ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 31 no. 4 pp. 17 - 32 2005

PL ISSN 0324-8461

THE INFLUENCE OF FENTON REACTION ON THE EXCESS SLUDGE SANITATION

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Keywords: sewage sludge, Fenton's reaction, sanitation, stabilization, advanced oxidation process.

WPŁYW REAKCJI FENTONA NA PROCESY HIGIENIZACJI NADMIERNYCH OSADÓW ŚCIEKOWYCH

W eksperymencie analizowano możliwość zastosowania reakcji Fentona w procesie higienizacji osadów ściekowych. Badania przeprowadzono w trzech etapach, przy wykorzystaniu stanowisk odpowiadających skali laboratoryjnej. Określono wpływ dawki reagentów chemicznych (jonów Fe^{2+}, H_2O_2, układu Fe^{2+}/H_2O_2) na ostateczny efekt technologiczny. Analizy mikrobiologiczne dotyczyły bakterii z grupy *coli*, bakterii *coli* typu kałowego, przetrwalnikowych form *Clostridium perfringens* oraz bakterii z rodzaju *Salmonella*. W surowym osadzie nadmiernym koncentracja bakterii z grupy *coli* wynosiła 4,7 · 10^6 NPM/g s.m., bakterii *coli* typu kałowego 3,2 · 10^6 NPM/g s.m. oraz przetrwalnikowych form beztlenowców *Clostridium perfringens* 1,2 · 10^4 JTK/g s.m. Stwierdzono również obecność bakterii z rodzaju *Salmonella*. Najskuteczniejszą metodą higienizacji analizowanych osadów ściekowych okazało się zastosowanie techniki pogłębionego utleniania. W wariancie najskuteczniejszym liczbę bakterii z grupy *coli* ograniczono do 6,2 · 10^1 NPM/g s.m., a beztlenowców do 4,9 · 10^4 JTK/g s.m. W tym przypadku nie stwierdzono bakterii z rodzaju *Salmonella*. Skuteczność prezentowanej technologii rosła wraz z kolejnymi dawkami reagentów chemicznych wprowadzanych do układu.

Summary

Fenton reaction was investigated for its potential to improve the sanitary effects of the excess sludge from wastewater treatment plants. The investigations were conducted in three phases, on laboratory-scale experimental stands. The importance of Fenton's reagents doses, ferrous sulphate and hydrogen peroxide doses as independent agents influencing the technological effects were determined. Microbial analysis concentrated on *coli* form bacteria, faecal *coli* form bacteria, anaerobic endosporous form of *Clostridium perfringens* and microorganisms of *Salmonella* genus. In activated sludge not exposed to chemical treatment, the number of *coli* form bacteria was approximately on the level of 4.7 · 10^6 MPN/g d. m., faecal *coli* forms 3.2 · 10^6 MPN/g d. m., however, anaerobic endosporous form of *Clostridium perfringens* was on the level of 1.2 · 10^4 CFU/g d. m. *Salmonella* microorganisms were present.

The most effective method to improve the sanitary effects of the excess sludge was advanced oxidation process (AOP). The best results revealed that the number of *coli* forms was reduced to 6.2 · 10^1 MPN/ g d. m. and anaerobic forms to 4.9 · 10^1 CFU/g d. m. *Salmonella* did not appear in the sludge. The efficiency of the presented method depended directly on chemical reagent doses.

INTRODUCTION

Wastewater treatment plant operation is closely related to the need for proper sludge management. Sludge generated in wastewater treatment processes must be subjected to processing and afterwards reused or disposed of [23]. Despite the considerable progress in past years regarding the technologies and methods of the sludge treatment, the question of the effective neutralization remains open. This problem is more and more difficult to solve because the amount of sludge systematically increases, and the quality rarely corresponds with the environmental protection requirements. Progress in sludge generation results from the high number of the new wastewater treatment plants and the requirements concerning the quality of treated wastes [7, 14, 23, 33].

Presence of pathogen organisms in sewage sludge is really hazardous for natural environment and is one of the most relevant problems of sanitary menace. It has to be taken into consideration at sewage neutralization [14, 17, 27]. Stabilized sludge composition is chemically favorable, has soil-forming features and generally dewatering is easy. However, besides these desirable features the sludge is usually settled by microorganisms involving bacteria, viruses, parasites, fungi, protozoan ect. Pathogen microorganisms, dangerous for people and saprophytic ones neutral from the sanitary point of view can be present there [14, 17].

