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Effect of selected factors on the removal of organic matter in a model of moving bed biofilm reactor

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Abstract: The aim of the study was to determine the impact of selected factors on the reduction of organic pollutants, expressed in BOD_5 and COD_{Cr}, in wastewater treated in a laboratory scale model of moving bed biofilm reactor (MBBR). The factors included in the experiment: the degree of filling the fluidized bed with biomass carriers, hydraulic load, and aeration intensity. The tested model of the bioreactor consisted of five independent chambers with diameter D = 0.14 m and height H = 2.0 m, which were filled with biomass carriers at 0%, 20%, 40%, 60%, 70% of their active volume. During the test period, hydraulic loads at the level of $Q_{h1} = 0.073\ m^3 \cdot m^{-2} \cdot h^{-1}$ and $Q_{h2} = 0.036\ m^3 \cdot m^{-2} \cdot h^{-1}$ were applied, which ensured one-day and two-day sewage retention, respectively. The said reactors were subjected to constant aeration at $P_1 = 3.0\ dm^3 \cdot min^{-1}$ and $P_2 = 5.0\ dm^3 \cdot min^{-1}$. The highest efficiency of the reduction of the analysed indicators was demonstrated by reactors filled with carriers in the degree of 40–60%. Based on the statistical analyses (the analyses of the ANOVA variations and the Kruskal-Wallis test) carried out, it was found that the studied factors significantly modified the mutual interaction in the process of reducing BOD_5 in treated wastewater of the reactors tested. The significance of the impact of the discussed factors on the values of the studied indicators in treated wastewater depends on mutual interactions between the investigated factors.

Introduction

In recent years, there has been an increased interest in high--efficiency waste water treatment technologies that allow for the achievement of extensive elimination of pollution and rapid modernization of existing treatment plants without increasing the volume of the reactors already in use (Jóźwiakowski et al. 2015, Pawełek 2016, Pawełek and Bugajski 2017). According to numerous scientific reports, moving bed technology is one such solution (Helness and Ødegaard 1999, Ødegaard and Rusten 1993, Podedworna and Żubrowska-Sudoł 2001). The moving bed technology includes the MBBR (Moving Bed Biofilm Reactor), which is widely recognized around the world. MBBRs combine the advantages of activated sludge technology and biological deposits while minimizing their disadvantages (Ødegaard et al. 1994, Ødegaard et al. 1998). Moving bed bioreactors with regard to small agglomerations may be a strong competition for the known constructed wetland due to the less space needed for their construction and operation. MBBR reactors represent a different view on modern wastewater treatment (Borowski 2007). According to Ødegaard et al. (2000), specially designed biofilm carriers are the fundamental feature of the MBBR technology, as their shape, size, and material have been created to maximize the efficiency of the purification process.

The maximum filling of the reactor volume with carriers depends on the free movement of the bed. Ødegaard (2006) recommends using cylindrical carriers with less than 70% of the reactor volume to allow unobstructed, free-floating in the water. Falletti and Conte (2007) recommend filling the chamber at 43%. Research by Xiao and Ganczarczyk (2006) shows that with the filling of up to 70%, the density of attached biomass is 5 to 13 times higher than in the biomass of the activated sludge. Mannina and Viviani (2009) conducted research on the removal of organic matter in MBBR type reactors with 33% and 66% fill, which resulted in a small variability of the removal efficiency of these compounds depending on the degree of filling.

Research shows that the MBBR technology, due to the possibility of microorganism population density, shows less sensitivity to unfavorable environmental conditions. Bacteria in the biofilm are more resistant to the toxic effects of large amounts of ammonium nitrogen and are less sensitive to sudden changes in the content of pollutants in the reactor (Jokela et al. 2002). According to Sombatsompop et al. (2006) and Chan et al. (2009), the MBBR technology, in contrast to the conventional system with activated sludge, is distinguished by better oxygen permeability, shorter sewage retention time, higher charges of organic compounds, a higher degree of nitrification, and a larger contact area with sewage. Chudoba and Pannier (1994) and Chen et al. (2008) list the successive features of MBBR flow reactors that place them above the activated sludge system, namely: high biomass concentration, high impact tolerance of pollutant loads, smaller reactor sizes and no sediment swelling problem. Other advantages of the MBBR technology compared to systems based on activated sludge include: high efficiency of wastewater treatment at low temperature and lower operating and investment costs, mainly due to the reduction in the volume of MBBR reactors (Kruszelnicka et al. 2014, Rodgers and Zhan 2003). According to studies by Podedworna and Żubrowska-Sudoł (2006), the volume of the MBBR reactor can be up to 4 times lower than that of a reactor operating in an activated sludge system with exactly the same working conditions.

