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The Influence of Different Intensity Electromagnetic Fields on Phosphorus and COD Removal from Domestic Wastewater in Steel Packing Systems

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Abstract

The possibility of an electromagnetic field (EMF) influencing the intensification of phosphorus (P) and organic compound (COD) removal from domestic wastes was investigated. The impact of an EMF as the only factor or as an intensifying element in steel packing systems that limits pollutant concentrations in the treated wastes was analysed. The research was conducted in three stages in a static system at the laboratory scale. A significant dependence between the kind of system used, time of detention, flux intensity electromagnetic field and the effectiveness of the pollutants limitation were observed. Most efficient was the system that combined simultaneously steel filling and under electromagnetic flux intensity $\Phi = 100.0$ μWb and $\Phi = 135.0$ μWb. In the case of 48 hours the reaction time let to remove from the system the whole phosphorus amount as $P\text{-}PO_4$ for treated sewage. These technological variants seem to be the most effective as for P_{tot} and COD.

Keywords: electromagnetic field, wastewater treatment, steel filling, metal corrosion, domestic wastewater

Introduction

There are a lot of well known methods applied on a large-scale for phosphorus limitation in wastewater. These methods are based on suitable bacterial strains that - as a result of growth and biomass increase - are able to accumulate phosphorus compounds $P\text{-}PO_4$ and to limit phosphorus concentration in wastewater [1, 2, 3, 4]. Another, as popular as mentioned above, method connected with phosphorus removal is introducing chemical reagents to the systems. This is aimed at phosphate ion precipitation from the solutions in forms of slowly soluble salts or to make adsorption components with added reagents. The most commonly used compounds are aluminium (Al), iron (Fe) and calcium (Ca) salts [5].

These technologies often run into difficulties in practice. Activated sludge methods are quite complicated and suitable for microorganisms aerobic/anoxic conditions need to be prepared. Besides, the bacteria of activated sludge are sensitive to the concentration of the influents, wastewater pollutants concentration and toxic substances, including [2, 4]. Chemical precipitation, although it makes possible perfect results of wastewater treatment, is quite expensive and is related to the increase in sludge mass [6].

The consequence of the imperfections of using such methods is the need to search for new, effective systems that let on the efficient phosphorus and organic compounds limitation in the wastewater. Independent systems that make it possible to achieve high quality effluents and the technologies that let on the modernization and improvement of the existing wastewater treatment plants are desir-

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able. The operations steering on the wastewater treatment intensification head towards using the technologies that let on the introduction to the solutions clear forms of metals and wide range of the physical factors using [7, 8, 9]. The impact of the ultrasounds, microwaves, electrical current, and UV or gamma radiation were tested. It has been proven that an electromagnetic field (EMF) intensifies coagulation and the biodegradation of organic compounds of the activated sludge and under specific conditions can be one of the elements that determines the effectiveness of pollutant removal [9, 10]. However, there is not a lot of research connected with the determination of the impact and mechanisms of EMF on nutrient concentration in the solutions.

The aim of the experiment was to determine the influence of the different flux intensity electromagnetic field (EMF) on the possibility and the efficiency of the phosphorus as P-PO_4, P_{tot} and organic as COD compounds removal from the domestic wastewater in the steel packing systems.

Experimental Procedures

The research was carried out in three stages in a static system at the laboratory scale. The technological systems used in the particular parts of the experiment were different. The whole of the analyses were conducted at an ambient temperature of approximately 20ºC. Domestic wastewater was taken from the sewage system of the University of Warmia and Mazury in Olsztyn. Wastewater composition was as for typical sanitary waste.

During the first stage of the experiment the impact of the metal packing as the only factor that limits pollutant concentration in the treated wastes was analyzed. In this stage treated solutions were supplied to the model reactors at a volume of 1 dm^3, in that the metal medium was wire spirals at the contact surface with wastes about 215 cm^2 (Fig. 1).

In the next part of the experiment only the impact of the different intensity EMF on the changes of the pollutants concentration in the analysed wastes was determined. In this connection the particular sorts of wastes were supplied to separate reactors and were exposed on the direct influence of the EMF. The individual series differed by the electromagnetic flux intensity using (Fig. 2).

In the third stage in the technological system metal packing and physical factors were used simultaneously.