The most common methods of sludge management such as anaerobic or aerobic stabilization, liming dos not let obtain completely safe products in the respect of sanitary effects. Biological pollutants leaching to the soil disturb biocenotic balance and are potentially hazardous for other organisms [7, 14, 19, 35]. The composition of sludge from municipal wastewater treatment plants is complex. The sludge consists of pathogens not only from the sick or disease carriers but also from landfills, slaughterhouses and other sources such as trade, industry and agriculture. The pathogens reach wastewater treatment plants and get out during treatment process [17].

Needed most of all are modifications and changes to the currently practiced, ones moreover, search and study at new, effective and cheap solutions determining environmentally hazardous substances removal. The operations should effectively improve sludge dewatering parameters, decrease mass of the sludge, remove organic substances susceptible to putrefaction and diminish the number of pathogenic and parasitic organisms [19, 23].

In wastewater treatment alternative methods versus commonly applied in contaminant removal make use of chemical methods mainly advanced oxidation process (AOP) [5, 23]. One of the methods of AOP is Fenton reaction that occurs while using hydrogen peroxide (H_2O_2) and iron ions as a catalyst of the process. The reaction leads to catalysis break-down of hydrogen peroxide in presence of ferrous ions Fe^{2+} which results in free radicals generation $OH^{\cdot}$, with high oxidizing potential of 2.8 V [5].

The aim of the study was to assess the AOP with Fenton's reagents on sanitary effect of the excess sludge. Moreover, the results were compared with methods using merely sludge conditioning with ferrous ions and hydrogen peroxide.

MATERIALS AND METHODS

In presented study raw excess sludge from wastewater treatment plant was used. Physico-chemical and microbial parameters of the sludge are shown in Table 1. The investigations were conducted in three phases; on laboratory-scale experimental stands at the ambient temperature ranging from 19°C do 22°C.

Table 1. Characteristic of the sewage sludge used in the experiment

Parameter	Unit	Min	Max	Mean
Hydration	[%]	96.23	95.72	95.97
Filtration resistivity	[kg/m]	$1.732 \cdot 10^{12}$	$3.410 \cdot 10^{12}$	$2.571 \cdot 10^{12}$
CSK	[s]	386	525	455
Dry mass	[g/dm^3]	37.690	42.780	40.235
Mineral fraction	[g/dm^3]	12.700	16.820	14.760
Volatile fraction	[g/dm^3]	23.150	27.520	25.335
COD of the filtrate	[mg O_2/dm^3]	267.8	549.4	408.6
P-PO_4 of the filtrate	[mg P-PO_4/dm^3]	176.7	284.2	230.4
N_{tot} of the filtrate	[mg N/dm^3]	316.8	401.4	359.1
N-NH_4 of the filtrate	[mg N-NH_4 /dm^3]	253.5	379.8	316.6
Reaction	[pH]	6.70	7.52	7.1
Coliform bacteria	[MPN/g d. m.]	$4.3 \cdot 10^6$	$5.1 \cdot 10^6$	$4.7 \cdot 10^6$
Faecal coliforms	[MPN/g d. m.]	$3.0 \cdot 10^6$	$3.4 \cdot 10^6$	$3.2 \cdot 10^6$
Clostridium perfringens	[CFU/g d. m.]	$1.0 \cdot 10^4$	$1.4 \cdot 10^4$	$1.2 \cdot 10^4$
Salmonella sp.	-	+	+	+

+ present in the sewage sludge

The research phases varied from the type of chemical reagents supplied to the technological system. Depending on the experimental phase the following substances were doze to the analyzed sewage sludge:

- Phase I – ferrous ions (Fe^{2+}) in the form of $FeSO_4 \cdot 6H_2O$,
- Phase II – hydrogen peroxide (H_2O_2) in the form of 30% perhydrol dilution,
- Phase III – ferrous ions (Fe^{2+}) in form of $FeSO_4 \cdot 6H_2O$ and hydrogen peroxide (H_2O_2) in form of 30% perhydrol dilution – Fenton's reagent.

The applied doses of the reacting substances are shown in Table 2.

Each experimental phase was divided into six technological variants varied from chemical substances doses applied in the system. Doses of reacting substances were chosen on the basis of preliminary experiment and literature data [12, 13, 23–26].