Moreover, an additional advantage of the MBBR reactor is always the smaller sludge growth. According to Podedworna and Żubrowska-Sudoł (2011), the only downside of the MBBR technology in relation to the treatment plant operating in the technology of the activated sludge itself is the increased demand for oxygen (up to 36%). Sindhi and Shah (2013) also include a limited possibility of process control and lower popularity of this technology as the disadvantages of MBBR reactors.

The objective of this study was to investigate the influence of selected factors on the effectiveness of the removal of organic matter in the laboratory-scale moving bed biofilm reactors. The analyzed factors included the degree of filling of the biofilm carriers, the amount of hydraulic load, and the intensity of aeration. The said parameters have been chosen because of their crucial importance in the proper functioning and operation of flow reactors with a moving bed.

Materials and methods

Experimental set-up

The tested model (Fig. 1) comprised five independent bioreactors K1, K2, K3, K4, K5 with diameter D = 0.14 m and height H = 2.0 m, which were filled with biomass carriers to 70%, 60%, 40%, 20%, 0% of their active volume. The active volume of each reactor was 26.93 dm^3. The reactor chambers were made of acrylic glass (PLEXI), which allowed for continuous observation of wastewater treatment and development of the biofilm on the surface of biomass carriers. To fill the reactors, type 2H BCN 009 polyethylene carriers with dimensions of 9x7 mm, specific biofilm surface area 834 $m^2 \cdot m^{-3}$ and surface area 517 $m^2 \cdot m^{-3}$ were used. The shapes were retained in the reactor chamber with the mounting of the grate and the protective mesh that prevented the outflow of carriers along with the outflow of purified sewage. Each reactor was aerated with a central membrane blower and an air distributor. The air flow was regulated by means of rotameters, which are the part of each reactor. The diffusers used, apart from the oxygenating function, also played the role of mixing sewage and keeping the biomass carriers in continuous motion. Sewage purified in a given reactor, through a safety mesh, went to a drain pipe, located at the central point of each reactor, from where it would gravitationally flow into the sampling container.

To each of the reactors tested, the same quantity of sewage pre-treated in an initial settling tank, having identical physical and chemical properties, was supplied. The wastewater dosing

