

1 APPLICATION OF H₂O₂ TO OPTIMIZE AMMONIUM REMOVAL 2 FROM DOMESTIC WASTEWATER

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24

25 Abstract

26 The paper presents the results of application of hydrogen peroxide (H₂O₂) for the optimization of
27 the effects of ammonia nitrogen removal from domestic wastewater. The investigations were carried
28 out at a model wastewater treatment plant consisting of a preliminary sedimentation tank and a sand
29 filter with a horizontal flow of wastewater at a constant hydraulic load of 1.44 l/day. The efficiency of
30 ammonia nitrogen removal was analyzed for different wastewater oxygenation levels: 0-10%, 10-20%,
31 20-30%, 30-40% and 40-50%, maintained by controlled application of a 0.1% H₂O₂ solution. It was
32 demonstrated that the gradual increase in oxygen concentration in treated wastewater due to H₂O₂
33 dosing resulted in an increase in ammonia nitrogen removal from 39.0 to 81.2%. The best removal
34 efficiency was obtained when the oxygenation level was in the range of 30-40%. It was also shown
35 that application of hydrogen peroxide resulted in an effective removal of biochemical oxygen demand
36 (BOD₅). The highest BOD₅ removal efficiency (94.3%) was obtained at the oxygenation level of 30-
37 40%. The results indicate that oxygenation of wastewater with hydrogen peroxide can be applied for
38 the optimization of the nitrification process in wastewater treatment plants.

39

40 **Keywords:** hydrogen peroxide (H₂O₂); ammonium nitrogen; domestic wastewater; wastewater
41 treatment; nitrification

42 1. Introduction

43 Recent decades have seen an increasing interest in unconventional methods of degradation
44 of pollutants present in wastewater, including nitrogen compounds. One of the methods which
45 enjoy growing popularity is chemical oxidation. Among the oxidants commonly applied in the

46process, which include chloride and its compounds, potassium permanganate, ozone and
47hydrogen peroxide, only the last one does not form toxic oxidation by-products, and is thus
48sometimes referred to as an ecological oxidant [1]. Hydrogen peroxide is commonly applied
49in wastewater treatment, usually to assist biological treatment processes, since it is capable of
50degrading recalcitrant as well as toxic pollutants. It is applied for neutralization of
51cyanoalkaline wastewater and oxidation of sulfides. It has also been used for decolorization of
52industrial wastewater and for oxidation of recalcitrant organic compounds [2-4]. Besides,
53hydrogen peroxide can be used for removal of chromium as well as oxidation of aldehydes,
54toluene and anilines [1, 5]. Increased degradation of pollutants is achieved by joint application
55of hydrogen peroxide with ozone, UV radiation or iron ions [1, 6-7]; this allows for fast
56generation of hydroxyl radicals, which are highly reactive in the environment [8-9].
57Application of this method together with biological treatment allows for neutralization of
58wastewater containing heavy metals, recalcitrant organics, including chlorinated
59hydrocarbons, phenolic compounds, pesticides, dyes and pharmaceuticals [7, 10-15].

60 Due to its properties, hydrogen peroxide significantly decreases the load of recalcitrant
61pollutants discharged to a biological treatment unit, at the same time protecting biological
62processes against toxic pollutants. Moreover, some concentrations of hydrogen peroxide
63stimulate the activity of aerobic bacteria, including nitrifiers, leading to intensification of
64ammonia nitrogen oxidation [1, 16]. Thus, hydrogen peroxide can be used as an alternative
65oxygen source in the biological treatment process, despite the fact that H_2O_2 is a strong
66oxidant [17]. In the investigations performed by Fiedurek [18] and Fiedurek and Gromada
67[19], hydrogen peroxide was automatically dosed to perform unconventional oxidation of the
68substrate in the process of gluconic acid production. A significant increase (over six-fold) in
69intracellular catalase activity was obtained while the dissolved oxygen concentration
70remained stable (30% \pm 2%) [19]. Preliminary investigations of oxygen generation from 0.1%
71and 0.2% H_2O_2 solutions by microorganisms present in wastewater indicate that this
72procedure can be a convenient and inexpensive method of wastewater oxidation during
73ammonia nitrogen removal [20].