Table 2. Chemical reagents doses used in the experiment

Dose	Phase I		Phase II		Phase III			
					Fentons reagents			
	Fe^{2+} [g/dm^3]	Fe^{2+} [g/g d. m.]	H_2O_2 [g/dm^3]	H_2O_2 [g/g d. m.]	Fe^{2+} [g/dm^3]	Fe^{2+} [g/g d. m.]	H_2O_2 [g/dm^3]	H_2O_2 [g/g d. m.]
1	0.25	0.006	1.00	0.023	0.25	0.006	1.00	0.023
2	0.50	0.012	2.00	0.045	0.50	0.012	2.00	0.045
3	0.75	0.018	3.00	0.07	0.75	0.018	3.00	0.07
4	1.00	0.024	4.00	0.09	1.00	0.024	4.00	0.09
5	1.50	0.036	6.00	0.14	1.50	0.036	6.00	0.14
6	2.00	0.048	8.00	0.18	2.00	0.048	8.00	0.18

The researches were carried out in the model laboratory reactors with the working volume 1.5 dm^3. The reactors were fitted out with magnetic stirrer (Fig. 1). In each technological variant, dry mass analyzed sludge was corrected to 43.00 g/dm^3 in the first step and next chemical substances were dosed to the system

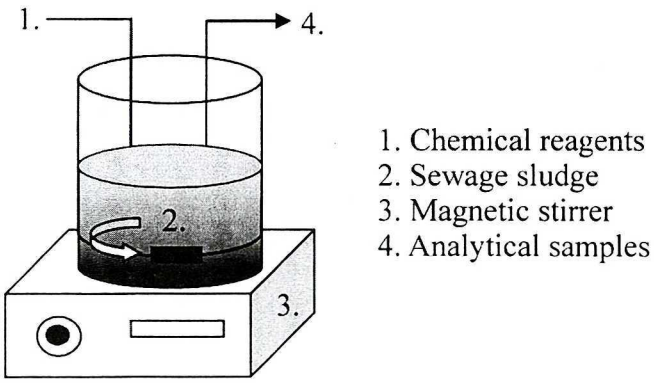

Fig. 1. Scheme of the experimental stand

At the beginning of the experimental cycle tested sewage sludge was supplied into the reactor in the amount of 1.0 dm^3 and then chemical reagents were dozen. In the case of third phase a ferrous ion were dozen firstly to the mass of sewage and after 10 minutes hydrogen peroxide, at a stable weight ratio of iron to hydrogen peroxide 1:4, was supplied. During initial 30 minutes of the experiment sewage sludge was mixed by means of magnetic stirrer at the rotation speed of 200 r/min. in order to obtain even concentration of the chemical reagents in the whole sludge mass. After that period sludge with reacting substances was left without stirring.

Sewage sludge retention time was 24 h. Samples were taken directly from the reactors at the beginning of the cycle before reacting substances had been applied to the system and then after 24 h of the reaction time. Sewage sludge was assayed for the following:

– *Coli* form bacteria,
– Faecal *coli* form bacteria,
– *Salmonella sp.*,
– Endosporous form of *Clostridium perfringens.*

Coliforms and faecal coliform bacteria from sludge samples were determined according to PN-EN-ISO 9308-1:2002(U). Samples were inoculated and incubated on lauryl-sulphate broth; the ability to gas production was checked. Incubation was carried out at the temperature of 37°C (48 hours) for *coli* form bacteria and at 44.5°C (24 hours) for faecal coliforms.

Presence of *Salmonella* sp. bacteria on the afore-mentioned media was determined after previous culturing of 100 cm^3 water in bullion with tetrathionate according to Müller-Kauffman (Merck) for 24 hours at 37°C. *Salmonella* sp. bacteria were analyzed on their capability to produce flagellar antigen using agglutinating serum for HM antigen (Biomed). They were finally identified by API 20E tests (bioMerieux).

In order to determine anaerobic spore-forming and sulphite reducing bacteria of *Clostridium perfringens*, sewage sludge was analyzed according to PN-EN-ISO 2646-1:2002. Bacteria were inoculated and incubated on Wilson-Blair's broth in anaerobic jars, using AnaeroGen (OXOID) for the generation of anaerobic conditions. Bacteria surrounded by black precipitate of ferric sulphide were counted.

RESULTS

In presented study it was shown that in the analyzed sludge not affected by chemical parameters the most probable number of *coli* form bacteria was approximately on the level of $4.7 \cdot 10^6$ MPN/g d. m., faecal coliforms – $3.2 \cdot 10^6$ MPN/g d. m., however, anaerobic endosporous form of *Clostridium perfringens* was on the level of $1.2 \cdot 10^6$ CFU/g d. m. Microorganisms *Salmonella* were present (Table 1).