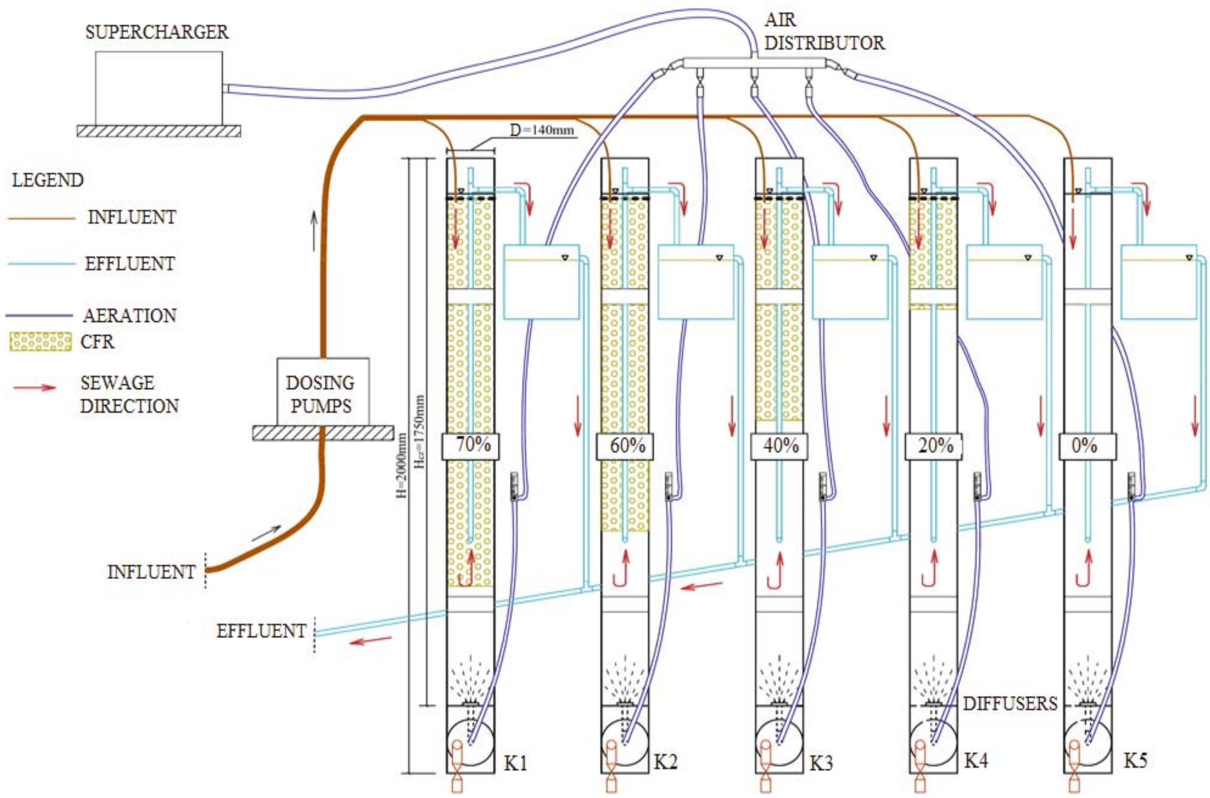

Fig. 1. Schematic diagram of the moving bed biofilm reactors used in this study

was carried out using a system of peristaltic pumps equipped with a controller.

Experimental procedure

In order to determine the composition of wastewater that came to the model, and of treated wastewater in individual reactors, a series of physical and chemical analyses were performed in the following areas: BOD_5, COD_{Cr}, pH, temperature, dissolved oxygen. Bioreactor tests were carried out for two variants of hydraulic load: Q_{h1} = 0.073 $m^3 \cdot h^{-1} \cdot m^{-2}$, allowing to obtain hydraulic retention time (HRT) equal to 1 day and Q_{h2} = 0.036 $m^3 \cdot h^{-1} \cdot m^{-2}$ at HRT = 2 days. For each variant of hydraulic load, two variants of aeration intensity were applied: 3.0 $dm^3 \cdot min^{-1}$ and 5.0 $dm^3 \cdot min^{-1}$. The tests were carried out in laboratory conditions for 183 days. In the analyzed period, 37 measurement series were carried out, collecting and subjecting physical and chemical analysis to 222 sewage samples. In each series, 6 sewage samples were collected (5 samples from each reactor and 1 sample from a settling tank) on average every 4–6 days. The start-up periods lasted for about 2 weeks after prior cleaning of the carriers.

Methodology for study results analysis

Having the values of the analyzed indicators of sewage pollutants treated in individual reactors and sewage flowing in from the settling tank, the effectiveness of pollution reduction in individual bioreactors was calculated. For the obtained results basic descriptive statistics were presented: minimum value, average value, maximum value, gap, standard deviation and coefficient of variation. The determined values of individual statistical parameters were aimed at characterizing the dynamics of changes in the composition of the sewage composition in the tested model.

Subsequently, a number of statistical analyses were carried out in order to verify the influence of the analyzed factors on the values of selected pollutants (BOD_5, COD_{Cr}). Statistical analyses were performed using two types of tests: multivariate analysis of ANOVA variance (for BOD_5) and in the absence of normal distribution of random variables and the possibility of their normalization, non-parametric Kruskal-Wallis rank test (in the case of COD_{Cr}). The significance level α=0.05 was assumed in the calculations (probability of rejection of the true null hypothesis about the lack of significant influence of the analyzed factor on the values of the tested indicator of pollutant wastewater pollution). In the conducted empirical studies, wherever the multivariate ANOVA analysis was applied, the Leven test did not reject the null hypothesis about the lack of significant differences between the variances. In the case when the analysis of variance showed that in the whole population the mean in individual groups differed significantly from one another, then the Tukey's HSD post hoc test was used, indicating between which groups medium differences were significant. Subsequently, the occurrence of significant interactions, i.e. modification of the interaction of one factor by another factor, was checked. After determining their occurrence, detailed comparisons were made for the effects of interaction, also using the Tukey test (HSD).

