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The Effect of the Magnetic Field on Nitrogen Compounds Transformations in Wastewater Treatment with Activated Sludge

Wpływ pola magnetycznego na przemiany związków azotu w procesie oczyszczania ścieków metodą osadu czynnego

In this work, the influence of the magnetic field of induction 40 mT on the transformation of nitrogen compounds in activated sludge wastewater treatment process was determined. The experiment was carried out in unfavorable temperature for nitrification process - 14 ± 1°C in laboratory scale in two continuously operating activated sludge systems in parallel under identical condition. In one of system a pair of permanent magnets was installed on the pipe used to recycle activated sludge. The data show that transformation of nitrogen compounds was more effective in the system, in which the activated sludge periodically exposed to the magnetic field compared to the system which has remained outside the influence of the magnetic field. It has been noted that the oxygen uptake rate of second phase of nitrification was higher by 1.6 to 2.1 times in system with magnets compared to control system.

Keywords: **magnetic field, activated sludge, nitrification rate**

Introduction

Recently, much attention has been given to research on the influence of the magnetic field (MF) in the biological wastewater treatment process, targeted at pollutant removal, intensification and acceleration. Currently it is assumed that MF can significantly accelerate the growth of microorganisms and their activity. Positive results were obtained in many studies concluding that the MF was beneficial to the biological wastewater treatment process [1-7].

The studies of Ji et al. [5] revealed that MF of induction 20 mT have a positive impact on the growth of mixed bacteria in the activated sludge and bacteria magnetically pre-acclimated have a higher biodegradation ability than those without the same pre-acclimation. The beneficial effect of unipolar southern MF on the biodegradation of phenol was observed by Jung et al. [1] at magnetic induction 490 mT and Jung and Sofer [2] of induction 150 and 350 mT. Raja Rao et al. [3] also demonstrated a positive influence of MF on the biodegradation of phenol, but at a lower induction equal to 22 mT. However, in this case of the MF was used the coil powered with direct current.

Positive results have been reported by Łebkowska et al. [6, 7] in research on the effect of the static MF at induction of 7 mT on formaldehyde biodegradation by activated sludge in synthetic and industrial wastewater. MF increased the efficiency of formaldehyde biodegradation in a reactor treating synthetic wastewater by 30% and in the reactor treating industrial wastewater by 20% compared to a control reactor. The positive effect of MF on the biological wastewater treatment process was also observed by Yavuz and Çelebi [4], who showed that MF of induction 17.8 mT supports biodegradation of glucose by activated sludge. In this case, the wastewater characterized easily biodegradable substrate was used.

Currently, there are also the information indicating that the MF a positive influence on the process of nitrification by using granular sludge [8] activated sludge [9-11] and biofilm [12, 13]. The feasibility of enhancing the granulation of aerobic nitrification by using a static MF has been researched by Wang et al. [8]. The authors showed that the MF of induction of 48 mT could enhance the activities and growth of nitrite-oxidizing bacteria.

Filipic et al. [9] have shown that static MF positively influenced ammonia oxidation and stimulated growth of *Nitrosomonas europaea*. The bio-effect on nitrification induced by the magnetic carrier with surface MF of 4 mT has been investigated by Yao et al. [13] by comparing the performance of sequencing batch biofilm reactors filled with magnetic and non-magnetic carriers. They have shown that the bioreactor with magnetic carriers had better performance for nitrification than bioreactor with non-magnetic carriers. The authors have demonstrated the 1.6-fold faster ammonium oxidation rate in the reactor with magnetic carriers at high influent concentration of ammonia nitrogen, while nitrite oxidation rate was always accelerated regardless of influent ammonia nitrogen concentration.

Already in previous studies regarding the influence of MF induction of 40 mT on treatment of wastewater with activated sludge Tomska and Janosz-Rajczyk [10] and Tomska and Wolny [11] have demonstrated that the transformation of nitrogen compounds were more effective in a system in which the activated sludge periodically exposed to MF compared with control system. The statistically significant the effect of MF on the efficiency of the processes of nitrification, denitrification and the removal of nitrogen compounds on rotating biological contactor have been observed by Rodziewicz et al. [12].

The aim of this work was to evaluate the effect of the MF induction of 40 mT on the transformation of nitrogen compounds and the activity of nitrifying microorganisms in activated sludge wastewater treatment process.

