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Effect of the Constant Magnetic Field on the Composition of Dairy Wastewater and Domestic Sewage

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Abstract

We investigated an effect of the direct impact of a constant magnetic field on wastewater properties modification. Wastewater from two sources (differing in physical and chemical properties) was used in the experiment. Analyses regarded the impact of a constant magnetic field on the properties of wastewater prepared from powdered milk and on the composition of sewage taken directly from municipal sewage system. The experiment was carried out in the laboratory scale with the use of the technological systems comprised of magnetic activators of liquids. An obvious and regular reduction was observed in COD (25-55%), chlorides (25–40%), N-NH_4 (50-66%), P-PO_4 to the values of 3.37-6.00 mg/dm^3, and a considerable increase of Fe concentration. The parameters of both magnetically-treated wastewater types were modified to a similar degree and displayed analogous modification tendencies.

Keywords: magnetic treatment of wastewater, magnetic field, magnetizer, wastewater treatment

Introduction

There is an actual need to seek factors intensifying the processes of pollutant degradation. Methods are sought to enhance the removal effectiveness of toxic substances, organic compounds resistant to biological degradation, and nutrients, but also having a positive effect on other parameters of wastewater.

Most necessary are such modifications that would allow limiting the application of chemical reacting substances and yet effectively remove pollutants [1]. More frequently the technological systems are introduced with physical factors. For instance, positive results can be obtained when treating wastewater with a periodical field of external oscillations, e.g. an acoustic, temperature field with defined parameters, as well as ultrasounds or UV-radiation [2, 3, 4].

One of the most important physical factors is the magnetic field. For a long time now, in numerous research centres investigations have been made in order to discover the mechanism of changes occurring in flowing solutions under an impact of this physical factor. However, the optimal conditions for magnetic activation of liquids are sought, and attempts made to determine the favourable technological effects of such treatment. Until now, there has been no uniquivocal explanation about the modifications mechanisms in the magnetically-treated wastewater.

Despite the limited information and data concerning magnetic preparation of wastewater, one may conclude that magnetizers may be one of the simpler and more economically justified ecological investments, having measurable effects [5, 6, 7, 8, 9, 10].

The aim of the presented experiment was to determine the impact of the constant magnetic field on the properties of wastewater with different physico-chemical

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Table 1. Course of the individual phases of the experiment.

Phase of the experiment	Phase I		Phase II	
Type of wastewater	dairy wastewater		domestic sewage	
Series	Series I	Series II	Series I	Series II
Detention time	24 h	48 h	24 h	48 h
Sampling frequency	2h 6h 12h 24h	6h 12h 24h 48h	2h 6h 12h 24h	6h 12h 24h 48h

Table 2. Technical parameters of the magnetic liquid activators applied in the experiment.

Parameter	Series I	Series II
total length	340 mm	680 mm
rated pipe diameter	150 mm	150 mm
volume	6.0 dm^3	12.0 dm^3
total liquid detention time in the direct-impact magnetic field	2 h 53 min.	5 h 46 min.
magnetic induction	0.4 – 0.6 T	0.4 – 0.6 T

parameters, while using different systems employing that physical factor.

Experimental Procedures

Synthetic wastewater was used in the experiments prepared from powdered milk, and typical sanitary sewage taken directly from a municipal sewage system. The experiments were run in two phases, on two research posts corresponding with the laboratory scale (Table 1). All analyses were done at the ambient temperature of 20ºC.

In both phases of the experiment the direct impact of constant magnetic field on the modification of the wastewater properties was determined with special regard to pollutant removal. Phase I regarded the wastewater prepared from powdered milk while phase II was grounded on the analysis of modifications of the domestic sewage properties. The individual series of the experiment differed with the liquid detention time in the system and with the size of the area exposed to the magnetic field activity. The set of one or two magnetic activators of liquids was applied (Table 2, Fig. 1, Fig. 2). Each series of the experiment was repeated four times and the averaged results are presented in the figures.

The experiments were conducted with the use of devices for magnetic activation of liquids (Fig. 1, Fig. 2). Each magnetizer consisted of a steel cylindrical body and a mag-

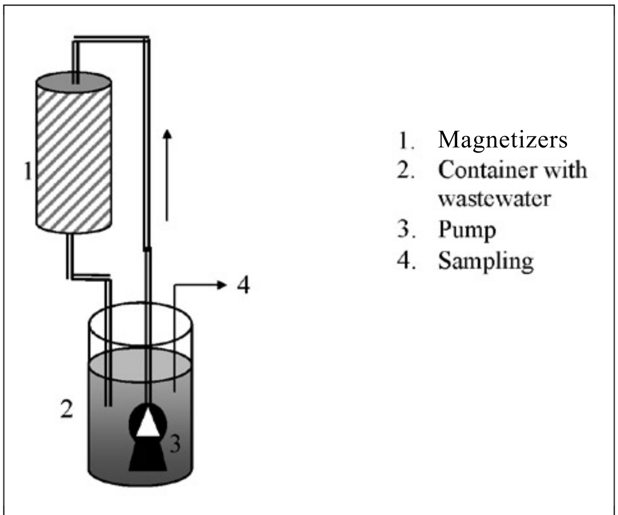

Fig. 1. Scheme of the experimental post in series I (phase I, II).