Results and discussion

Physical and chemical parameters of inflowing sewage

Average values of pH and temperature in the domestic sewage, supplied to the studied models and treated in them were in the range of 5.12–6.39 (pH) and 14.00–21.90ºC (temperature). Table 1 shows the dissolved oxygen values for the two aeration variants used. These values were determined in treated domestic sewage in individual MBBR type bioreactors. It was found that in the case of aeration at the level of 5.0 $dm^3 \cdot min^{-1}$, the average values of dissolved oxygen in the wastewater in individual reactors were in the range of 2.37–4.14 $mgO_2 \cdot dm^{-3}$. In 3.0 $dm^3 \cdot min^{-1}$ aeration conditions, the average oxygen content in individual chambers was lower and was in the range of 2.25–3.77 $mgO_2 \cdot dm^{-3}$. In the case of both variants of aeration, it was noticed that in reactors with a higher degree of filling with carriers, the coefficient of variation was at a lower level. In the case of 5.0 $dm^3 \cdot min^{-1}$ aeration, the coefficient of variation ranged of 0.13–0.40, indicating a small and average variation in dissolved oxygen concentration. Whereas, for aeration at the level 3.0 $dm^3 \cdot min^{-1}$, this coefficient obtained average values and ranged from 0.20 to 0.33. In reactors with a level of 60% (K2) and 70% (K1), significantly higher mean values of dissolved oxygen were noted compared to the values quoted by other authors, who state that in the aerated chambers, the content of dissolved oxygen ranges from 2.0 to 3.0 $mgO_2 \cdot dm^{-3}$ (Rusten et al. 2006). For the remaining reactors, the dissolved oxygen concentration was in the usual range.

Table 1. Average values of the dissolved oxygen in the effluent of the bioreactors for the two aeration variants used

Parameter			Sampling zone				
			K1	K2	K3	K4	K5
Dissolved oxygen [$mgO_2 \cdot dm^{-3}$]	Aeration intensity: P_1 = 5.0 $dm^3 \cdot min^{-1}$	minimum	2.49	3.24	0.89	1.99	0.88
		average	3.96	4.14	2.59	2.98	2.37
		maximum	4.68	5.34	4.45	4.25	3.67
		coefficient of variation	0.13	0.17	0.40	0.25	0.33
	Aeration intensity: P_2 = 3.0 $dm^3 \cdot min^{-1}$	minimum	1.77	1.50	1.24	1.70	0.88
		average	3.77	3.67	2.85	2.85	2.25
		maximum	4.77	4.83	4.29	4.05	3.50
		coefficient of variation	0.20	0.21	0.32	0.25	0.33