1. Material and methods

1.1. Experimental set-up

The experiment was carried out in laboratory scale in two continuously operating activated sludge systems in parallel under identical condition. Each of the experimental systems consisted of: an aeration vessel with a capacity 3.7 L of activated sludge, a secondary clarifier which holds 1.8 L, dosing pumps for raw wastewater and for recycle activated sludge, an air pump, a storage vessel for raw wastewater and collection vessels for effluent. The total capacity of individual laboratory system was 5.8 L.

In one of the system a pair of permanent magnets was installed on the pipe used to recycle activated sludge from the secondary clarifier to the aeration vessel. The magnets were installed so that the MF was influenced only on activated sludge return. The second system outside of the MF influence was used as a control. The scheme of the experimental set-up with magnets installed on the pipe used to recycle the activated sludge shown in Figure 1.

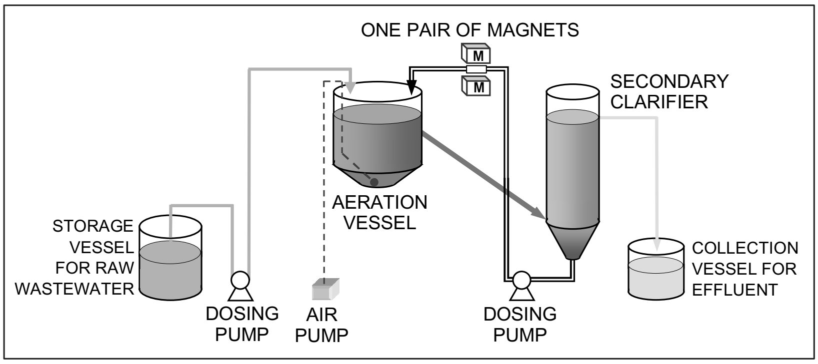

Fig. 1. The experimental set-up

Between permanent magnets the glass pipe with diameter 18 mm was central located. The magnets were installed in this way, that maximum induction of MF was 40 mT along pipe used to recycle the activated sludge. This allowed for periodic exposure sludge in MF in time of 3.3 min/d.

1.2. Activated sludge and synthetic wastewater

The activated sludge was obtained from the Central Wastewater Treatment Plant in Czestochowa. In the studies the synthetic, domestic-like wastewater was used with the following composition: peptone (110 mg/L), bouillon (110 mg/L), K_2HPO_4 (28 mg/L), NaCl (7 mg/L), $CaCl_2 \cdot 2H_2O$ (4 mg/L), $MgSO_4 \cdot 7H_2O$ (2 mg/L), CH_4N_2O (20 mg/L) and NH_4Cl (20 mg/L). The concentration of organic substrates was changed to obtain the required values of COD in raw wastewater. Also were changed the mineral substrates concentrations. The $CO(NH_2)_2$ and NH_4Cl concentration in raw wastewater were constant.

1.3. Analysis methods

In the raw and treated wastewater COD, total Kjeldahl nitrogen (TKN), ammonia nitrogen [14], nitrate nitrogen(III and V) [15] were determined. The suspended solids sludge [14] and dissolved oxygen concentrations in activated sludge were also determined.

In studies transformations of nitrogen compounds were evaluated by the rate of nitrification v_1 and v_2. The nitrification rate v_1 was expressed as a sum of nitrate nitrogen(III) and nitrate nitrogen(V) produced in the biodegradation process in respect of retention time. While the nitrification rate v_2 was expressed as the amount of nitrate nitrogen(V) produced in the biodegradation process in respect of retention time. The method of calculating the nitrification rate v_1 and v_2 is shown in Table 1.

Table 1. **Calculating method the rate of nitrification**

Formula number	Nitrification rate	Formula	Unit
(1)	v_1	$\frac{\Delta N_{NO_2^- + NO_3^-}}{\tau}$	mg N/L·h
(2)	v_2	$\frac{\Delta N_{NO_3^-}}{\tau}$	mg N-NO_3^-/L·h

$\Delta N_{NO_2^- + NO_3^-}$ - sum of nitrate nitrogen(III) and nitrate nitrogen(V) produced in the biodegradation process, mg/L

$\Delta N_{NO_3^-}$ - amount of nitrate nitrogen(V) produced in the biodegradation process, mg/L

τ - hydraulic retention time, h

The biodegradation process was also controlled by measuring the rate of oxygen consumption by the nitrifying microorganisms (I and II phase of nitrification) [16]. This method involves determining the rate of oxygen uptake by microorganisms of activated sludge without and with inhibitors sequentially introduced in amounts providing a in complete inhibition of nitrification of individual phases. Consecutively were introduced inhibitors of nitrification. Firstly was fed $NaClO_3$ (inhibitor for second phase of the nitrifying bacteria) and was measured of oxygen consumption and allylthiourea (inhibitor for first phase of the nitrifying bacteria) and again measured the oxygen uptake by activated sludge microorganisms. The difference between the total uptake of oxygen without inhibitor and uptake of oxygen with $NaClO_3$ was considered as the rate of the oxygen uptake for the second phase of nitrification. Whereas the difference between the uptake of oxygen with $NaClO_3$ and uptake of oxygen with two inhibitors was considered as the rate of the oxygen uptake for the first phase of nitrification.