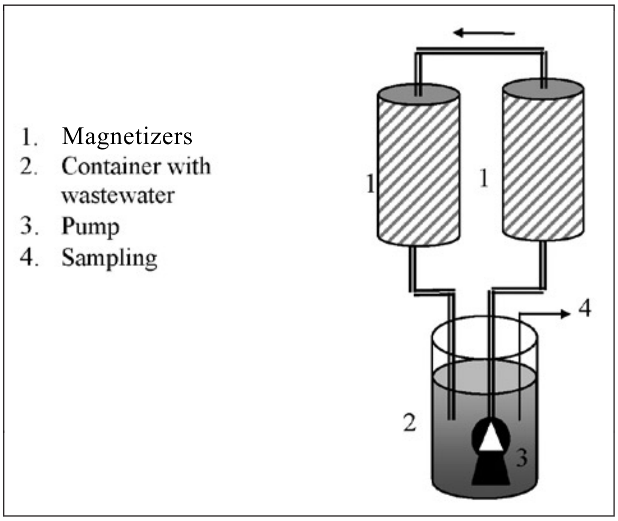

Fig. 2. Scheme of the experimental post in series II (phase I, II).

Table 3. Composition of raw wastewater applied in the experiment.

Parameter	Unit	wastewater prepared from powdered milk		domestic sewage	
		Series I	Series II	Series I	Series II
ammonium N	[mg $N\text{-}NH_4/dm^3$]	12.40	12.89	13.89	15.36
chlorides	[mg Cl/dm^3]	91.50	89.00	71.75	59.50
COD	[mg O_2/dm^3]	1935.36	2042.88	244.24	179.5
total acidity	[$mval/dm^3$]	0.61	0.60	0.94	0.82
reaction	[pH]	6.25	6.24	6.86	6.85
orthophosphates	[mg $P\text{-}PO_4/dm^3$]	37.00	63.00	48.85	34.00
electric conductivity	[S/m]	0.69	0.85	0.97	0.83
total hardness	[$mval/dm^3$]	7.60	7.80	6.66	6.18
total alkalinity	[$mval/dm^3$]	11.60	11.20	8.34	8.20
iron	[mg Fe/dm^3]	1.20	1.10	0.90	0.52

netic pile. The magnetic pile, made of permanent magnets, was generating a constant-induction magnetic field of an intensity between 0.4T and 0.6T. Depending on the series of the experiment, different sets of the magnetic activators of liquids were applied. The applied technological systems varied with the main technical parameters (Table 2).

Waste liquids subjected to the magnetic treatment were contained in a 50 dm^3 reactor and fed to the magnetizer with a submersible pump of 5000 dm^3/h delivery. That corresponds with a 100-time introduction of the examined solutions to the magnetic field activity zone in every hour of the experiment.

The physico-chemical analyses regarded the main pollution indicators such as: reaction, total alkalinity, total acidity, electrical conductivity, total hardness, chlorides, orthophosphates, iron, ammonium N, and COD. Before analyses the wastewater samples were filtered on filter paper.

Analyses of the parameter values in control samples of wastewater were taken into consideration in the experiment. Control samples of the domestic sewage and dairy wastewater were pumped over the system at the same capacity (5000 dm^3/h) and during the same time as the other series. The magnetic field was not used. Wastewater quality after magnetic treatment was compared with raw wastewater quality (i.e. wastewater not subjected to any treatment processes).

Results

The physico-chemical parameters of the waste liquids tested in the individual series of the experiment are presented in Table 3.

Minor changes of the measured wastewater parameters in control samples in the system without the magnetic field were observed. Effectiveness of COD removal from the wastewater prepared from powdered milk after 24 hours of the experiment was 5%. After 48 hours of the reaction an 11% decrease of COD was observed. The day-round pumping operation of domestic sewage without the magnetic activator resulted in about 8% reduction of carbon compounds. After 48 hours of the reaction the decrease of COD value ranged from 15% to 19%. $P\text{-}PO_4$ concentration changed depending on the kind of wastewater. It was found that the decrease of the $P\text{-}PO_4$ concentration ranged from 7% to 15% in wastewater prepared from powdered milk depending on the reaction time. After 24 hours of the experiment the effectiveness of $P\text{-}PO_4$ removal in the domestic sewage was on the level of 2%, after 48 hours 6% of the $P\text{-}PO_4$ reduction was observed. The effectiveness of the $N\text{-}NH_4$ removal in the control sample after 48-hour detention of dairy wastewater in the reactor was nearly 19%. As for the sanitary sewage the effectiveness of this parameter was 22%. Minor changes of other wastewater parameters in the control technological system were determined.