74 Ammonia nitrogen present in wastewater is removed in the process of nitrification [21].
75*Nitrosomonas*, *Nitrosococcus*, *Nitrosolobus*, *Nitrosospira* and *Nitrosovibrio* participate in
76stage I of nitrification, while *Nitrobacter*, *Nitrococcus* and *Nitrospira* take part in stage II of
77the process [22]. Nitrification performance depends on many conditions, including
78temperature, pH, load of organic pollutants, presence and concentration of toxic substances,
79and concentration of nitrogen in the inflowing wastewater. Still, the most important factor is



80 dissolved oxygen concentration [23]. The minimal dissolved oxygen concentration for proper
 81 performance of nitrification should be at least 1-2 mg O₂/l. Higher concentrations enhance
 82 nitrification performance [24].

83 The investigation of nitrogen removal optimization in wastewater treatment, also in
 84 constructed wetlands, has been one of the leading research directions in the recent years [25-
 85 39]. The methods of wastewater oxidation used so far for nitrogen removal in wastewater
 86 treatment plants (usually with air compressors) are energy-consuming. High capital and
 87 operating costs of conventional solutions result in continuous search for aeration methods
 88 which would be inexpensive in terms of investment and operation.

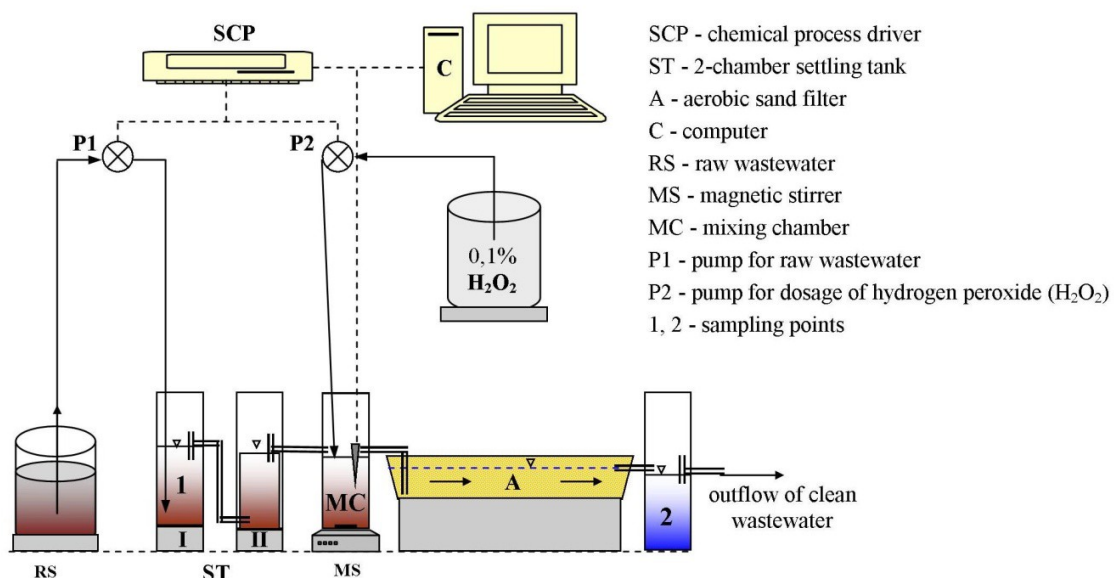
89 The aims of this study were to evaluate the potential of application of hydrogen peroxide
 90 for the optimization of removal of ammonia nitrogen from domestic wastewater and to define
 91 the optimum conditions for nitrification with the unconventional method of wastewater
 92 oxidation using a 0.1% solution of hydrogen peroxide (H₂O₂).

93

94 2. Materials and methods

95 2.1. Characteristics of experimental setup

96 The investigations were performed in a laboratory-scale model of a wastewater treatment
 97 plant consisting of a primary sedimentation tank (ST) and a sand filter with a horizontal
 98 subsurface flow of sewage - HF (A) at a constant flow of 1.44 l/day (which corresponded to
 99 hydraulic load of 0,016 m³/m²/day) (Fig. 1).



100

101

Fig.1. Schematic of the wastewater treatment plant model (WWTP)

102 The experimental set was unplanted, since the main research objective was to evaluate the
 103 impact of H_2O_2 on the efficiency of ammonia nitrogen removal in a filter without plants.

104 Table 1 summarizes the parameters of the component parts of the wastewater treatment
 105 plant model. The surface area of the sand filter was $0.091m^2$ and its depth was 0.06 m. The
 106 slope of the bottom was 1% in the direction of sewage outflow. The substrate of the filter was
 107 coarse sand ($\phi=1-2$ mm).