Organic matter removal

BOD_5 and COD_{Cr} values in sewage flowing into the tested bioreactors and in treated wastewater are presented in Table 2. It was established on this basis that sewage pre-treated, inflowing from the settling tank to the research model, was characterized by high variability of BOD_5 and COD_{Cr} values, containing successively in range 110.00–1350.00 $mgO_2 \cdot dm^{-3}$ and 224.00–1450.00 $mgO_2 \cdot dm^{-3}$. The maximum BOD_5 value in raw sewage was found to be significantly higher than the values reported by other authors: 530.00 $mgO_2 \cdot dm^{-3}$ (Henze et al. 1997), 500 $mgO_2 \cdot dm^{-3}$ (Błażejewski 2003). The maximum value of COD_{Cr} was 710 $mgO_2 \cdot dm^{-3}$ higher than the value presented by Henze et al. (1997). The coefficient of variation was 0.55 and 0.40 respectively, indicating the high variability of the values of discussed indicators (Mucha 1994). The analyzed reactors with moving bed K1, K2, K3, K4, and K5 were characterized by BOD_5 values (Tab. 2) in the range 5.00–230.00 $mgO_2 \cdot dm^{-3}$, 3.00–220.00 $mgO_2 \cdot dm^{-3}$, 5.00–240.00 $mgO_2 \cdot dm^{-3}$, 16.00–225.00 $mgO_2 \cdot dm^{-3}$and 16.00–975.00 $mgO_2 \cdot dm^{-3}$. The COD_{Cr} values in the individual reactors were 17.00–350.00 $mgO_2 \cdot dm^{-3}$, 18.00–360.00 $mgO_2 \cdot dm^{-3}$, 20.00–400.00 $mgO_2 \cdot dm^{-3}$, 74.00–566.00 $mgO_2 \cdot dm^{-3}$ and 77.00–712.00 $mgO_2 \cdot dm^{-3}$. BOD_5 values in the reactors tested showed greater variability than COD_{Cr} values. In the case of BOD_5, the value of the coefficient of variation indicated high and very large variability of results, ranging from 0.67 to 1.10, while COD_{Cr} values were characterized by a coefficient of variation of 0.42–0.55 (Mucha 1994). Table 2 also presents the average values of BOD_5 and COD_{Cr} reduction efficiency, which were obtained in individual reactors. It shows that the largest reduction of BOD_5, 90.51% and 88.51%, was achieved in reactors with 60% and 70% filling. The highest efficiency of COD_{Cr} reduction (70.46–72.59%) was obtained in reactors with filling of carriers from 40% to 70%. Together with the decreasing number of biofilm carriers used, the effectiveness of the reduction of discussed indicators decreased to the level of 65.88% in the case of BOD_5 and 59.73% for COD_{Cr} in the reactor without biomass carriers. Ødegaard (2006) presents similar values of BOD_5 reduction in MBBR reactors, ranging from 85% to 95%. While Makowska et al. (2005) give higher values of the BOD_5 reduction achieved, ranging from 97.4% to 98.9%, Zhao et al. (2006) report higher efficiency of COD_{Cr} reduction, amounting to 88.5%, with hydraulic wastewater retention time equal to 2.5 hours. Studies by Husham et al. (2014) confirm the high effectiveness of eliminating COD_{Cr}, ranging from 76.2% to 98.6%.

Effect of selected factors on BOD_5 in treated wastewater

In order to determine whether the degree of filling of carriers, the amount of hydraulic load, and the intensity of aeration are factors significantly differentiating the average BOD_5 values in treated wastewater in the analyzed reactors, a multifactor analysis of variance (ANOVA) was used. On its basis a significant influence of the degree of filling with biomass carriers and aeration intensity was found ($p<0.05$), in the absence of significance of the influence of hydraulic load size ($p=0.25$), BOD_5 indicator in treated wastewater in tested reactors. Moreover, at $p<0.05$, the three-factor interaction of the considered factors was confirmed (filling degree, hydraulic load, aeration). It means that the studied factors significantly modified mutual interactions.

In order to answer the question, which of the analyzed averages were significantly different from each other, the Tukey test (HSD) was performed, which showed that the average for the reactor without filling is significantly different from the average for all other reactors. In the case of reactors filled to 20% and 40%, significant differences between the averages were recorded in comparison with 60% and 70% filled reactors. The average for the remaining comparisons did not differ significantly.

On the basis of further analyses, it was found that the mean for the applied aeration sizes differed significantly.

Table 2. Summary of basic descriptive statistics of BOD_5 and COD_{Cr} values along with their reduction in pre-treated sewage and after purification in individual reactors

Parameter	BOD_5 [$mgO_2 \cdot dm^{-3}$]						COD_{Cr} [$mgO_2 \cdot dm^{-3}$]					
	Influent	Effluent					Influent	Effluent				
		K1	K2	K3	K4	K5		K1	K2	K3	K4	K5
minimum	110.00	5.00	3.00	5.00	16.00	16.00	224.00	17.00	18.00	20.00	74.00	77.00
average	521.24	40.08	39.08	69.84	85.84	157.16	711.33	176.42	167.72	167.61	230.69	257.33
maximum	1350.00	230.00	220.00	240.00	225.00	975.00	1450.00	350.00	360.00	400.00	566.00	712.00
amount of samples	37	37	37	37	37	37	37	37	37	37	37	37
interval	1240.00	225.00	217.00	235.00	209.00	959.00	1226.00	333.00	342.00	380.00	492.00	635.00
standard deviation	286.22	44.15	37.35	55.34	57.74	170.09	287.78	76.63	82.22	91.71	97.54	123.02
coefficient of variation	0.55	1.10	0.96	0.79	0.67	1.08	0.40	0.43	0.49	0.55	0.42	0.48
removal percentage [%]	–	88.51 31.82–99.0	90.51 54.0–98.8	83.75 40.91–99.0	80.08 22.73–95.93	65.88 0.0–97.71	–	70.46 26.32–95.45	71.70 24.12–97.44	72.59 32.66–97.44	63.48 24.62–93.12	59.73 16.72–91.74