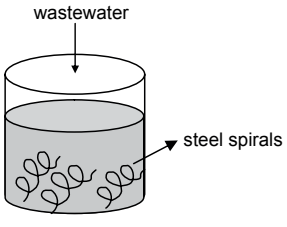

Fig. 1. Scheme of the experimental post in the first stage of the experiment with steel packing using.

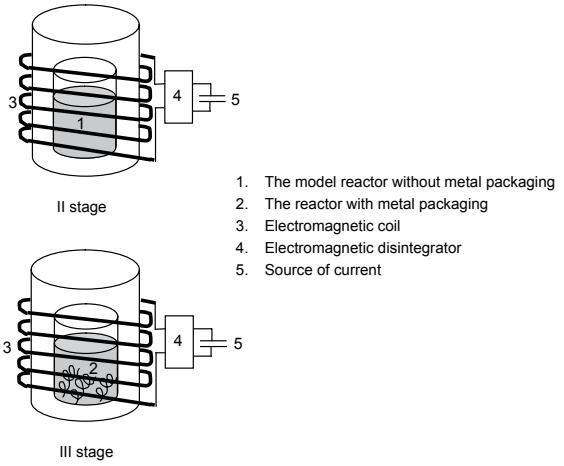

Fig. 2. Scheme of the experimental post in the second and third stage of the experiment.

Depending on the series, different electromagnetic flux intensities were used (Fig. 2).

The base of the experimental device was a cylindrical container made of the plastic material of 200 mm diameter and at height of 740 mm. Electromagnetic coil was wound on its circumference. The coil was joined to the electromagnetic disintegrator and, thanks to it specific current and magnetic flux intensity, could be used. Analysed wastes were place in the laboratory glass reactors at volume of 1 dm^3 exposed to the influence of the EMF (Fig. 2). The experiment in two final stages was carried out under the different current intensity f = 25.0 kHz, f = 10.0 kHz, f = 50.0 kHz and under different magnetic flux intensity Φ = 45.0 μWb, Φ = 100.0μWb, Φ = 135.0 μWb (Table 1).

Each series of the investigations was repeated three times and the average results of the analyses are shown in the figures and in the tables. The waste samples were taken from the reactors after 3, 24 and 48 hours of the experiment. During the investigations changes of P-PO_4, P_{tot} and Fe concentrations were analysed. Additionally, organic compounds concentration expressed as COD and induction currents generated on the packing surface were controlled. Chemical parameters were determined using HACH DR/2000 spectrophotometer. Wastewater contents were analysed in the control-comparative samples without packing and EMF influence. The quality of the treated wastes was compared with the quality of the wastes that were not exposed to any physical and chemical processes.

Results

The values of the pollutants in wastes in the control samples that were not under EMF and without metal packing decreased but not in a large range. There was the decrease in COD concentration approximately from 5% to 10% after 24 hours and from 20% to 25% after 48 hours of the reaction. The decrease in the P concentration was

Table 1. Experiment break-down during the second and third stages.

Stage II				Stage III			
Series	Fe packing	F [kHz]	Φ [μWb]	Series	Fe packing	F [kHz]	Φ [μWb]
I	-	50.0	45.0	I	+	50.0	45.0
II	-	10.0	100.0	II	+	10.0	100.0
III	-	25.0	135.0	III	+	25.0	135.0

Table 2. Changes of the analysed parameters during the 48-hour treatment with steel packing system using (stage I).

Time [h]	Fe packing system only		
	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]
0	3.50	4.70	147.0
3	1.70	2.80	139.5
24	0.24	0.64	86.0
48	0.10	0.21	70.0

observed but it was different depending on the detention time. After 48 in the domestic wastes the efficiency of P_{tot} removal was about 15%.

In the first stage of the experiment the impact of metal packing on pollutant removal efficiency was measured. The reduction was noticeable after just three hours of the experiment for both forms of phosphorus and COD. After 48 hours detention in the technological system in domestic wastes, the efficiency of $P\text{-}PO_4$ removal was 97% and as for P_{tot} removal it was on the level of 95.5% (Table 2). After two days of the treatment process the COD reduction was 52%. Finally, in the effluent there were 0.10 mg P/dm^3 in form of $P\text{-}PO_4$, 0.21 mg P/dm^3 in form of P_{tot} and COD 70 mg O_2/dm^3 (Table 2).

It was found that Fe corrosion was intensive in the wastewater. After 24 hours the Fe concentration was 16.01 mg Fe/dm^3 and after next day of the experiment the concentration was 34.80 mg Fe/dm^3 (Table 3).