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Tab.1. Parameters of the wastewater treatment plant model

Parameters	Units	Primary sedimentation tank chambers I and II	Sand filter
Length [L]	[m]	-	0.390
Width [W]	[m]	-	0.235
Diameter [D]	[m]	0.075	-
Total depth [H]	[m]	0.240	0.060
Height of wastewater level (h)	[m]	0.160	0.050
Area [A]	[m ²]	-	0.091
Total volume [V]	[l]	1.059	5.499
Active volume [V _{cz}]*	[l]	0.707	4.582

110

1112.2. Experimental procedures

112 During the investigations, an automatic dosing unit was used for dosing the 0.1% solution
 113 of H_2O_2 and for controlling the dissolved oxygenation level in treated wastewater in the range
 114 of 0-10%, 10-20%, 20-30%, 30-40% and 40-50%. The investigations were carried out for 10
 115 weeks (2 weeks with each level of wastewater oxidation).

116 The dissolved oxygen (DO) concentration of the treated wastewater was measured with an
 117 Oxyferm 120 electrode (Hamilton Comp.). The value of the reading was expressed as
 118 percentage of the initial level of saturation. The method of automatic H_2O_2 dosing and
 119 adjustment of the selected oxygenation level of the substrate was adapted from Fiedurek [18].
 120 Consumption of hydrogen peroxide re-calculated for the 1% solution varied from 5 to 25
 121 ml/day and was dependent on the adopted level of wastewater aeration. The highest
 122 consumption of H_2O_2 was observed when the concentration of dissolved oxygen in the
 123 inflowing wastewater was 20-30%. The H_2O_2 solution was dosed to the mixing chamber (MC)
 124 upstream of the sand filter (A) (Fig. 1). Real wastewater after mechanical treatment was used.

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126

1272.3. Wastewater characteristics

128 During the whole investigation real domestic wastewater after mechanical treatment was
129used (Tab. 2). The wastewater was collected form outflow of two chambers septic tank in
130household wastewater treatment plant with average flow of 0.6 m³/day.

131

132 Tab. 2. Average values (\pm standard deviation) of the selected parameters
133 in the domestic wastewater after mechanical stage

Temperature [°C]	pH	TN (mg/l)	NH ₄ ⁺ -N (mg/l)	NO ₃ ⁻ -N (mg/l)	NO ₂ ⁻ -N (mg/l)	BOD ₅ (mg/l)
18.6 \pm 0.5	7.59-7.83	133.3 \pm 9.1	116.5 \pm 8.3	2.30 \pm 4.22	0.40 \pm 0.71	67.0 \pm 18.7

134

135 The wastewater discharged to pilot plant was characterized by relatively low concentration
136of organic matter expressed in BOD₅ and high concentration of total nitrogen mainly in form
137of the ammonia nitrogen. In consequence the mean ratio of BOD₅/ TN was very low and equal
138to 0.5 (Tab. 2).

139

1402.4. Analytical methods

141 The samples were taken at two points of the pilot wastewater treatment plant model (Fig.
1421). The following parameters were measured: temperature, pH, concentrations of ammonia
143nitrogen, nitrite nitrogen, nitrate nitrogen and total nitrogen, and BOD₅ for the different
144oxygenation levels. Temperature and pH were determined using a multiparameter measuring
145device Multi 340i produced by WTW. The concentration of ammonia nitrogen was measured
146with an MPM 2010 photometer produced by WTW, and the concentrations of nitrite and
147nitrate nitrogen – with an LF 300 photometer produced by Slandi. The total nitrogen
148concentration was determined using a PC spectro spectrophotometer manufactured by
149AQUALYTIC, after oxidation of the sample at 100°C in a CR4200 thermo reactor from
150WTW. BOD₅ was measured by the dilution method using Oxi 538 from WTW. Variance
151analysis of the results (ANOVA) was performed using STATISTICA 10. Division into
152homogenous samples was performed using the Tukey procedure at the significance level
153 $\alpha=0.05$.

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1573. Results and discussion

1583.1. Effects of the application of H₂O₂ on ammonium nitrogen removal

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159 In all the experimental series, real wastewater of a similar chemical composition was used
 160(Tab. 3).