Raw wastewater prepared from powdered milk was highly concentrated. During the whole process of the physical factor impact (i.e. of the magnetic field), a regular decline tendency was observed in regard to chlorides, orthophosphates, ammonium N and carbon compounds (Fig. 3). Chlorides after 24 h of the reaction amounted to 70.42 mg/dm^3 (Fig. 4). The day-round passage of the wastes through the magnetic activator of liquids resulted in over 35% reduction of COD while the concentration of $P\text{-}PO_4$ was diminished to 6.00 mg/dm^3. As for reaction, total alkalinity and total acidity, the magnetic field had no considerable effect on these parameters (Figs. 5, 6). On the other hand, an obvious increase of iron concentration in the solution was noted. It was observable only after the first 2 hours of the magnetic treatment of the wastewater prepared from powdered milk. In the following experiments, the parameter's size was regularly growing and after 24 hours it was nearly 6 times higher than the initial value (Fig. 4).

In the second series, it has been determined whether expansion of the area exposed to the magnetic field acquired through the addition of an extra magnetizer, had caused more efficient removal of the pollutants. Moreover, the medium's detention time was extended to 48 h. As a result, a slightly higher efficiency of chlorides, COD and orthophosphates reduction was observed (Fig. 7, Fig. 8). However, it seems that the changes resulted directly from the extended detention time of the medium in the technological system, as the visibly better technological effect was determined after only 48 h of treatment. In the magnetically treated wastewater determined was: 37% reduction of chlorides, 43% decrease of COD content, and a high 90% reduction of P-PO_4. Concentration of N-NH_4

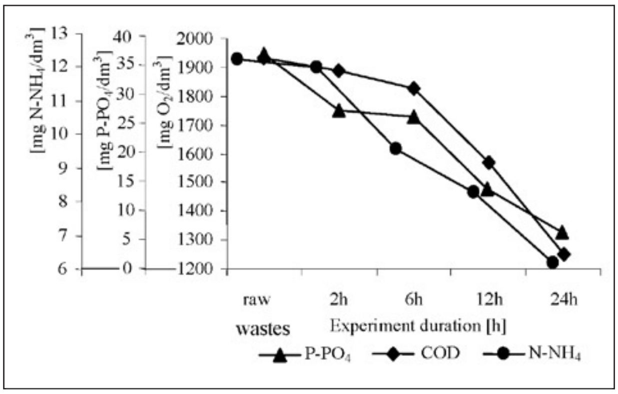

Fig. 3. Changes of COD, N-NH_4 and P-PO_4 values (phase I, series I).

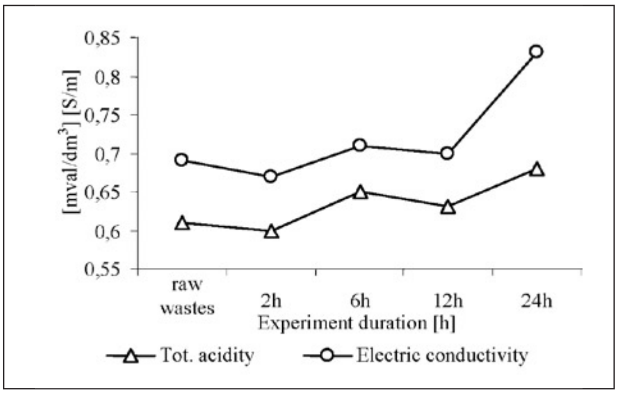

Fig. 6. Changes of total acidity and electric conductivity values (phase I, series I).

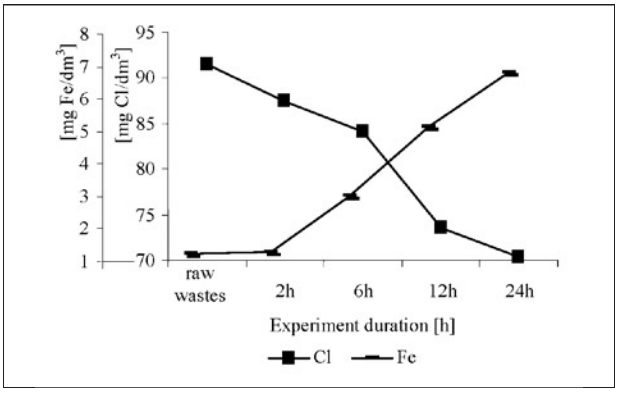

Fig. 4. Changes of Cl and Fe values (phase I, series I).