Figure 2 presents statistically significant interactions between the degree of filling of the reactors and the hydraulic load at the tested aeration levels (3.0 $dm^3 \cdot min^{-1}$, 5.0 $dm^3 \cdot min^{-1}$). In the conditions of lower aeration, the lowest values of BOD_5 were recorded in reactors filled with carriers at 40%, 60% and 70% with a hydraulic load of 0.036 $m^3 \cdot h^{-1} \cdot m^{-2}$ and HRT=2 days. In a chamber devoid of biomass carriers and in a reactor filled with carriers at the level of 20%, lower BOD_5 values were obtained with a hydraulic load of 0.073 $m^3 \cdot h^{-1} \cdot m^{-2}$, HRT=1 day. In conditions of more intense aeration (5.0 $dm^3 \cdot min^{-1}$), reactors filled with carriers from 0% to 60% were characterized by lower BOD_5 values at higher hydraulic load (0.073 $m^3 \cdot h^{-1} \cdot m^{-2}$). The lowest values of the tested indicator were obtained in a reactor filled with biomass carriers at 70%, with a hydraulic load equal to 0.036 $m^3 \cdot h^{-1} \cdot m^{-2}$ (HRT=2 days).

Influence of selected factors on the COD_{Cr} in treated wastewater

The nonparametric test of Kruskal-Wallis was used for the analysis of the impact of selected factors on the COD_{Cr} in treated sewage, due to the fact that the tested variable was not subject to normalization.

Factor I analysis: the degree of filling the reactor bed with biomass carriers

Based on the statistical analysis (Tab. 3), it was found that in the case of increased hydraulic load Q_{h1}, regardless of the applied aeration, there is no significant influence of the degree of filling with carriers on COD_{Cr} values in treated wastewater. In the case of reactors operating under lower hydraulic load Q_{h2}, for each variant of aeration (P_1 = 5.0 $dm^3 \cdot min^{-1}$ and P_2 = 3.0 $dm^3 \cdot min^{-1}$), the degree of filling with biomass carriers significantly differentiated the values of the analyzed indicator ($p<0.05$).

In order to indicate between which degrees of reactor filling there are significant differences, a post-hoc test was carried out. The analysis showed that under hydraulic loading conditions Q_{h1}, with 5.0 $dm^3 \cdot min^{-1}$ aeration, the reactors filled with 0% to 20% carriers significantly differed only from the reactors with the filling from 60% to 70%. In the case of 3.0 $dm^3 \cdot min^{-1}$ aeration, no significant differences between the reactor filling ratios in terms of the value of the tested indicator were found.

Factor II analysis: hydraulic load

According to the results of the Kruskal-Wallis test, presented in Table 4, it was found that the tested hydraulic load quantities