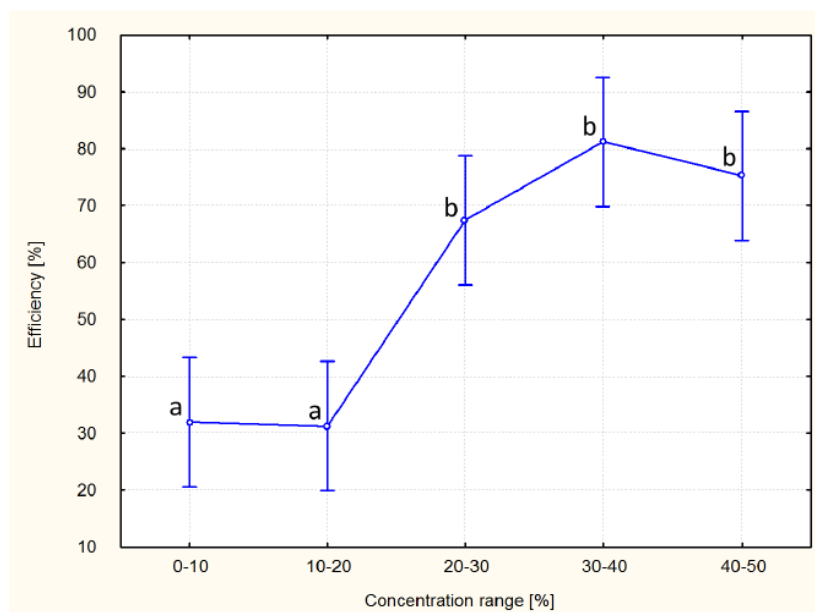
161 Tab. 3. Characteristics of wastewater with different levels of oxygenation

Parameters	Level of wastewater oxygenation (% O ₂)									
	0-10		10-20		20-30		30-40		40-50	
	In	Out	In	Out	In	Out	In	Out	In	Out
Temperature [°C]	18.3	18.2	19.2	18.9	19.0	18.7	18.3	17.8	18.3	18.1
pH	7.6-7.8	7.9-8.1	7.6-7.7	8.1-8.2	7.8-7.8	7.5-7.6	7.7-7.8	7.5-7.6	7.6-7.7	7.4-7.5
Ammonium nitrogen [mg/l]	117.0	80.0	109.0	74.9	120.0	38.0	117.0	22.0	119.0	29.5
Nitrate nitrogen [mg/l]	0.11	0.11	0.11	12.20	1.15	63.20	8.36	85.50	1.81	84.50
Nitrite nitrogen [mg/l]	0.09	0.02	0.06	0.83	1.22	7.65	0.59	2.35	0.11	4.79
Total nitrogen [mg/l]	133.0	91.0	129.5	100.5	128.5	107.0	134.0	117.0	142.0	126.5
BOD ₅ [mg/l]	47.8	24.1	55.0	12.5	86.0	12.7	77.4	4.4	69.0	61.4

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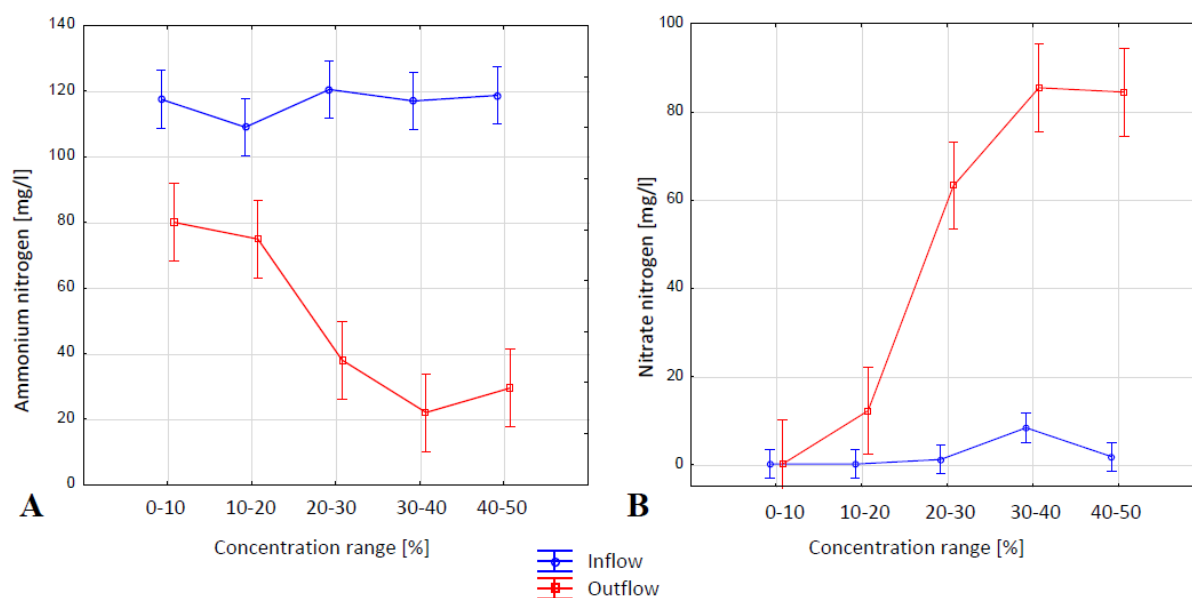
163 The pH of discharged wastewater fluctuated insensibly between 7.6 and 7.8. Also the
 164temperature of wastewater during the investigations varied insignificantly in the range from
 16518.3 to 19.2°C. Both monitored parameters were close to the nitrification process optimum
 166(Tab. 3). The concentrations of ammonia nitrogen, total nitrogen and BOD₅ in the inflow
 167wastewater were 109.0-120.0; 128.5-142.0; and 47.8-86.0 mg/l, respectively. The only
 168significant variable was oxygen concentration in the wastewater discharged to the pilot plant
 169model (sand filter). At the same time, it was noted that the increase in the oxygenation level
 170resulted in higher concentrations of nitrates and nitrites in wastewater (Tab. 3).