During the experiment the most efficient method of the excess sludge sanitation was application of AOP. The reduction effectiveness of the number of coliforms and *Clostridium perfringens* correlated with the increasing reagents doses (Fig. 4). In the first variant, the application of 0.25 g Fe^{2+}/dm^3 and 1.0 g H_2O_2/dm^3 revealed that the number of faecal coliforms was $5.1 \cdot 10^4$ MPN/g d. m. as for *coli* form bacteria $1.0 \cdot 10^5$ MPN/g d. m., however for *Clostridium perfringens* it was $7.2 \cdot 10^3$ CFU/g d. m. (Fig. 4, Fig. 7). It was visible that at this dose of Fenton's reagents bacteria from *Salmonella sp.* genus were present. *Salmonella sp.* was eliminated from the sludge in variants with reagents doses above 0.50 g Fe^{2+}/dm^3; 2.0 g H_2O_2/dm^3 (Table 3). Reduction effectiveness of coliforms increased with chemical reagents doses, however in the range from 1.0 g Fe^{2+}/dm^3; 4.0 g H_2O_2/dm^3 to 2.0 g Fe^{2+}/dm^3; 8.0 g H_2O_2/dm^3, final results were comparable (Fig. 4).

The lowest number of anaerobic cells $4.9 \cdot 10^1$ CFU/g d. m. was observed at Fenton's reagents doses on the level of 2.0 g Fe^{2+}/dm^3; 8.0 g H_2O_2/dm^3 (Fig. 7). The application of the highest Fenton's reagents doses to stabilized sludge let obtain $2.2 \cdot 10^2$ MPN/g d. m. of faecal coliforms and $6.2 \cdot 10^2$ MPN/g d. m. of coliforms (Fig. 4).

The results of the sewage sludge sanitation with the application of inorganic coagulant

or hydrogen peroxide as a single sanitation substances were not so satisfactory (Fig. 2). Application of only ferrous ions resulted in inefficient reduction of both *coli* form bacteria and endosporous form of *Clostridium perfringens* (Fig. 2, Fig. 5). The most effective variant let achieve $8.4 \cdot 10^5$ MPN/g d. m. of coliforms and $5.9 \cdot 10^5$ MPN/g d. m. of faecal coliforms (Fig. 2). The obtained results stand out of the data observed for sewage sludge stabilization by AOP. The data have revealed that the results were worse with relation to the values determined as for sludge chemically untreated. Coliform bacteria were on the level of $4.7 \cdot 10^6$ MPN/g d. m. and faecal coliforms $3.2 \cdot 10^6$ MPN/g d. m. (Table 1). Application of only inorganic coagulant to sludge mass had an insignificant influent on change in endosporous form of *Clostridium perfringens* (Fig. 5). None of tested technological variants with inorganic coagulant allowed the reduction of bacteria from genus of *Salmonella sp.* (Table 3).

Hydrogen peroxide used in phase II did not let obtain the final results comparable to the results with the application of Fenton's reagent (Fig. 3, Fig. 6). Sanitation degree was higher than observed in the first phase of the experiment. In the case of the highest dose of oxidizing agent coliforms were reduced to $1.0 \cdot 10^4$ MPN/g d. m., however anaerobic organisms to $1.2 \cdot 10^3$ CFU/g d. m. (Fig. 3, Fig. 6). In variants with the application to sewage sludge of hydrogen peroxide in the amount ranging from 6.0 g H_2O_2/dm^3 to 8.0 g H_2O_2/dm^3 bacteria from genus of *Salmonella sp.* were not present (Tab. 3).

Table 3. Presence of *Salmonella* in analyzed sewage sludge depending on the phase of the experiment and chemical reagents doses

Phase I Fe^{2+}	Dose [g Fe^{2+}/dm^3]	0.25	0.50	0.75	1.00	1.50	2.00
	Salmonella sp.	+	+	+	+	+	+
Phase II H_2O_2	Dose [g H_2O_2/dm^3]	1.00	2.00	3.00	4.00	6.00	8.00
	Salmonella sp.	+	+	+	+	-	-
Phase III Fentons reagent	Dose [g Fe^{2+}/dm^3] [g H_2O_2/dm^3]	0.25 1.00	0.50 2.00	0.75 3.00	1.00 4.00	1.50 6.00	2.00 8.00
	Salmonella sp.	+	+	-	-	-	-