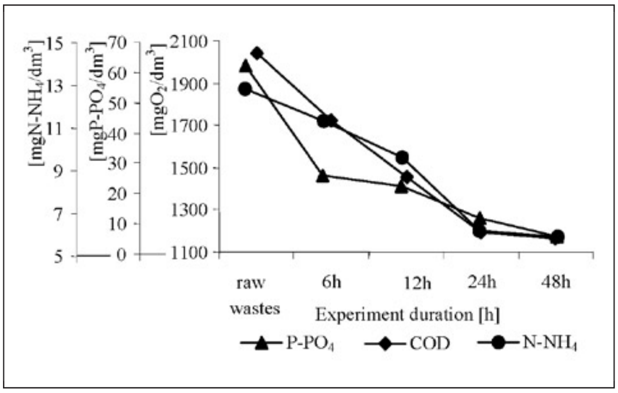

Fig. 7. Changes of COD, N-NH_4 and P-PO_4 values (phase I, series II).

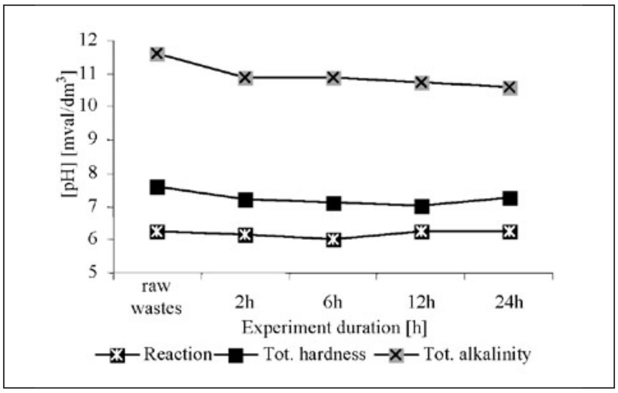

Fig. 5. Changes of reaction, total hardness and total alkalinity values (phase I, series I).

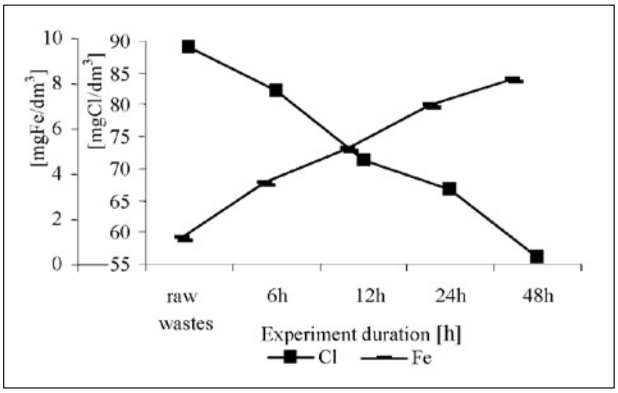

Fig. 8. Changes of Cl and Fe values (phase I, series II).

in the effluent equalled 5.94 mg/dm^3, at the initial value of 12.89 mg/dm^3. In the modified technological system, the other wastewater parameters changed to a minor degree (Figs. 9, 10).

The results obtained in the second phase (series I) with the domestic sewage application confirmed the impact of magnetic field on the modification of some properties of the polluted solutions (Figs. 11, 12). The decrease of chloride concentration was comparable to that obtained in the first phase of the experiment and equalled about 30%. In 24 h of the reaction, an effective, gradual decrease of COD value was noted. The initial concentration of organic compounds of 244.24 mg/dm^3 was limited to the level of 120.40 mg/dm^3, thus

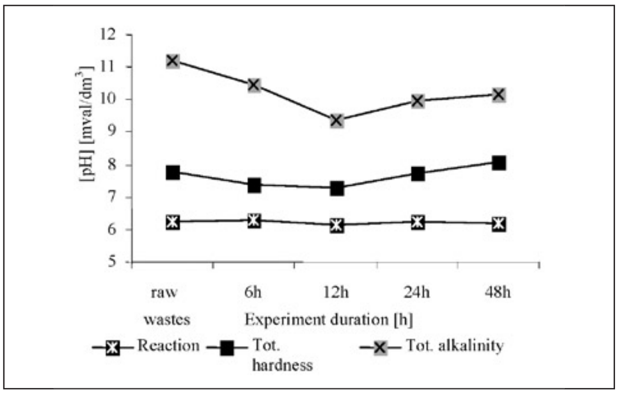

Fig. 9. Changes of reaction, total hardness and total alkalinity values (phase I, series II).