171 The efficiency of ammonia nitrogen removal in the WWTP at different ranges of
 172oxygenation with a division into uniform groups is presented in Figure 2.



173
174

175 Fig. 2. The influence of the oxygenation level on the efficiency of ammonia nitrogen removal;
176 the significances of differences between mean values are marked with letters a, b at $p \leq 0.05$
177



178
179

180 Fig. 3. Concentration of ammonia nitrogen (A) and nitrate nitrogen (B) at the inflow and
181 outflow at different oxygenation levels of treated wastewater
182

183 Results for oxygenation up to 20%

184 The oxygenation levels 0-10% and 10-20% brought similar effects in terms of ammonia
185 nitrogen depletion in wastewater flowing through the sand filter. The decrease in
186 concentration was slightly higher than 31% (Fig. 2), and the concentration of ammonia
187 nitrogen downstream of the sand filter was at a fairly high level of 75-80 mg/l (Fig. 3A). An
188 analysis of pH and temperature fluctuations did not show any significant changes which could



189 confirmed enhancement of nitrification process. Moreover the small change in wastewater pH
190 towards alkaline could have resulted from ammonification of organic nitrogen. In this
191 condition of high supply of N-NH_4^+ ions, the achieved results could be explained by the too
192 low oxygen concentration. According to many authors, ammonia ions are known as inhibitors
193 of nitrification [40-41]. Also, the character of wastewater flow through the filter (horizontal -
194 plug flow) certainly has not enhance the oxygenation and in consequence not favor the
195 nitrification process. Despite the fact that the filter surface was not isolated from the air,
196 horizontal flow of wastewater enabled fast and uniform oxygen supply to microbial cells,
197 limiting the rate of many biochemical transformations, including ammonia nitrogen oxidation
198 [25, 42]. The low nitrification efficiency can also be explained by slow growth of some
199 groups of nitrifiers. Directly after certain environmental conditions are established, the
200 number of nitrifying bacteria is low and increases with time. A stable level is usually reached
201 after several days [43-44].

202

203 **Results for oxygenation over 20%**

204 An analysis of achieved results indicates that the efficiency of ammonia nitrogen removal
205 increased at higher levels of oxygenation. At the oxygenation level of 20-30%, removal
206 efficiency of ammonia nitrogen in the pilot plant was equal to 68.5%, at the level of 30-40% it
207 was 81.2%, and at the level of 40-50% - 75.1% (Fig. 2). Statistical analysis indicated that
208 these values significantly differed from the results obtained at the two lower oxygenation
209 levels discussed above (Fig. 2). The results of our study are in accordance with previous
210 study by Fiedurek and Gromada [19], whose observed that a significant (over 6-fold) increase
211 in intracellular catalase activity was achieved at a stable dissolved O_2 concentration ($30\% \pm$
212 22%).

213 So far it has been demonstrated that the efficiency of ammonia nitrogen removal in single-
214 stage horizontal flow (HF) constructed wetlands (CWs) does not exceed 54%, for high $\text{NH}_4\text{-N}$
215 concentrations [45]. According to Vymazal [42], the 50% threshold in such CW systems
216 cannot be exceeded because of low oxygen transfer which sets a limit on nitrification [37, 39,
217 46-48]. Much more higher removal efficiency of ammonium nitrogen had been confirmed for
218 hybrid and vertical flow CWs. In such system it is possible to achieve very effective removal
219 of nitrogen compounds up to 90% due to better oxygenation which is achieved by changeable
220 flow in hybrid system or by intermittent discharge in VF system or by force aerated beds
221 (FAB) [36, 49-52].