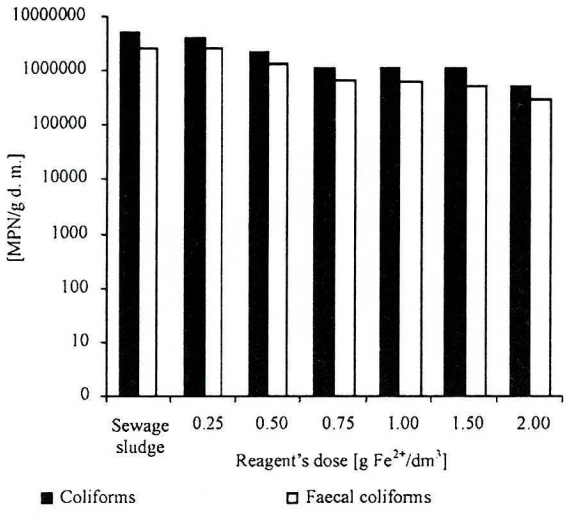

Fig. 2. Reduction of MPN coliforms and faecal coliforms in the excess sludge in phase I

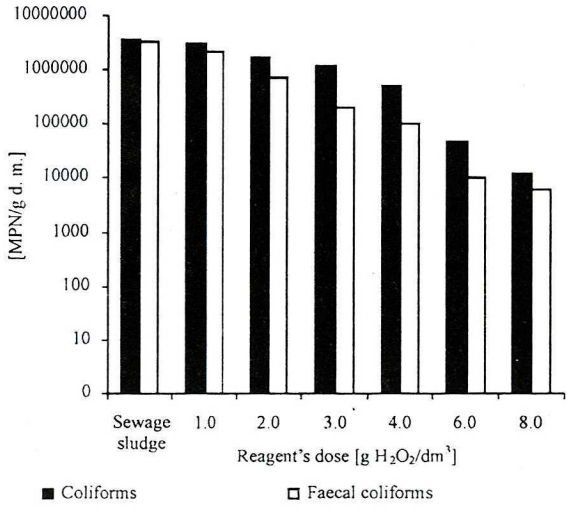

Fig. 3. Reduction of MPN coliforms and faecal coliforms in the excess sludge in phase II

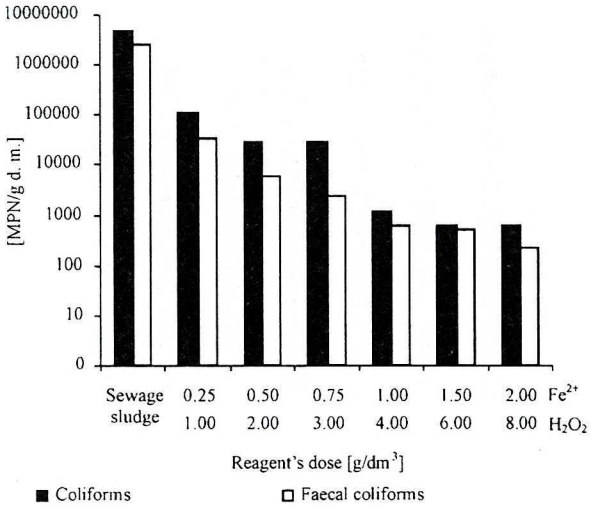

Fig. 4. Reduction of MPN coliforms and faecal coliforms in the excess sludge in phase III

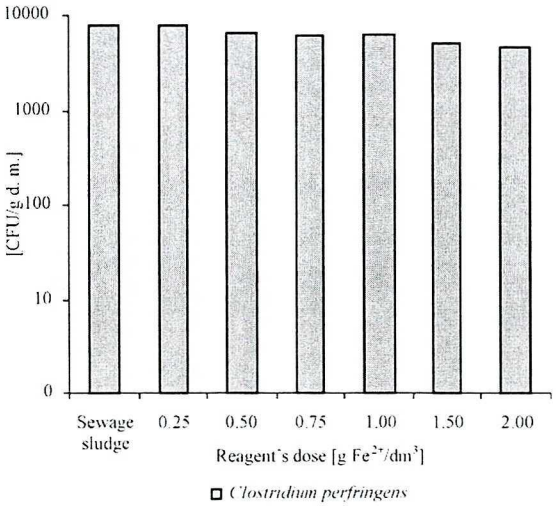

Fig. 5. Reduction of CFU *Clostridium perfringens* in the excess sludge in phase I

