarding the real biodegradation process factors. Our experiments were using a synthetic solution to provide proper experimental repeatability, inoculated with fresh sludge from an aerated semi-batched basin at municipal plant, to provide appropriate active microorganisms. The initial increase in TN removal observed at (30 to 50) mT, can be explained by stimulation of the ammonium oxidizing bacteria. Regarding the quick response of activated sludge during the continuous exposure, a short-term magnetic treatment was also tested for MF strength and length.

In the view of technological applicability on semi-industrial level, the periodical stimulation of activated sludge can be induced by recirculation through a separate column surrounded by the electromagnetic coil. Another idea is a cultivation of target microorganisms on mobile biofilm-carriers in a separate bioreactor under continuous MF exposition, without any need for structural changes of the treatment plant.

The findings are opening a promising research field, with special focus on MF impact on enzymatic activity, and viability of target microorganisms that are capable for removal of specific industrial pollutants before effluent disposal. Our lab-magnetic devices are suitable for further investigations. We are planning to test the eventual MF impact on glucose oxidizing activity of immobilized enzymes.

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7. References

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