In the next stage, during that only EMF effect was investigated, the tendency of minor pollutants reduction along with the waste retention time prolonging in the technological system was observed (Table 4).

The highest removal efficiency of analysed pollutants was obtained after two days treatment independently on the intensity of used EMF. At the intensity of EMF on the level of 45.0 μWb in series I the lowest effectiveness was observed (Table 4). 3-hour retention time was not sufficient to achieve significant technological effect as for both forms of phosphorus and organic compounds. After 24 hours of the reaction time there was the reduction of $P\text{-}PO_4$, P_{tot} and COD on the level of 5.7%, 3.2% and 15.6% respectively. After 48 hours an increase in these compounds removal effectiveness was observed. Final $P–PO_4$, P_{tot} and organics (expressed as COD) concentrations were adequately 3.20 mg P/dm^3, 4.50 mg P/dm^3 and 108.1 mg O_2/dm^3 (Table 4).

In series II and III, at the intensity of EMF on the level of 100.0 μWb, 135.0 μWb, respectively, changes of analysed parameters and the removal efficiency were similar to series I. After 3 hours of the experiment the decrease in phosphorus concentration in domestic sewage was not measured. The contents of this nutrient maintained on the same level (Table 4). Analysis of both phosphorus form concentrations indicated systematic reduction. In series II after 48 hours of the reaction time $P\text{-}PO_4$ and P_{tot} concentrations in the effluent were adequately 3.25 mg P/dm^3 and 4.20 mg P/dm^3. For series III the concentrations were 3.20 mg P/dm^3 and 4.30 mg P/dm^3, respectively. COD removal effectiveness was approximately 40% (Table 4).

In the third stage of the experiment in technological system both EMF and metal packing were used. Simultaneous use of these elements influencing the rate and treatment efficiency caused an increase in pollutant removal effectiveness in all series of research.

The systems at EMF intensity on the level of 100.0 μWb and 135.0 μWb were equally effective. High treatment effects were obtained after 24 hours of retention

Table 3. Changes of the Fe concentration during the first and third stage of the experiment with metal packing and EMF use.

Reaction time [h]	Fe concentration [mg/dm^3]			
	without EMF	F = 50.0 kHz. Φ = 45.0 μWb	F = 10.0 kHz. Φ = 100.0 μWb	F = 25.0 kHz. Φ = 135.0 μWb
0	0.18	0.18	0.18	0.18
3	8.23	8.65	14.30	9.70
24	16.01	27.50	30.60	21.80
48	34.80	49.50	81.00	82.40

Table 4. Changes of the analysed parameters during the 48-hour treatment with different flux intensity electromagnetic fields (stage II).

Time [h]	EMF system only								
	F = 50.0 kHz; Φ = 45.0mWb			F = 10.0 kHz; Φ = 100.0mWb			F = 25.0 kHz; Φ = 135.0mWb		
	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]	$P\text{-}PO_4$ [mg P/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]
0	3.50	4.70	147.0	3.50	4.70	147.0	3.50	4.70	147.0
3	3.50	4.70	130.0	3.50	4.70	141.0	3.50	4.70	137.0
24	3.30	4.55	124.0	3.40	4.65	94.1	3.30	4.55	121.0
48	3.20	4.50	108.1	3.25	4.20	79.2	3.20	4.30	88.6

Table 5. Changes of the analysed parameters during the 48-hour treatment with different flux intensity electromagnetic fields and steel packing system (stage III).

Time [h]	Fe packing and EMF system								
	F = 50.0 kHz; Φ = 45.0mWb			F = 10.0 kHz; Φ = 100.0mWb			F = 25.0 kHz; Φ = 135.0mWb		
	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]	$P\text{-}PO_4$ [mgP/dm^3]	P_{tot} [mgP/dm^3]	COD [mgO_2/dm^3]
0	3.50	4.70	147.0	3.50	4.70	147.0	3.50	4.70	147.0
3	1.40	2.50	130.0	1.10	2.20	134.0	1.20	2.30	128.0
24	0.26	0.36	84.0	0.08	0.25	66.0	0.05	0.27	50.0
48	0.08	0.36	71.0	0.00	0.13	56.8	0.00	0.11	49.5

time. Parameter concentrations are shown in Table 5. $P\text{-}PO_4$, P_{tot} and COD removal effectiveness was 100%, 97.0% and 61-66%, respectively. At the intensity of EMF on the level of 45.0 μWb the treatment effects were not so high. It is confirmed by the results obtained after 24 hours of retention time. $P\text{-}PO_4$, P_{tot} and COD removal efficiency was adequately 97.7%, 92.3% and 51.7%. After 48 hours an increase in these compounds removal effectiveness was observed. Finally, the effluent contained $P\text{–}PO_4$ 0.08 mg P/dm^3, P_{tot} 0.36 mg P/dm^3 and COD 71.0 mg O_2/dm^3 (Table 5).