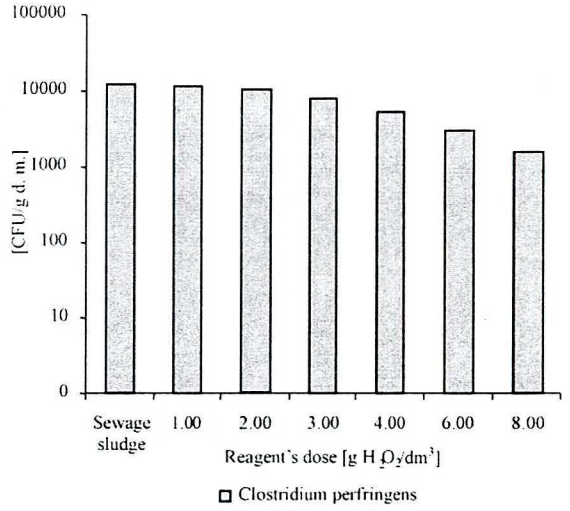

Fig. 6. Reduction of CFU *Clostridium perfringens* in the excess sludge in phase II

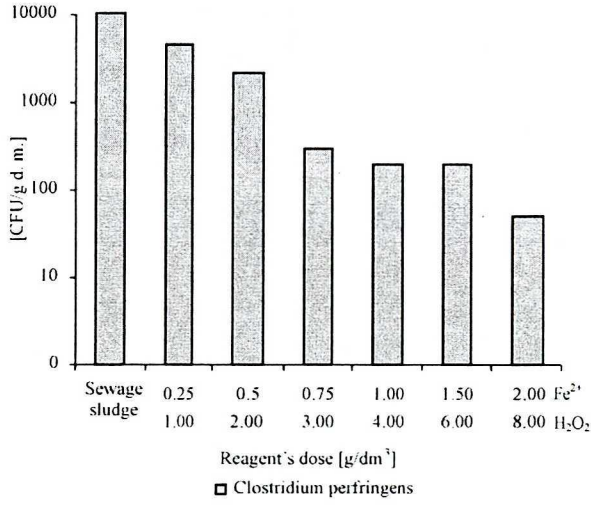

Fig. 7. Reduction of CFU *Clostridium perfringens* in the excess sludge in phase III

DISCUSSION

The technologies commonly used for wastewater treatment lead to insignificant reduction of pathogen organisms. Most of pathogens are adsorbed on faecal particles or go inside flocs and in this way during sedimentation they become part of sewage sludge [7]. Sludge makes up concentrate of pathogen organisms. There is need to make an assumption that the sludge leaving wastewater treatment plant after conventional treatment process has to be classified as potentially hazardous from the sanitation point of view. Needed most of all are development and implementation of modern, efficient and economical technologies and methods leading to highly effective sewage sludge sanitation [14, 19].

Methods currently used on technical scale are anaerobic stabilization under higher temperature, aerobic stabilization and chemical stabilization with the lime [1, 2, 11]. Anaerobic conditions of sewage sludge degradation affect destructive on pathogen organisms. The mechanism of the process is not commonly known. Probably, there is a comprehensive interaction of the physical, chemical and biological factors. Special importance is attached to antagonistic interaction in a native microflora. High temperature is undoubtedly very important as destructive property for biotic function of pathogenic microorganisms [3, 27]. However, under mesophilic conditions pathogens reduction is limited. Both vegetative and endosporous forms of microorganisms and viruses are resistant to this method of sanitation [15, 19, 38].

Higher efficiency of pathogens elimination under mesophilic conditions can be obtained in a two-stage process of sewage sludge decomposition. Effective results of sanitary indicators reduction such as faecal coliform bacteria, *Escherichia coli*, faecal *streptococcus* and *Ascaris* eggs were observed [27]. Better results were achieved in a two-stage thermophilous process and especially high reduction of analyzed pathogens was shown in acid phase of the fermentation. In this case lots of data were below a detectable level [9, 27].

Chemical stabilization with lime is the process that occurs while using reagents in form of CaO in the amount causing an increase in the reaction to 12 pH or more and maintaining such conditions for 2 h. Additionally, rapid temperature increase in sludge mass is observed in the process because hydration of calcium oxide is an exothermic reaction. The temperature increase of the sludge mainly depends on hydration degree. As a result of sludge and lime mixing, the reaction and temperature usually make it possible to obtain sludge with sanitary safe amount of pathogenic bacteria, viruses, helminthes and mould. Moreover, more water evaporates from the sludge because the mixture temperature is higher than the temperature of the surrounding. However, the reaction (pH) decrease at long storage of sludge stabilized by lime is observed in the case of fixation of carbon dioxide from the air and secondary microorganism's growth [7].