222 According many authors aeration of wastewater before discharge to HF beds could be
223 applied to overcome problem of lack of oxygen [53-54]. A study conducted by Jamieson et al.
224 [55] in a model wastewater treatment system indicated that nitrogen removal efficiency could
225 be increased from 50.5 to 93.3% by aeration with compressed air. Nitrogen removal
226 efficiencies similar to those obtained in the present study at an oxygenation level of 30-40%
227 were reported by Ju et al. [29] in their model-scale investigations performed with a vertical
228 flow filter in a novel electrolysis-integrated tidal flow CW system. Liu et al. [56] achieved
229 97% efficiency of nitrogen removal in lab-scale investigations using zeolites as substrates.
230 According to Araya et al. [57] combination of zeolite as the support medium and the aeration
231 strategy with a suggested cycle of 4 h/d in a single CW demonstrated the importance of
232 aeration for the regeneration of adsorption sites and the maintenance of the COD and $\text{NH}^{+4}\text{-N}$
233 removal efficiencies above 70% over time.

234 In our studies application of higher doses of hydrogen peroxide and maintaining a
235 wastewater oxygenation level of 30-40% or 40-50% had the best effect on the activity of
236 nitrifying bacteria and ammonia nitrogen oxidation. Under these conditions, the ammonia
237 nitrogen concentration decreased to an average level of 22.0-29.5 mg/l at the outflow (Fig.
238 3A). At the same time, at the oxygenation level of 30-50%, the concentration of nitrates
239 reached a maximum (Fig. 3B).

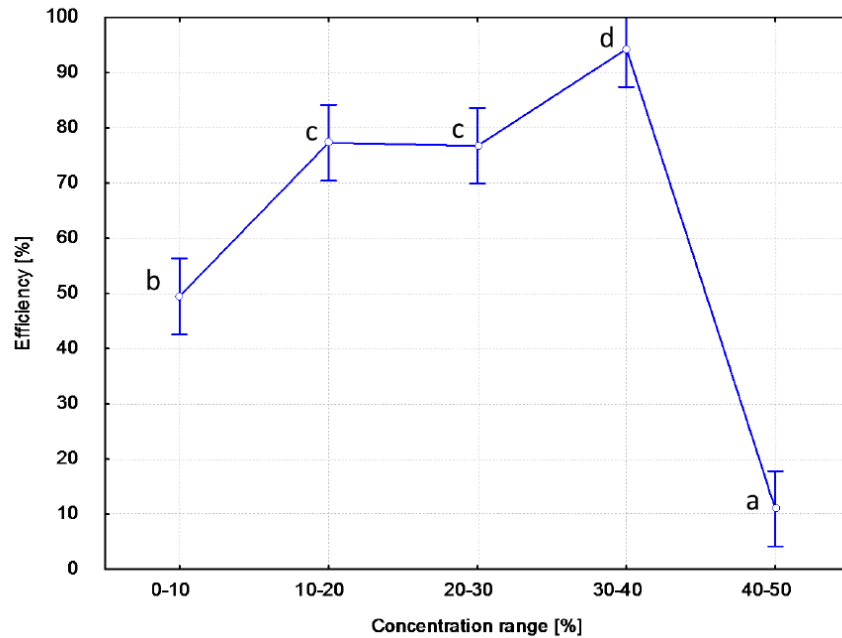
240 The obtained results indicate clearly that application of H_2O_2 resulted in the optimization of
241 the nitrification process in the analyzed WWTP model.