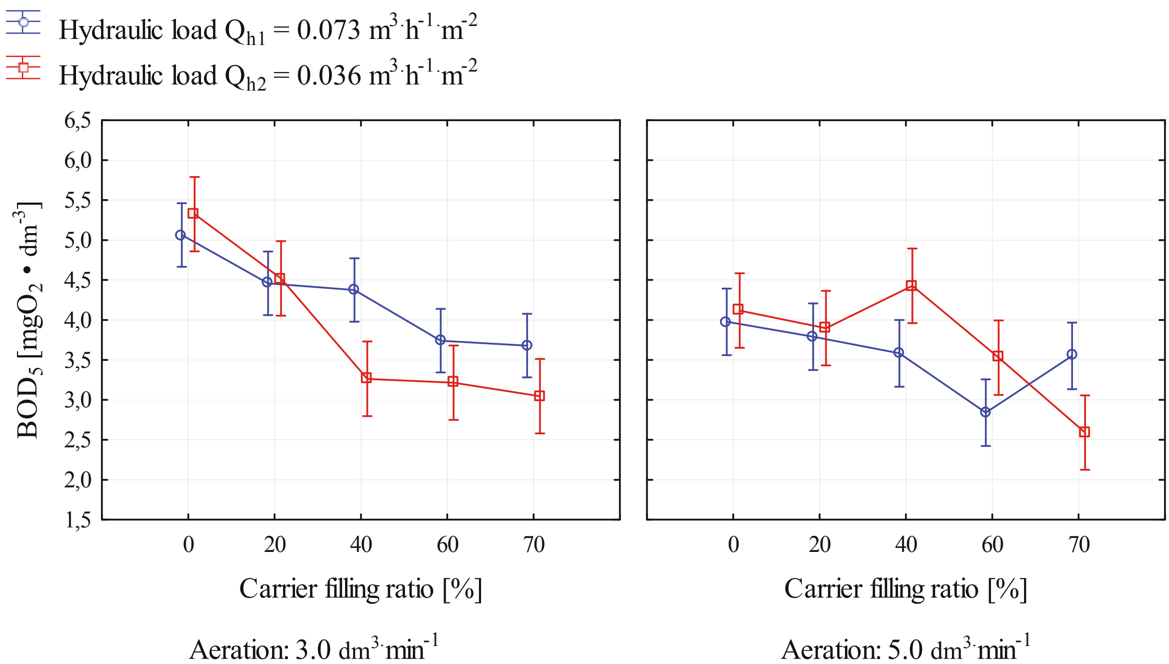

Fig. 2. Graphical interpretation of the interaction effect between the studied factors against the background of assumed aeration intensity for the BOD_5

Table 3. Results of significance of the effect of the degree of filling with biomass carriers on the COD_{Cr} value in treated wastewater of tested reactors

Hydraulic load [$m^3 \cdot h^{-1} \cdot m^{-2}$]	Aeration intensity [$dm^3 \cdot min^{-1}$]	χ^2	p
Q_{h1}=0.073	5.0	4.0000	0.4060
	3.0	6.8568	0.1437
Q_{h2}=0.036	5.0	27.0000	**0.0000**
	3.0	12.0000	**0.0174**

Bold marks test probability below 0.05

($0.073\ m^3 \cdot h^{-1} \cdot m^{-2}$, $0.036\ m^3 \cdot h^{-1} \cdot m^{-2}$), under P_1 aeration intensity, did not significantly differentiate the COD_{Cr} ($p>0.05$).

The hydraulic load, under the aeration conditions P_2, turned out to be a factor that significantly influenced ($p<0.05$) the values of the tested indicator in treated wastewater only in the reactor with the highest degree of filling (70%). Moreover, there were no significant differences between the tested hydraulic load values in terms of COD_{Cr} value in treated wastewater in the analyzed reactor.

Factor III analysis: aeration intensity

On the basis of the non-parametric test, the results of which are presented in Table 5, it was found that in the case of increased hydraulic load Q_{h1}, regardless of the degree of filling with biomass carriers, the tested aeration rates (P_1, P_2) did not significantly differentiate ($p>0.05$) COD_{Cr} values in treated wastewater.

In the conditions of the hydraulic load Q_{h2}, a significant effect of the assumed aeration was noted ($p<0.05$) in the case of reactors filled to the extent of 70% and 60% of active volume of reactors. On the basis of further statistical analyses (Post-hoc test) it was found that there are significant differences between the tested aeration values in terms of COD_{Cr} value in treated wastewater in reactors filled with carriers from 60% to 70%.

Conclusions

The tests have shown that the degree of filling with model MBBR type reactors had a significant impact on the efficiency of reducing the BOD_5 value in treated wastewater. In the case of COD_{Cr}, a significant impact was confirmed only in conditions of lower hydraulic load. The highest efficiency of the reduction of the analyzed indicators was demonstrated by reactors filled with carriers in the degree of 40–60%. There

Table 4. Results of the significance of the impact of hydraulic load on the COD_{Cr} value in treated wastewater in tested reactors

