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Treatment of Wastewater with High Ammonium Nitrogen Concentration

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ABSTRACT

The paper deals with the problem of wastewater treatment with specific physicochemical composition (increased ammonium nitrogen concentration) which were generated in Motor Rest Areas (MRA). Conventional biological wastewater treatment systems with activated sludge were used to purify the wastewater from sanitary equipment used in MRA. On the basis of the research conducted on four MRA, an attempt was made to determine the impact of the wastewater quality on biological wastewater treatment processes. The wastewater supplied to the treatment system was characterized by predominance of biologically non-degradable organic matter (average BOD/COD ratio 4.39 – 10.42) as well as high concentration of ammonium nitrogen 273.9 – 334.55 mgN-NH_4/dm^3. The wastewater alkalinity determined by high content of ammonium nitrogen had a negative impact on the biological treatment processes. Unequal pollution load and temporary, high hydraulic load caused leaching of solid suspension from settling tank as well as leaching of particles of activated sludge from the reactor's chamber. The lack of organic matter susceptible to biological decomposition makes it difficult to develop the biocenosis of activated sludge, and the limits of ammonium nitrogen concentration inhibit the nitrification processes.

Keywords: Motor Rest Area (MRA), activated sludge, organic matter, ammonium nitrogen, wastewater treatment

INTRODUCTION

Water intake and production of wastewater is inextricably linked to the human existence. In the areas of compact and dispersed housing, the problem of collecting and treating sewage is solved by using central sewage systems or possibly by individual wastewater treatment systems [Dąbrowska et al. 2017]. The constant increase of social awareness in the context of the quality of the generated wastewater has resulted in the development of high-efficiency treatment methods [Pawęska and Bawiec 2017, Prabakar et al. 2018, Ravndal et al. 2018]. This aspect is extremely important for the development of the road network and related technical infrastructure elements such as Motor Rest Areas (MRA). The wastewater with a physicochemical composition hindering the purification process with the use of conventional systems is primarily generated in Motor Rest Areas without separate catering outlets, equipped only with the devices related to its main function – the rest. Few studies related to the characteristics of this type of sewage mainly concern the insufficiently recognized problem of uneven wastewater inflow and high pollution loads [Etzel 1981, Kiss et al. 2011].

In classic wastewater treatment systems using the biological method, the possibility of carbon compounds decomposition in the aerobic environment using bacteria is considered one of the most important factors ensuring the correct purification process. The condition of this process is the susceptibility of organic matter contained in the wastewater to microbial degradation. With the reduction of carbon compounds (expressed by the BOD, COD, TOC value), the nitrogen removal processes occur simultaneously [Radetic et al. 2018, Zhou et al. 2015]. The correct proportions of nutrients, which in addition to carbon compounds are needed for bacterial growth, are described by the relationship BOD:N:P=100:5:1. Maintaining this proportion in wastewater is needed for the proper growth of microorganisms and the construction of new biomass [Abou-Elela et al. 2016]. The biodegradability of carbon compounds contained in the wastewater is indicative by the COD/BOD ratio. The higher the value (>2.5), the slower the decomposition and the higher the content of non-biodegradable substances are. The lowest values (<1.8) indicate that the sewage contains the substances susceptible to biological decomposition [Chen et al. 2015, Siwiec et al. 2018]. As soon as microorganisms deplete the food substance accumulated in organic compounds, the nitrogen compounds decompose (nitrification). The nitrification process, which is the beginning of the transformation of nitrogen compounds, is limited primarily by the wastewater pH, the ammonium nitrogen and dissolved oxygen concentrations, the BOD/TN ratio and temperature [Van Hulle et al. 2010, Mo et al. 2018].

On the basis of the European and global research, a characteristic feature of the wastewater from the Motor Rest Area is observed – high concentrations of total nitrogen in relation to low values of biodegradable carbon compounds expressed by BOD [Etzel 1981, Kiss et al. 2011, Londong and Meyer 2009, Parker et al. 1977, Scharfe and Malina 1987, Sylvester and Seabloom 1972]. The main component of urine in the wastewater stream – urea, during collection in treatment plant components on the MRA is hydrolyzed to ammonia, which cause the increase of pH. Finally, the wastewater with high ammonium nitrogen concentration and high pH flows into the purification system. Such wastewater does not create favorable (environmental) conditions for the growth of activated sludge biocenosis. The specific composition of the wastewater directly affects the type of technology used to treat it. The location of Motor Rest Area facilities along express roads at a considerable distance from cities makes it difficult to connect them to the collective sewage system, which is why local wastewater treatment plants are popular solutions [Heger et al. 2016, Kiss et al. 2011]. The traditionally used solutions of activated sludge reactors may not provide sufficiently high efficiency of wastewater treatment due to the conditions hindering the development of active biomass. In recent years, there has been an increase in interest in urine separation systems for its further use, which may be an alternative to traditional biological treatment plants [Maurer et al. 2006, Pronk and Kone 2009].