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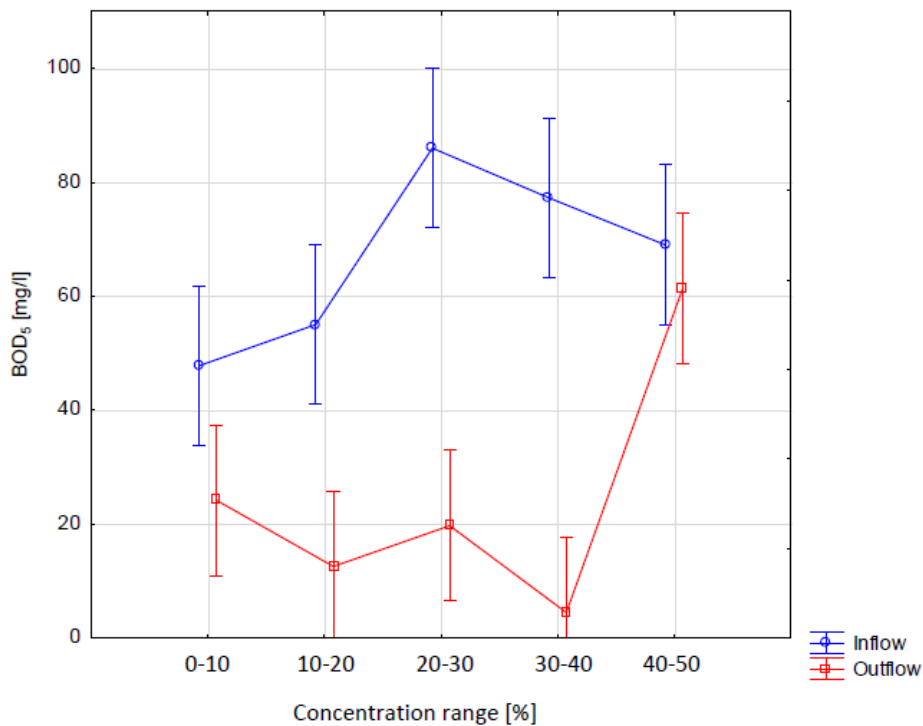
243 3.2. Effects of H_2O_2 application on BOD_5 removal

244 The study also confirmed that the application of hydrogen peroxide leads to an effective
245 decrease in BOD_5 concentration. The efficiency of BOD_5 removal in the wastewater treatment
246 plant model at different ranges of oxygenation, with a division into uniform groups, is
247 presented in Figure 4. The Anova confirmed significant differences in BOD_5 removal
248 efficiency at the different oxygenation levels. The Tukey test indicated that significantly the
249 highest efficiency of BOD_5 removal (94.3%) and the lowest BOD_5 concentration (4.4 mg/l)
250 were obtained at the oxygenation level of 30-40% (Fig. 4, 5). At the aeration level of 40-50%,
251 the decrease of BOD_5 removal efficiency to 11% was observed and the concentration of BOD_5
252 at the effluent increased considerably (Fig. 4, 5). One of potential explanations is that
253 increasing the dose of H_2O_2 over 40% most probably inhibited the biological processes, due to
254 oxygenation of microbes. Too high concentration of H_2O_2 could lead to lysis of cells and in the

255consequence the organic matter content increases. Also the remain fraction of relatively
 256hardly degradable organics and Org-N could be decomposed to less complexes compounds in
 257such conditions and during the analytical procedure could be recognized as increased of
 258BOD₅ concentration [4, 7].



259
 260 Fig. 4. The influence of oxygenation level on the efficiency of BOD₅ removal;
 261 the significances of differences between mean values are marked with letters a, b, c, d
 262 at $p \leq 0.05$



263
 264 Fig. 5. Concentration of BOD₅ at inflow and outflow at different oxygenation levels
 265 of treated wastewater
 266

267 During the conventional processes of pollutants removal mineralization of organic matter
268 demands 1 mg of oxygen per 1 mg of decompose organic matter expressed as BOD₅, in the
269 same time for nitrification of 1mg N-NH₄ is required about 4.3 mg of oxygen. Thus many
270 authors arise the problem of competitions between mineralization of organics (heterotrophic
271 bacteria) and nitrification process (autotrophic bacteria) in many wastewater treatment plants.
272 Such statement is particularly true in low –coats systems for wastewater treatment like
273 treatment wetlands technology [41, 58]. In such systems due to limited oxygen conditions
274 both organics and oxidation of ammonia nitrogen can be limited and insufficient [49].

275 The effect of BOD₅ removal in the analyzed model at the oxygenation level of 30-40%
276 (94.3%) was higher than that obtained during long-term operation of single-stage HF systems
277 [42, 45] and comparable to that obtained in hybrid VF-HF systems [59;], VF-VF-HF systems
278 [59] and VF-HF systems at the initial stage of operation, without plants [61].

279 The efficiencies of BOD₅ removal in constructed wetlands treating different types of
280 wastewater are usually high, at the level of 90-99%, while the nitrogen removal could varied
281 significantly from 20 up to 90% [41, 49]. Hybrid constructed wetlands have been reported to
282 effectively remove organic matter also from high-strength wastewater [39, 49] as well as in
283 case of unfavorable C:N ratio [36].