On the basis of presented technologies it seems that application of hydrogen peroxide, mostly Fenton's reagent should lead to more effective and economical final results of sludge sanitation. Lots of literature data confirm usefulness of hydrogen peroxide in reduction of the number of bacteria in wastewater treatment process, in food industry and medicine [6, 10, 28, 37].

It has been proved that the disinfection of most types of treated water is possible at the dose of hydrogen peroxide 0.2 g H_2O_2/dm^3 for 30 minutes. This value is also a border dose in the case of organoleptic properties. Hydrogen peroxide used for 10 days in water treatment process is antiseptic; moreover color and odor reduction is obtained [16].

Desinfective property of hydrogen peroxide can be directly connected with toxicity of this chemical compound. A lot of tests done on the organisms settled in water environments prove this theory. It has been shown that the concentration over 40 mg H_2O_2/dm^3 is toxic for trouts. In the case on lower organisms the toxicity threshold (LC_{50}) is the following: *Gammarus Pulex* – 5500 mg H_2O_2/dm^3, *Epeorus Assimilis* – 3000 mg H_2O_2/dm^3, *Paramaecium Caudatum* – 7000 mg H_2O_2/dm^3, *Vorticella campanula* – 2500 mg H_2O_2/dm^3. It is widely known that hydrogen peroxide concentration at the level of 200 mg H_2O_2/dm^3 is quite well tolerated by activated sludge of biological wastewater treatment plants. However at the concentrations of 3–10 mg H_2O_2/dm^3 antiseptic property of this reagent is observed, with little residual concentration [16].

Such types of interaction are presented in the studies concerning integrated chemical – biological system for treatment of the synthetic diary wastes [18]. Using this technology resulted in effective and fast organics removal before activated sludge chamber and improving final effect of organic and nutrient compounds reduction. The investigations were carried out in biological sequencing batch reactors SBR. In the first variant Fenton's reagent was mixed with wastes directly before the addition to biological reactor of activated sludge. In the second variant SBR reactor was preceded by separate chamber of advanced oxidation. The third variant was the most complex because wastes from separate chamber of advanced oxidation were clarified and then added to bioreactor with activated sludge. It was proved that preliminary advanced oxidation process should be performed according to the third variant. In other cases microorganisms' activity was significantly limited by residual hydrogen peroxide concentrations, which was confirmed by microscopic study of the activated sludge. The number of microorganisms in this process decreased [18].

It has been also evidenced that hydrogen peroxide concentration in drinking water should not exceed 1.0 mg H_2O_2/dm^3. The study showed that H_2O_2 is a source of peroxide radicals which can through tryptophan and cysteine oxidation, enzymes inactivation and nucleic acids modifications lead to mutation or cell mortification. Literature data show that hydrogen peroxide is mutagenic for coliform bacteria, *Staphylococcus Aureus* and *Nevrospora* and causes anomalous changes in chromosomes and the limitation of the replication activity of DNA [8, 32].

Other experiments revealed that direct influence of hydrogen peroxide on strains of the microorganisms rich in alimentary substances is insignificant and diverse [16, 20].

The comparison of the effectiveness of the reduction of bacterial spores from genus of *Bacillus* using hydrogen peroxide and ozonation indicated that ozone is more effective. In the most efficient variant at the concentration of 0.001 g O_3/dm^3 *Bacillus sp.* reduction was 6.1 $\log_{10}$ CFU/dm^3. Application of hydrogen peroxide in the amount of 10 g H_2O_2/dm^3 enables to obtain merely 1.6 $\log_{10}$ CFU/dm^3. It can be concluded that 10000-fold higher concentration of H_2O_2 than ozone concentration leads to almost the same final technological results [20].

For this reason some oxidizing substances used simultaneously in the system seem to be a good solution. Better results were observed during both chlorination and hydrogen peroxide dosing [16]. Similarly both ozonation and hydrogen peroxide (Peroxone) addition appeared to be effective in the case of organic substances removal and in the case of sanitation. Most of all, it is economical in contrary to separate ozonation or hydrogen peroxide oxidation [4, 21, 34]. In order to intensify the final technological effect simultaneous using of hydrogen peroxide with magnetic field, electromagnetic field or microvalves is

recommended [22, 23].