1.4. Experiment design

The process was carried out at temperature 14 ± 1°C during 20 days. The process was realized keeping preferred for nitrification process sludge age 12÷13 days. The dissolved oxygen concentration in the aeration vessel was kept at 2 mg O_2/L. The others parameters of process and concentration of contaminations in the raw wastewater shown in Tables 2 and 3.

Table 2. **The process parameters of wastewater treatment**

Parameters	Unit	Value (range value)
Hydraulic retention time	h	5
Sludge age	d	12÷13
Suspended solids in activated sludge	g/L	2.36÷3.87
Sludge load	g COD/g MLSS·d	0.43÷0.78
Dissolved oxygen concentration	mg O_2/L	2

Table 3. **The contaminations concentration of raw wastewater**

Contamination	Unit	Range value
Organic compounds (COD)	mg O_2/L	223÷536
Organic nitrogen	mg N_{org}/L	22.4÷53.8
Total Kjeldahl nitrogen (TKN)	mg N_{Kj}/L	37.3÷67.9
Ammonia nitrogen	mg N-NH_4^+/L	10.2÷25.5
Nitrate nitrogen(III)	mg N-NO_2^-/L	0.86÷3.15
Nitrate nitrogen(V)	mg N-NO_3^-/L	1.86÷7.4

2. Results and discussion

Studies have shown that periodic exposure of the activated sludge in the magnetic field of induction 40 mT did not result in the intensification of the removal of organic pollutants. It was observed that the elimination of organic compounds was high in a system in which activated sludge was periodically exposed to a MF, as well as in the control (was keeping in the range of 78 to 88%) (Table 4).

Table 4. **The contaminations concentration and removal efficiency of COD in the effluent wastewater treatment process**

Indicator	System	Unit	Time, d														
			2	3	4	5	7	9	10	11	13	14	15	16	18	19	20
Concentration	MF	mg O_2/L	40	46	53	43	58	46	51	54	56	57	58	67	72	80	67
	C		42	40	44	49	55	51	39	54	57	66	51	70	68	81	64
Removal efficiency	MF	%	82	80	79	84	79	85	82	84	85	86	86	84	86	85	87
	C		82	82	83	81	81	84	86	84	85	84	88	84	87	85	88

System MF - system in which activated sludge was periodically exposed to the MF
System C - control system

It should be noted that in the present research the biodegradation process was so intense in the control system, as well as in a test system, that could not be observe significant differences of the efficiency of the process between the systems. Similar observations have been made in earlier studies [10, 11]. To show the beneficial effect of the MF on the rate of removal of organic compounds, for example, should be shorten the retention time, increase the load of contaminants in raw wastewater or decrease the concentration of activated sludge in the aeration tank. However, these parameters, according to the assumptions of this study were changed only in so far that the nitrification process was not completely inhibited. In the literature, can be found also reports indicating that the MF was a factor that intensifies the easily biodegradable substrate [4, 5] and the biodegradation of industrial wastewater [2, 3, 6, 7].