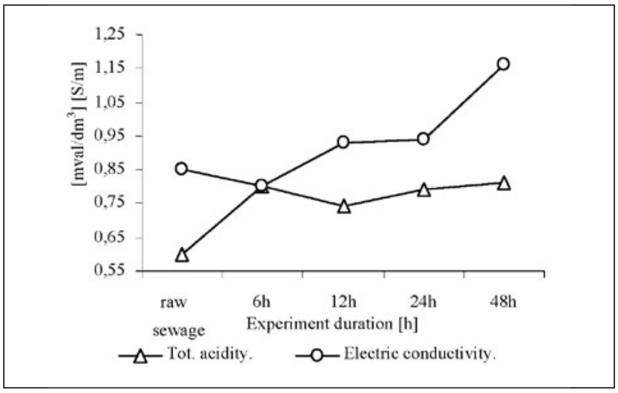

Fig. 10. Changes of total acidity, and electric conductivity values (phase I, series II).

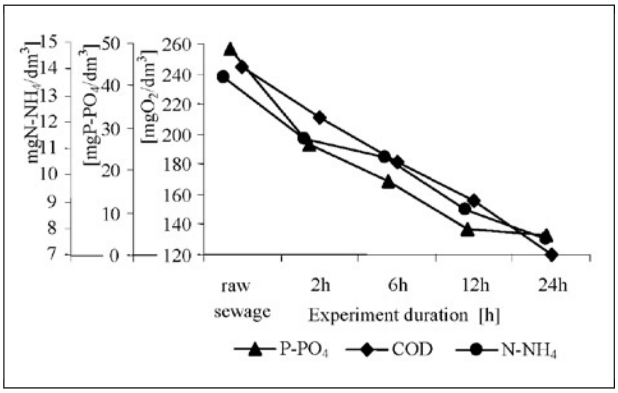

Fig. 11. Changes of COD, N-NH$_4$ and P-PO$_4$ values (phase II, series I).

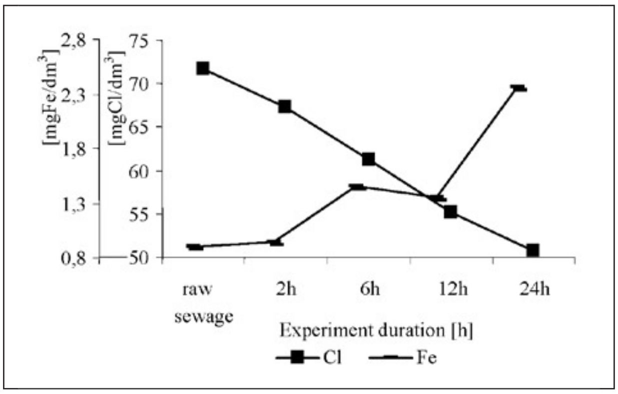

Fig. 12. Changes of Cl and Fe values (phase II, series I).

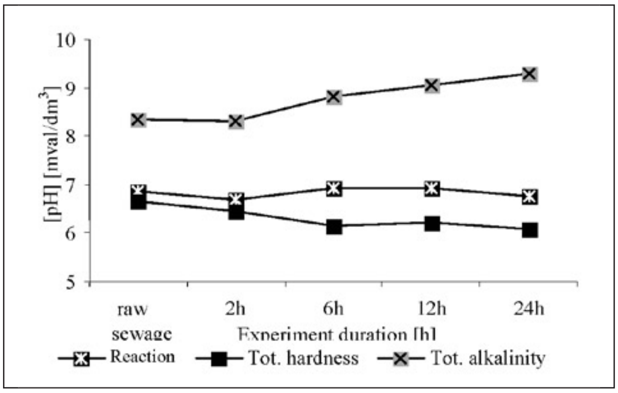

Fig. 13. Changes of reaction, total hardness, total alkalinity values (phase II, series I).

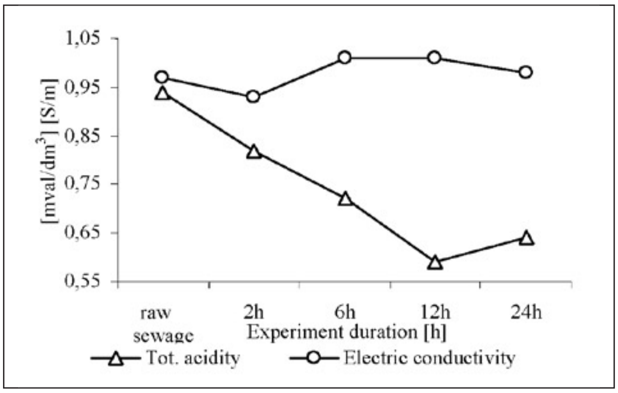

Fig. 14. Changes of total acidity and electric conductivity values (phase II, series I).

the reduction equalled about 50%. An intensive process was the reduction of $P\text{-}PO_4$ contained in the examined solution. Significant results of 87.7% were obtained after 12 h of the experiment duration. Further exposure of the sewage to the magnetic field resulted in a decrease of $P\text{-}PO_4$ to the level of 4.8 mg/dm^3. A nearly 50% reduction of $N\text{-}NH_4$ was determined in the sample after 24-hour detention in the reactor. Iron concentration in the sewage increased. The other measured parameters did not display any major changes (Figs. 13, 14).