After 48 hours Fe concentration was 49.5 mg Fe/dm^3 in first series. Higher metal leaching intensity was observed in second and third series of the experiment. After two days detention in the technological system of the reaction Fe concentrations were over 80.0 mg/dm^3 (Table 3).

In the presented experiment high steel corrosion and intensive Fe leaching to the treated wastes were observed (Table 6). These processes were more effective in the system using EMF. It seems to be caused by inductive currents on the packing surface. It was proved that inductive currents intensity range from 11.2 μA to 53.4 μA for metal packing depending on the detention time in the technological system and intensity EMF generated (Table 6).

Table 6. Changes of the inductive currents intensity during the third stage of the experiment with the metal packing and EMF using.

Inductive currents intensity [μA]			
Reaction time [h]	F = 50.0 kHz, Φ = 45.0 μWb	F = 10.0 kHz, Φ = 100.0 μWb	F = 25.0 kHz, Φ = 135.0 μWb
3	53.4	11.4	48.5
24	49.3	13.7	45.6
48	45.1	11.2	41.3

Discussion

The aim of the presented study was to determine the effectiveness of the phosphorus and COD removal in metal packing systems with different flux intensity EMF. Metal (Fe) in clean, ion forms are supplied to wastewater. This method assures the limitation of chemical reagents used contrary to technologies with coagulants when these compounds are supplied in the form of salts.

Use of the metal packing only in the technological system influenced higher pollutants reduction in the wastewater. After 48 hours of detention in the technological system the efficiency of $P\text{-}PO_4$ removal was almost 97% P_{tot} removal it was on the level of 95.5% and COD reduction was 52%.

The experimental results showed that steel packing was much more effective for phosphorus removal. Methods that use the technique of clear Fe leaching in wastewater treatment technologies are widely used from the same time. As an example, it can be activated filter with gravel or sand packing covered by $Fe(OH)_2$ or filter with steel packing. The research under gravel filter revealed very high results. Depending on hydraulic conditions, the phosphorus reduction ranged from 34% to 78%. In comparison to the filters without iron hydroxide $Fe(OH)_2$ the phosphorus compounds removal effectiveness was 6.4% [11]. Similar high treatment reduction was achieved for plants filtered with metal packing working in a laboratory

scale at wastewater treatment plant in Nowy Most, Poland. The researches under phosphorus ($P\text{-}PO_4$) removal from mains and ground water indicated the high quality effects [12].

Columns of filters were filled with sand or olivine and covered by iron or aluminium hydroxide. The effectiveness of the treatment process was over 90% and final $P\text{-}PO_4$ concentration was 0.05 mg/l [13]. Mentioned technologies confirmed the fact of iron ions leaching in wastewater conditions. It seems to be purposeful to carry out research under the improvement of the metal ions leaching for treated solutions, which influences better phosphorus reduction in wastewater.

Other research has tried to determine the impact of steel packing on improving sulphate removal efficiency in contrast to the parallel-operated UASB reactor without steel packing [14]. The experiment concerning anaerobic yeast waste treatment efficiency was carried out in a dynamic system. The disadvantage of such waste treatment is the fact that sulphates are transformed to sulphur hydrogen that can appear in fermentation gas. Anaerobic treatment in USAB reactor without steel packing let us obtain partial sulphate reduction. Sulphate load was 2.6-10 g $S\text{-}SO_4^{2-}$/d and 50% removal efficiency was observed. The increase in sulphate load to 18 g $S\text{-}SO_4^{2-}$/d caused a decrease in the reduction effectiveness to 36.5%. Changes in sulphate loading from 6.6 to 18 g $S\text{-}SO_4^{2-}$/d in anaerobic system with steel packing did not cause significant changes in sulphate reduction efficiency. During the experimental period sulphate removal effectiveness was on the similar level 85-95%, which results from positive effect of steel packing in the bioreactor [14].