In presented experiment AOP with Fenton's reagent for pathogenic microorganisms' reduction was used. The efficiency of this method is based on catalytic break-down of hydrogen peroxide by ferrus ions Fe^{2+}, with the creation of free hydroxyl radicals [39]. Higher sanitation effect resulted from the fact that free hydroxyl radicals have higher oxidizing potential in relation to hydrogen peroxide alone. There is effective interaction on microorganisms' cellular structure and leads directly to the reduction of a number of bacteria in sewage sludge.

Optimal pH of Fenton reaction ranges from pH 3.0 to pH 5.0. In the experiment the average value of sludge pH was 7.1 and authors resigned of pH correction. Decision concerning Fenton reaction performance without acidification of the environment resulted from implementation, technological and economical reasons. It is supposed that Fenton reaction in the environment at the pH different than optimal pH range may limit high technological effects. However, decrease in pH values of treated sewage sludge due to acids dosing, and then neutralization to neutral pH may cause significant increase in operating costs and lead to complication of the technological process.

Other factor deciding about abandoning of acidification of tested sewage sludge mass was the fact that in order to obtain optimal sludge pH range to Fenton reaction performance iron salts were added to the sludge mass. Value of pH directly correlated with the dose of iron salts and ranged from pH 6.85 to pH 3.1.

Consecutive factor deciding about abandoning of acidification of the investigated sludge was the fact that depending on oxidized substrate optimal pH range can possess the values in a wide range from pH 2.0 to pH 7.0, and even pH 9.0 [5].

It was shown that free radicals caused the damages in biological structures what resulted from the reaction with particles of cells' structural material [8, 36]. Each particle can potentially be affected by free radicals. This reaction mostly leads to limitation of biological or biochemical activity. Proteins determining intracellular changes can serve as an example. Small modifications of enzymes structure caused by free radicals lead to complete deactivation. Such protein is not useful for the organisms' cell. Similar phenomenon is shown for carbohydrates, fats and nucleic acid [8, 35].

Free radicals are associated with oxidation stress. In a correctly functioning living system there is a balance between generation of oxidizing particles and the number of the opponents – antioxidants that protect cells against destructive effect of free radicals [36]. However, from time to time the disturbance of this balance and increased generation of free radicals or reactive form of oxygen could be observed. Such state is described as oxidation stress and the results of its action are the damages mentioned above [36].

It has not been found to what extend Fenton reaction affects the generation of hydroxyl radicals. It was proved that Fenton reaction is the main process at oxidation of cellular membrane lipids, amino-acids and at the reactions with biological reducers such as ascorbic acids and tiols [5].

MFO (Mixed Function Oxidation) system where catalytic enzymes inactivation occurs is very interesting. Ions of Fe^{2+} and H_2O_2 produced by MFO systems are subjected to Fenton reaction. Generated hydroxyl radicals destroy the amino-acids which lead to local damages of protein. Similar processes are taken into consideration for explanation of the mechanisms of organisms ageing, oxidation stress and a wide range of pathological phenomena [30].

Fenton reaction used in sewage sludge stabilization revealed satisfactory results because this method, besides effective sanitation, leads to degradation of organic compounds susceptible to putrefaction, odor removing, improving of dewatering parameters and the reduction of the mass and the volume of the sludge [12, 13, 23–26, 29, 31].

CONCLUSIONS

1. Technology of sewage sludge sanitation based on Fenton's reagent used leads to effective final results with relation to all of analyzed in presented experiment groups of microorganisms.
2. The efficiency of suggested method depended directly on Fenton's reagent doses. An increase in the efficiency correlated with the increase in chemical reagents doses, however, in the ranges from 1.0 g Fe^{2+}/dm^3, 4.0 g H_2O_2/dm^3 to 2.0 g Fe^{2+}/dm^3, 8.0 g H_2O_2/dm^3 changes in the number of bacteria were more significant.
3. Application of Fenton's reagent turned out to be more effective method in contrary to another method presented in the experiment. The final results of sewage sludge sanitation surpassed several times the results observed in the case of hydrogen peroxide or ferrous ions application alone.
4. Suggested method of sanitation for the sake of the obtained results, easy performance and chemical reagents accessibility can become alternative technology of sewage sludge stabilization.
5. Needed most of all is searching of the agents intensifying final technological results at economical chemical reagents management.

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Received: June 6, 2005; accepted: October 27, 2005.