2853. 3. Economic aspects of H₂O₂ application

286 The results of the study indicate that hydrogen peroxide can be an attractive alternative to
287 conventional methods of wastewater aeration, bringing similar effects but at a lower energy
288 consumption. Evaluation of the actual costs of the application of the two types of methods is
289 quite complicated and has to be based on an assumed effect. Each of the methods has a
290 specific character and is defined by completely different factors. In the case of traditional
291 aeration, the major factor is energy consumption during aeration defined as aeration capacity
292 per unit power [62]. Assuming that the expected effect is to achieve a strictly defined
293 optimum level of oxygenation (40%), this factor varies from 0.25 to 0.30 kWh/m³. It is worth
294 noting that in practice the capacity of aerators as well as the efficiency of aeration depend on a
295 number of indirect factors, such as pressure, temperature, depth and technology of air
296 injecting as well as the level of consumption per unit aeration [63].

297 In the case of hydrogen peroxide dosing, the basic characterizing factor is reagent
298 consumption. Basing on the experience gained in this study, it can be concluded that to obtain
299 the oxygenation level of 30-40% approximately 0.25 kg/m³ of 50% hydrogen peroxide has to
300 be used. Calculations based on the average prices of energy and hydrogen peroxide indicate

301that the costs of H₂O₂ dosing are higher than aeration with compressed air. These estimations
302can significantly change with time and be different for different countries. Moreover, they are
303only based on operation costs and do not include capital or amortization charges that are
304considerably higher in the case of aeration with compressed air.

305 Apart from various applications in chemical degradation of the pollutants present in
306wastewater, hydrogen peroxide can also be used to significantly aid biochemical treatment.
307Due to the fact that microorganisms are able to produce oxygen from a 0.1% solution of H₂O₂,
308dosing of hydrogen peroxide can be a convenient and cost-effective way of intensifying
309nitrification at the early stages of wastewater treatment, when wastewater contains low
310oxygen concentrations [20]. As it was indicated earlier, increasing of hydrogen peroxide doses
311combined with filtration of wastewater improves the efficiency of nitrogen removal. The
312highest removal efficiency was obtained at the oxygenation levels of 30-40% and 40-50%.
313Because the investigations were performed in a model-scale set-up and the investigation
314conditions were similar during the various experiments, it can be concluded that the decrease
315in ammonia nitrogen concentration in wastewater resulted from the application of hydrogen
316peroxide in the form of a 0.1% solution and was not related to other factors such as the grain
317size of the filter material or filtration rate [64].

318 The pilot investigations of the wastewater treatment plant model with a sand filter indicate
319that aeration with hydrogen peroxide can be used to optimize nitrification and increase
320ammonia nitrogen and BOD₅ removal efficiency at different WWTPs. Application of this
321method could also bring positive effects for WWTPs with activated sludge [65-66] as well as
322sand filters or drainage systems (which are known to have a low ammonia nitrogen removal
323efficiency). However, application of this method would require further investigations under
324laboratory and technical-scale conditions.

325 Recently there is an increasing interest in multistage constructed wetlands all over the
326world. The systems with alternately vertical and horizontal flow beds, are capable of effective
327removal of nitrogen and organic matter, fulfilling the criteria of sustainability development
328[67]. Application of H₂O₂ in multistage wetland systems as well as in other technological
329solutions of wastewater treatment can optimize ammonia removal and help to control
330eutrophication of surface waters.

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3355. Conclusions

336 Hydrogen peroxide can be applied as a source of oxygen for microorganisms and as an
337agent intensifying biochemical transformations during ammonia nitrogen oxygenation in the
338nitrification process.

339 In the present study, the efficiency of ammonia nitrogen removal in the sand filter with a
340horizontal flow of wastewater was directly dependent on the dose of H_2O_2 and thus the level
341of wastewater oxygenation. The highest removal efficiency of ammonia nitrogen was
342obtained at the oxygenation levels of 30-40% and 40-50%, while the lowest removal
343efficiency was obtained at 0-10% and 10-20% oxygenation. The differences in removal
344efficiency between the various oxygenation levels were statistically significant. Application of
345high doses of hydrogen peroxide in combination with wastewater filtration can result in
346ammonia nitrogen removal exceeding 80%.

347 It was demonstrated that application of hydrogen peroxide also results in effective removal
348of BOD_5 . The highest BOD_5 removal efficiency (94.3%) was obtained at the oxygenation
349level of 30-40%, and such level of oxygenation is advanced as optimal for both organic and
350ammonium nitrogen removal in WWTP which needs the improvement towards fulfill the
351requirements of final effluent.

352

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357

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