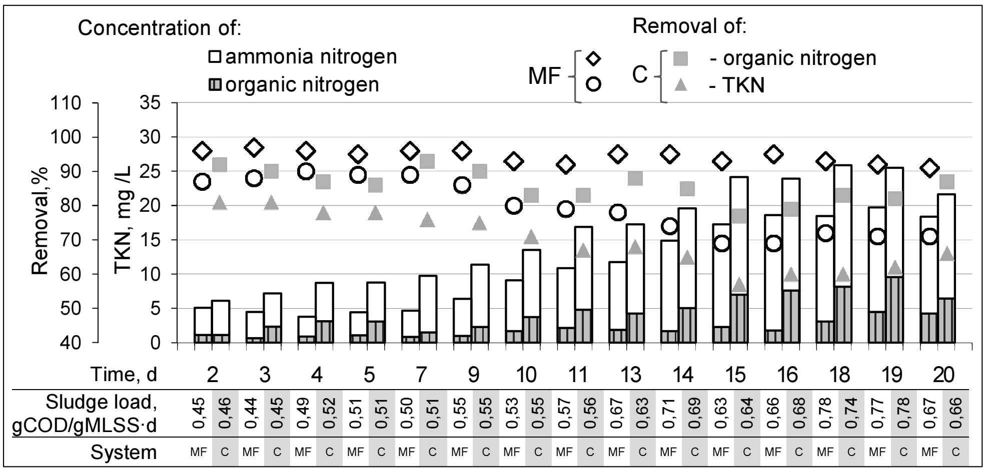

Fig. 2. Changes in the removal and concentration of nitrogen compounds in the effluent wastewater treatment process in relation to activated sludge load in the subsequent days of research (MF - system in which activated sludge was periodically exposed to the MF, C - control system)

However the wastewater treatment process in the area of the transformation of nitrogen compound was more effective in the system, in which the activated sludge periodically exposed to the MF compared to the control.

In each subsequent day of measurement was noted a lower concentration of the organic nitrogen and TKN in the system where installed magnets. The concentration of organic nitrogen was lower on 1.5 to 4.2 times in the system with magnets in comparison with the control system (Fig. 2). The degree of nitrogen removal was achieved a high value above 90% in the system, in which the activated sludge periodically exposed to the MF and the degree of organic nitrogen removal was higher than the control by 3 to 16%. The degree of organic nitrogen removal - over 90% - was also observed in earlier studies, carried out under similar conditions but at a higher temperature of 22 ± 2°C in the system, which has remained outside the influence of the MF [10].

The degree of removal of the TKN was also higher in system with magnets of 5 to 13% compared to controls (Fig. 2). Should be noted that the degree of removal of TKN in system with the magnets also achieved similar values to those obtained at a temperature of about 8°C higher in the system, which was beyond the reach of MF [10].

The confirmation of intense transformation of nitrogen compounds in the system in which you installed magnets is also a higher the rate of nitrification v_1 and v_2 determined in accordance with the formulas shown in Table 1. The rate of nitrification v_2 was higher by 1.2 to 1.9 times in the system in which activated sludge was periodically exposed to a MF, as compared to the system will remain outside the influence of the field (Fig. 3). In the system with magnets the rate of nitrification v_2 was varied from 1.89 to 3.59 mg N/L·h and in the control system from 0.92 to 2.87 mgN/L·h.

The differences between the rate of nitrification v_1 were relatively low between the test system and control, however, in each subsequent day of the measurement were higher in the system with magnets (Fig. 3).

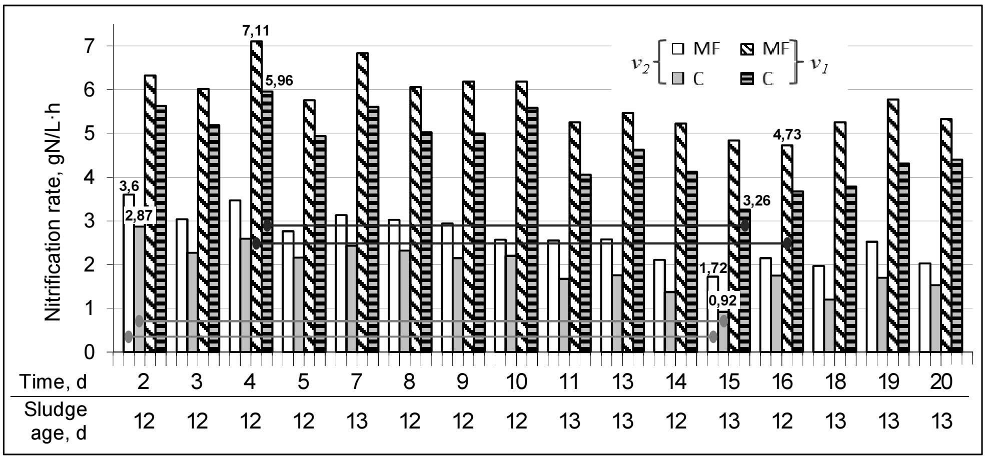

Fig. 3. The nitrification rate in relation to the sludge age in the effluent wastewater treatment process in the subsequent measurement days (MF - system in which activated sludge was periodically exposed to the MF, C - control system)

Confirmation of intense transformation of nitrogen compounds in the system, in which the magnets were installed is also a higher oxygen uptake rate mainly for the second phase of nitrification (Fig. 4). The oxygen uptake rate of second phase of nitrification, in each subsequent day of measurement, was higher by 1.6 to 2.1 times in system in which the activated sludge was exposed to MF compared to control system. It was found that the oxygen uptake rate for the second phase of nitrification has obtained similar values in the system in which the activated sludge was exposed to MF at temperature 14 ± 1°C (in the range of 8.9 to 11.9 mg O_2/L·h) (Fig. 4) and in the system, which has remained outside the influence of the MF at temperature 22 ± 2°C (in the range of 8.8 to 14.2 mg O_2/L·h) [10].