Many theories and mathematical models describe the mechanisms and kinetics of electrochemical Fe leaching in water solution. The authors emphasize that the rate of metal ion leaching depends on many different factors like pH, intensity of electricity and inhibitors: acetates, nitrates, sulphates or oxygen concentration [15, 16, 17].

The most popular conception of the Fe corrosion mechanism in an aqueous solution pathway is given as:

$$Fe + OH^- \leftrightarrow Fe(OH)_{ads} + e$$
$$Fe(OH)_{ads} \rightarrow FeOH^+ + e$$
$$FeOH^+ + H^+ \leftrightarrow Fe^{2+} + H_2O$$

The effect can be heightening by electrochemical metal leaching in technological systems, which is confirmed by research under water and wastewater treatment. Electrocoagulation lies in the fact that metal ions are leaching to the solution by means of electrolytic metal leaching that is an electrode. The effects of the phosphorus removal and energy-intensity of electrocoagulation were determined depending on aluminium or iron electrode. The research indicated higher effectiveness and lower energy consumption in the case of aluminium electrodes. Under optimal conditions phosphorus reduction was over 95% [7].

The method that is described in the presented study is based on the similar mechanisms, but metal ion leaching is spontaneous and this is additionally a result of different intensity flux EMF use. High steel corrosion and intensive Fe leaching to the treated wastes in the system using EMF were observed. It seems to be caused by inductive currents on the metal packing surface. It was proved that inductive currents intensity range from 11.2 μA to 53.4 μA for metal packing depending on the intensity EMF generated.

Satisfactory results were obtained in the case of advanced oxidation method application and EMF for sludge conditioning for a 24-h period. EMF of a defined induction was generated by electric current flow with alternating intensity through metal medium. The effect of the sludge properties variation was achieved owing to the triple mechanism: oxidation by free radicals, stimulating activity of EMF, and coagulation with iron salts supported by corrosion of the metal medium [18].

The reference literature is not supportive in explaining the direct mechanisms responsible for orthophosphates removal under the impact of the electromagnetic waves. It has been evidenced that the physical factors modifies the electrokinetic potential [19] and influences the coagulation process [8]. 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 [20]. 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 electromagnetic treatment impact on the physical and 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 magnetic activation. Additionally, a tendency was observed for fine sludge particles coagulation in the magnetically-prepared wastewater, which eventually accelerates sedimentation and increases the dewatering capacity [10]. Probably the suspensed solids removal had a positive effect on the reduction of carbon compounds contained in the treated wastewater.

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 concentration 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 [10, 19].

The phenomenon of effective penetration of the atmospheric oxygen into the solutions prepared with the magnetic field is very advantageous also 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 intensive and so is the degradation of organic matter [9, 21, 22]. 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. The fact has been confirmed by the laboratory studies of biological degradation of the 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 the organic compounds degradation continues for about 12 hours after termination of exposure [10].

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 [19].

Another phenomenon which may occur under the impact of magnetic field is the intensification of free radicals formation [23, 24]. High reactivity and high oxidation potential of those chemical compounds may have effectively reduced the concentration of organic matter contained in the analysed liquids. The process of a water molecule disintegration with formation of free radicals takes place when sufficient energy has been provided [24]. It can be obtained through UV-radiation, gamma-radiation or electromagnetic field. 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 electromagnetic fields, which in effect reduces the number of the 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 [9, 24, 25].

The impact of magnetic fields on the rate and number of generated hydroxyl radicals in Fenton reaction was determined in an experiment analysing the variations of sodium sulphite concentration in a deoxidized solution. The results have shown that magnetic field has much effect on the number of generated hydroxyl radicals. It has been 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 [24].

Until now, 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 [26]. 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 physical and chemical parameters of the treated liquids, including wastewater.

Conclusions

- using the metal packing in the technological system influence on higher pollutants reduction in the wastes
- phenomena that were caused by the electromagnetic field favorably influence on the wastewater treatment
- the most efficient was the system that combined simultaneously steel filling and under magnetic flux intensity $\Phi = 100.0$ μWb and $\Phi = 135.0$ μWb
- in case of 48 hours the reaction time let to remove from the system the whole phosphorus amount as $P\text{-}PO_4$ for treated sewage. This technological variant seems to be the most effective as for P_{tot} and COD
- as a result of efficient corrosion of steel packing, derivative pollution of the iron compounds was observed

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