Analysis of the results obtained in the second series confirmed the directions of the domestic sewage properties modifications. Effectiveness of chlorides and COD reduction after 24-hour detention in the technological system was similar to that obtained in the first series of the experiment (Fig. 16). After 48 hours of the reaction the values of 35.87 mg Cl/dm^3 and 80.84 mg O_2/dm^3 were measured while the initial concentrations equalled 59.50 mg Cl/dm^3 and 179.57 mg O_2/dm^3 (respectively). Relatively high was also the reduction of $P\text{-}PO_4$ at 90% reduction, the concentration was limited to 3.37 mg/dm^3. Magnetic treatment of the domestic sewage also stimulated a 67.4% reduction of the $N\text{-}NH_4$ (Fig. 15). The second series of the experiment resulted in the increase of iron concentration to the value of 3.02mg/dm^3 and minor oscillations of the other analyzed indicators (Figs. 17, 18).

Discussion of Results

The aim of the presented investigations was to determine the impact of the constant magnetic field on the quality of wastewater prepared from powdered milk and domestic sewage originating from a sewage system.

It is thought that modifications to the properties of solutions flowing through the magnetic field resulted from changes in the molecular structure of liquids, polarization and arrangement of particles, and finally from changes of the electric potential [8, 9, 10]. It has been proven that a strong magnetic field, with properly selected parameters, has an effect on such properties of liquids as: surface tension, density, viscosity, light extinction and wettability of solid substances. It is also said that those changes are mostly periodical and die-out gradually during a few seconds up to a few dozen hours, which is due to the flow turbulence and contact with the atmosphere. When secondary processes occur in the treated liquid, such changes

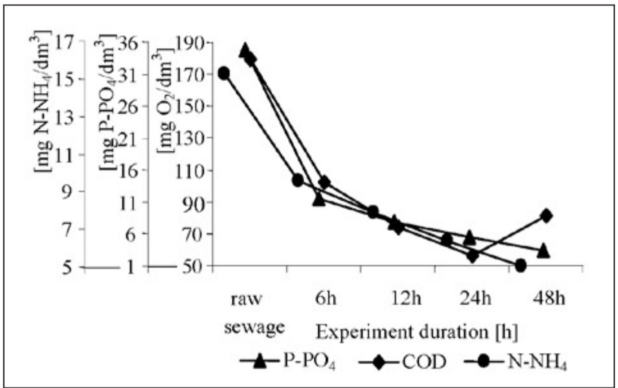

Fig. 15. Changes of COD, $N\text{-}NH_4$ and $P\text{-}PO_4$ values (phase II, series II).

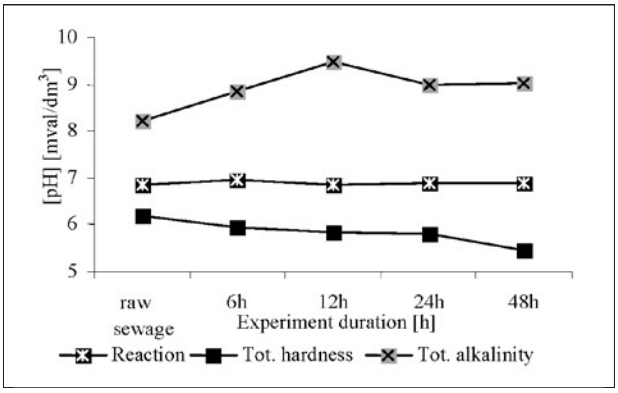

Fig. 17. Changes of reaction, total hardness and total alkalinity values (phase II, series II).

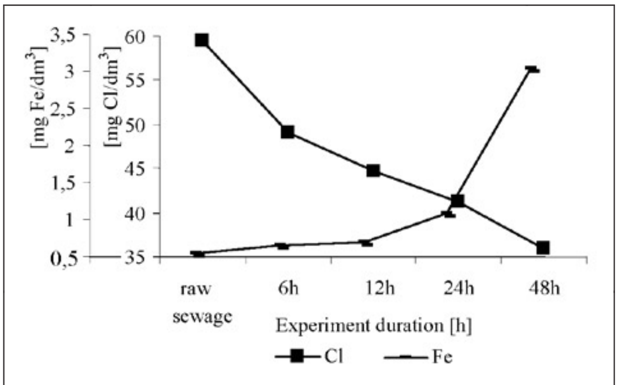

Fig. 16. Changes of Cl and Fe values (phase II, series II).