Aeration intensity [$dm^3 \cdot min^{-1}$]	Filling with carriers [%]	χ^2	p
$P_1 = 5.0$	70 (“K1”)	3.6000	0.0578
	60 (“K2”)	0.2813	0.5959
	40 (“K3”)	0.0000	1.0000
	20 (“K4”)	1.9013	0.1679
	0 (“K5”)	3.6000	0.0578
$P_2 = 3.0$	70	4.9684	**0.0258**
	60	0.5400	0.4625
	40	0.0384	0.8447
	20	0.0384	0.8447
	0	0.5397	0.4625

Bold marks test probability below 0.05

Table 5. Results of significance of the effect of aeration intensity on the COD_{Cr} value in treated wastewater in bioreactors

Hydraulic load [$m^3 \cdot h^{-1} \cdot m^{-2}$]	Filling with carriers [%]	χ^2	p
$Q_{h1} = 0.073$	70 (“K1”)	2.3760	0.1232
	60 (“K2”)	1.2886	0.2563
	40 (“K3”)	0.0434	0.8350
	20 (“K4”)	2.3760	0.1232
	0 (“K5”)	2.3760	0.1232
$Q_{h2} = 0.036$	70	9.0000	**0.0027**
	60	4.0000	**0.0455**
	40	1.0000	0.3173
	20	1.0000	0.3173
	0	1.0000	0.3173

Bold marks test probability below 0.05

was no significant influence of the tested hydraulic load values on BOD_5, and in the case of COD_{Cr} the analyzed factor was characterized by a significant impact, only in the reactor with the highest degree of filling (70%), operating in conditions of lower aeration (3.0 $dm^3 \cdot min^{-1}$). Studies on the impact of aeration intensity showed that this factor significantly differentiated BOD_5 values, and in the case of COD_{Cr}, a significant effect was noted only in reactors with a level of 60–70%, operating at lower hydraulic load (0.036 $m^3 \cdot h^{-1} \cdot m^{-2}$). Based on the statistical analyses carried out, it was found that the studied factors significantly modified the mutual interaction in the process of reducing BOD_5 in treated wastewater of the reactors tested. The significance of the impact of the discussed factors on the values of the studied indicators in treated wastewater depends on mutual interactions between the investigated factors.

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Wpływ wybranych czynników na eliminację zanieczyszczeń organicznych w modelowym reaktorze ze złożem ruchomym

Streszczenie: Celem badań było określenie wpływu wybranych czynników na zmniejszenie zanieczyszczeń organicznych, wyrażonych wskaźnikami BZT_5 i $ChZT_{Cr}$, w ściekach oczyszczanych w modelu reaktora przypływowego ze złożem ruchomym typu MBBR. Czynniki, które uwzględniono w eksperymencie to: stopień wypełnienia złoża nośnikami biomasy, obciążenie hydrauliczne oraz intensywność napowietrzania. Badany model bioreaktora stanowił pięć niezależnych komór o średnicy D = 0,14 m i wysokości H = 2,0 m, które były wypełnione nośnikami biomasy w stopniu: 0%, 20%, 40%, 60%, 70% ich objętości czynnej. W okresie badań zastosowano obciążenia hydrauliczne na poziomie $Q_{h1} = 0{,}073\ m^3 \cdot m^{-2} \cdot h^{-1}$ oraz $Q_{h2} = 0{,}036\ m^3 \cdot m^{-2} \cdot h^{-1}$, co zapewniało odpowiednio jednodobowe oraz dwudobowe zatrzymanie ścieków. Przedmiotowe reaktory poddawane były stałemu napowietrzaniu na poziomie $P_1 = 3{,}0\ dm^3 \cdot min^{-1}$ oraz $P_2 = 5{,}0\ dm^3 \cdot min^{-1}$. Największą skuteczność redukcji analizowanych wskaźników wykazywały reaktory wypełnione kształtkami w stopniu 40–60%. Na podstawie przeprowadzonych analiz statystycznych (analiza wariacji ANOVA oraz test Kruskala-Wallisa) stwierdzono, iż badane czynniki istotnie modyfikowały wzajemne oddziaływanie na siebie w procesie zmniejszania BZT_5 w ściekach oczyszczonych badanych. Istotność wpływu omawianych czynników na wartości badanych wskaźników w ściekach oczyszczonych, zależy od wzajemnych interakcji między badanymi czynnikami.