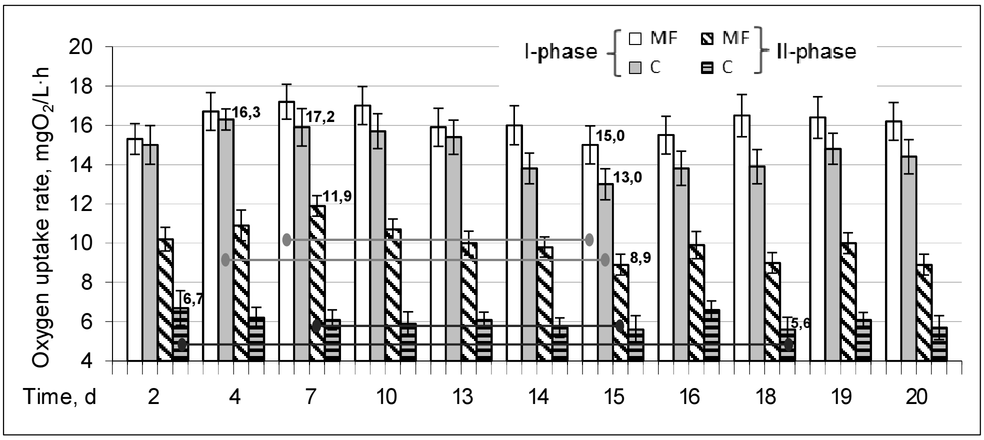

Fig. 4. The oxygen uptake by the nitrifying bacteria in the effluent wastewater treatment process in the subsequent measurement days (MF - system in which activated sludge was periodically exposed to the MF, C - control system)

Similar conclusions on the positive impact of the MF on the nitrification process were obtained by other researchers [8, 9, 13]. Filipic et al. [9] in the experiments with activated sludge, have demonstrated that static MF of 50 mT increased ammonium removal rates by activated sludge bacteria in sequencing batch reactors by up to 77% and increased the abundance of sludge ammonia-oxidizing bacteria. Yao et al. [13] found that the MF improved the nitrite and ammonia oxidation activities in biofilm and Wang et al. [8] noted that field is helpful and reliable for accelerating the aerobic nitrifying granulation. Although different types of biological treatment processes were used for the magnetic enhanced bio-effect, the processes of nitrification in all systems proved to be enhanced with the MF.

These findings suggest that MF may have important implications in the biological wastewater treatment and suggest the possibility to use a MF to enhance the removal of nitrogen compounds in the wastewater treatment plant.

Conclusion

- Transformations of nitrogen compounds at temperature 14 ± 1°C were more effective in the system, in which the activated sludge periodically exposed to the magnetic field of 40 mT induction at the time of 3.3 min/d compared to the system which has remained outside the influence of the magnetic field.
- The magnetic field may be a factor supporting the nitrification process - especially when it is observed (in connection with change of the seasons) decline of the temperature during the process of biodegradation.

Acknowledgements

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Streszczenie

W pracy przedstawiono wyniki badań wpływu pola magnetycznego o indukcji 40 mT na przemiany związków azotu podczas oczyszczania ścieków metodą osadu czynnego. Badania prowadzono w niekorzystnej dla procesu nitryfikacji temperaturze - w 14 ± 1°C w skali laboratoryjnej w dwóch równolegle pracujących układach do hodowli osadu czynnego. W jednym z układów na przewodzie przeznaczonym do recyrkulacji osadu czynnego z osadnika wtór-

nego do komory napowietrzania zainstalowano jedną parę magnesów stałych. Badania wykazały, że przemiany związków azotu przebiegały efektywniej w układzie, w którym osad czynny okresowo eksponowano w polu magnetycznym w porównaniu z układem pozostającym poza wpływem pola magnetycznego. Zaobserwowano, że aktywność oddechowa bakterii II fazy nitryfikacji była wyższa o 1,6 do 2,1 razy w układzie z magnesami w porównaniu z kontrolą.

Słowa kluczowe: **pole magnetyczne, osad czynny, szybkość nitryfikacji**