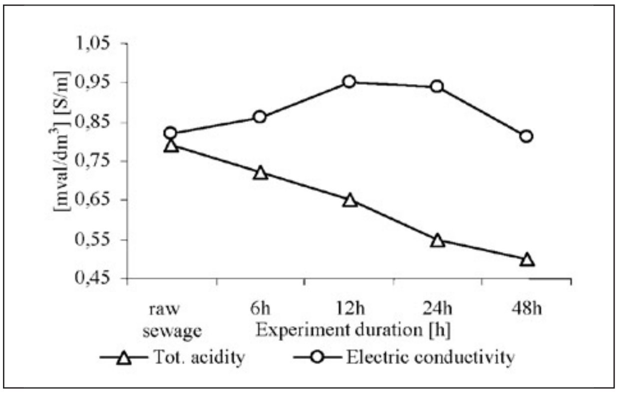

Fig. 18. Changes of total acidity and electric conductivity values (phase II, series II).

are irreversible [5, 6, 7, 10]. Most of the tests conducted hitherto with the magnetic field application have regarded the impact of this factor on water properties [5, 6, 7, 11].

The present study attempts to determine the impact of the magnetic treatment on wastewater properties modification, with special regard to the contained pollutants. The effectiveness of the technological systems consisting of magnetic activators of liquids was analyzed. The parameter whose concentration clearly varied was organic matter. The COD-values were systematically decreasing in both types of examined wastewater, along with the time of the experiment duration.

The reason for the reduction may have been degradation at the contribution of atmospheric oxygen. A confirmed effect of water and wastewater magnetic preparation is the modification of the contained gases concentration. Magnetization of tap water allows it to achieve its full oxygenation capacity. Likewise, in municipal sewage such treatment considerably increases oxygen concentration. Magnetized solutions are characteristic among others of the diminished surface tension and in contact with the atmosphere adsorb the paramagnetic particles of oxygen; eventually their concentration in water solutions increases. High concentrations of the molecular oxygen in the analyzed wastewater may have accelerated the processes of organic matter degradation, especially since the compounds resistant to degradation were absent in that case [9, 10].

The phenomenon of effective penetration of the atmospheric oxygen into the solutions prepared with the magnetic field is advantageous from another point of view. Most microorganisms breaking down the organic compounds are aerobic by nature. Thus, in the magnetized liquids, with increased oxygen concentration, their growth is more intense and so is the degradation of organic matter [9, 10, 11, 12, 13]. The relatively long detention time in the technological system, which in the second phase amounted to 48 hours, may have positively stimulated and determined the growth of some microorganism groups. It seems that the proliferating bacterial biomass may have taken up the organic substratum present in the magnetically-treated wastewater, which has been confirmed by laboratory studies of biological degradation of organic compounds introduced in the magnetic-activity area. It was revealed that within the induction range of 0.005-0.14 T the constant magnetic field intensifies biological degradation processes by activated sludge of most of the tested organic compounds and pollutants contained in wastewater. It was also confirmed that the magnetic field's effect on organic compound degradation continues for about 12 hours after termination of exposure [9].

Likewise, it was evidenced that magnetic activation of liquid and gaseous fuels allows for selective oxygen saturation of the fuel mixture in the unrestricted flow zone. Therefore, the combustion conditions for such mixture are nearly optimal, which can be proven by a radical reduction of toxic substances in exhaust gases and more economic fuel consumption [10].

Another phenomenon which may occur under the impact of magnetic field is the intensification of free radicals formation. High reactivity and high oxidation potential of those chemical compounds may have effectively reduced the concentration of organic matter contained in the analyzed liquids. The process of water molecule disintegration with the formation of free radicals takes place when sufficient energy has been provided [8]. In the AOP it can be obtained through UV-radiation or gamma-radiation [2, 4, 8].

These reactive molecules are formed during the homolytic dissociation of bonds or as a result of electrons transfer between the molecules of chemical compounds. Free radicals have one or more unpaired electrons, which explains their extreme reactivity. Through intersystem crossing they often enter a configuration which stimulates bond creation between the radicals. However, this process can be hindered by relatively weak magnetic fields, which in effect reduces the number of radicals transformed into the singlet state, with parallel preservation or increase of their total number. Therefore, the magnetic waves are regarded as a factor which has direct influence on the total concentration of free radicals in a solution [8, 14].

The impact of magnetic field on the rate and number of generated hydroxyl radicals in Fenton reaction was determined in an experiment analyzing the variations of sodium sulphite concentration in a deoxidised solution. The results have shown that a magnetic field has much effect on the number of generated hydroxyl radicals. It was observed that application of the magnetic field increased the oxidation rate by more than 10 times in comparison to the system applying only the chemical reactants [8].

The reference literature is not supportive in explaining the direct mechanisms responsible for orthophosphate removal under the impact of the magnetic waves. Nonetheless, the importance of the electromagnetic field for intensification of iron corrosion, in relation to phosphorus reduction has been determined [1]. In the experiment, wastewater prepared from bullion stock was used. The electromagnetic waves were generated by the passage of current (of a definite intensity) through an electromagnetic inductor. The passing current, having an impact on the metallic medium, was stimulating intensive iron corrosion and migration of the iron ions to the solution. As a result, very efficient coagulation was observed and orthophosphates precipitation in the form flocs resistant to dissolving [1]. Moreover, it was noted that such a technological system had a positive effect on the reduction of carbon compounds contained in the treated wastewater.

It seems that a similar mechanism may have worked in the experiment on the domestic sewage and the wastewater prepared from powdered milk. A magnetiser was applied with permanent magnet piles. Such magnetiser consists of a cylindrical steel casing with magnetic inserts. The media pass through the space between the magnets and in consequence through the field of force induced by the permanent magnets. The piles are exposed to long, direct contact with the passing solutions. This may lead to corrosion and eventually to migration of the iron molecules to the medium and orthophosphates bonding. Obviously, the process is technologically favourable although very unwelcome from the viewpoint of the operation time of the magnetizers.

The efficient coagulation induced by the magnetic field may also have positively influenced the bonding and removal of phosphates. It has been proven that the physical factor modifies the electrokinetic potential [10] and influences the coagulation process [15]. The electrokinetic potential of water equals about 70 mV. In such conditions, the colloids contained in water are stable and coagulation does not occur. Change of the value to about 30 mV, achieved by the addition of a relevant electrolyte or colloid with opposite sign, initiates slow coagulation. When the electrokinetic potential approaches the zero value, rapid coagulation is observed [3]. Having the above in mind, one may conclude that the coagulation process in solutions can be initiated by magnetic waves having the effect on a flowing liquid without the application of any supporting chemical agents. The survey on the magnetic treatment impact on the physico-chemical properties of municipal sewage has revealed that the time of complete sedimentation in the magnetically-prepared wastewater was considerably shorter than in the system without the magnetic activation. Additionally, a tendency was observed for fine sludge particle coagulation in the magnetically-prepared wastewater which eventually accelerates sedimentation and increases the dewatering capacity [9,10].

Easily-available orthophosphates may have also been used by the microorganisms present in the prepared liquids, for growth and development. Irrespective of which of the presented mechanisms had determined removal of this chemical factor, it should be concluded that the process was relatively fast and efficient.

Reduction of the ammonium N may have been stimulated by a few factors resultant of the magnetic field activity. Magnetized liquids are characteristic of diminished surface tension, which in connection with the increase of oxygen concentration may have provoked expelling of the ammonium N to the atmosphere. Activation of the oxidation process induced by the preparation of the liquid with this physical factor might have also limited the presence of this form of nitrogen. Thirdly, in case of sufficient oxygen concentration in the solution and development of aerobic microorganisms, very possible is the nitrification and transformation of ammonium N into nitrites and nitrates.

Magnetic treatment of liquids introduces oxygen to the prepared medium and removes the gases with higher atomic weight. It has been revealed that in the municipal wastewater the introduction of magnetic field to the technological system allowed for carbon dioxide, ozone, hydrogen sulphide and chlorine reduction [10].

Until the present, the method of the magnetic treatment of liquids has been recommended for use mainly in the systems suffering from scaling (caused by medium's flow, heating up and heat exchange) or internal corrosion of installations and containers. It was explained by the fact that treatment of water solutions of salts by the magnetic field causes crystallisation not on the metallic walls of the installations but in the whole water volume, and the so-created suspension has no cementing properties [5, 6, 7]. Nonetheless, it seems that the application of magnetic treatment of liquids should be more widespread, as properly adjusted process parameters can positively influence many other physico-chemical parameters of the treated liquids, including wastewater.

Conclusions

- Quality of both types of the examined wastewater was modified to a similar degree and revealed analogous variation tendencies.
- Obvious and regular reduction was observed concerning organic matter (25-55 %), chlorides (25–40 %), ammonium N (50-66 %), and orthophosphates (to the value of 3.37-6.00 mg/dm^3).
- Iron concentration in wastewater increased along the experiment course, up to 2.35-8.10 mg/dm^3.
- The parameters such as: reaction, total alkalinity, total acidity, electric conductivity, total hardness, and colour were subjected to small oscillations.
- Extension of the wastewater detention time in the technological system has increased the efficiency of pollutant removal.
- Introduction of an additional magnetizer to the system had no effect on the size of the wastewater quality changes.

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