The observed problem led the authors to focus on the subject of wastewater treatment with a high concentration of ammonium nitrogen resulting from the operation of Motor Rest Area facilities. On the basis of the research conducted at four facilities (MRA), an attempt was made to determine the impact of the quality of wastewater generated in the treatment plants designed for travel facilities (MRA) on biological treatment processes.

MATERIALS AND METHODS

Locations and description of the treatment facility

The tests were carried out at 4 Motor Rest Area facilities located along the expressway (S-8–1, near Wrocław, Poland). The facilities are equipped with the systems for wastewater treatment for PE (population equivalent) 50 with an average daily flow of 10.0 m^3/d, to ensure the legally required reduction of organic matter and nitrogen forms. The permissible designed load of pollutants for BOD, total suspended solids, total nitrogen and total phosphorus was 3 kg/d, 3.5 kg/d, 0.6 kg/d, 0.09 kg/d, respectively.

Each treatment plant consists of a preliminary settling tank and a bioreactor with a fixed submerged bed, clarification chamber, control cabinet and aerators. In the preliminary settling tank, with a capacity of 6.9 m^3, sedimentation and flotation reduce the concentration of total suspended solids and organic matter expressed in the form of BOD and COD. The outflow from the settler after clarification is subjected to biological treatment processes, which are conducted in the reactor chamber by settled microorganisms in the form of a biofilm on the bed filling (Fig. 1). It is assumed that as a result of the life activity of microorganisms, the concentration of organic matter and biogenic compounds (nitrogen and phosphorus) is further reduced. The biological membrane covers the grate immersed in the sewage, under which the fine bubble diffuser assembly responsible for aeration of the bed has been mounted. The wastewater after treatment and clarification in a secondary settler is discharged into a ditch located nearby.

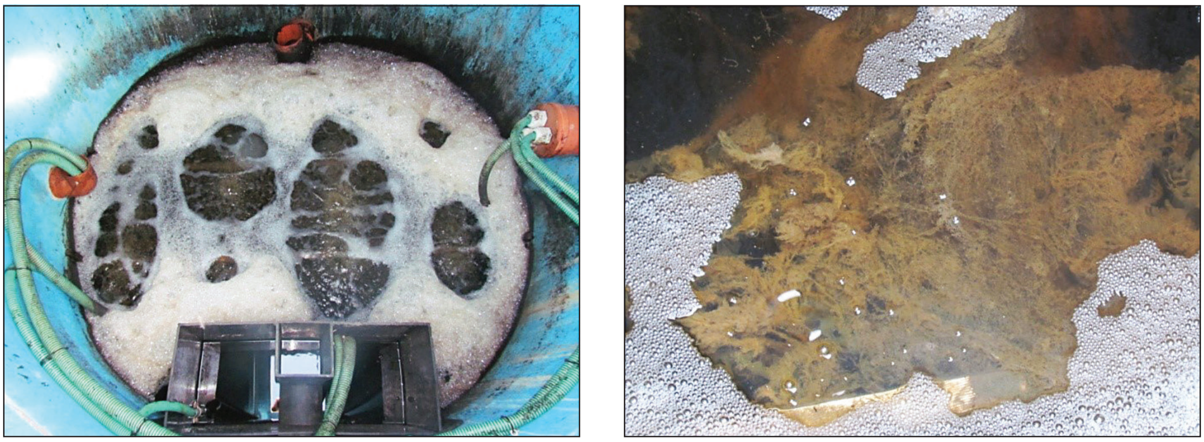

Figure 1. Interior view of the treatment plant series in the Motorway Rest Area

Sampling and analysis

The impact of the quality of sewage generated in Motor Rest Area on the effectiveness of biological treatment processes was assessed based on the physicochemical analyses of the sewage samples taken directly from the primary settling tank (raw wastewater) and after biological treatment and clarification in the secondary settling tank (treated wastewater). In the analyzed samples, the parameters like pH, content of organic matter (BOD, COD), alkalinity, total suspended solids as well as nitrogen forms (total nitrogen, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen) were determined. The analyses were conducted according to standards [APHA-AWWA-WEF 1995]. Basic descriptive statistics and statistically significant relationships were determined for individual parameters. The correlations between the selected parameters were determined using the STATISTICA software. The statistical relationship was determined based on the Spearman rank correlation coefficient (r) used in the absence of a normal distribution, with the significance level $\alpha = 0.05$.

RESULTS AND DISCUSSION

Wastewater samples from primary settling tank

The wastewater samples were taken from operated facilities, where the daily water intake during the research period ranged from 1.3 – 3.9 m^3. Designed hydraulic load of wastewater treatment plants was estimated at 4.0 m^3/d. Each MRA was classified as a category I facility, without gastronomic points [Mastalerczuk 1997]. The equipment in each facility was similar: 5 stands with washbasins and toilet cabins, 2 urinals. The composition of wastewater flowing into the bioreactor did not show the typical composition of domestic sewage (Table 1). The pH in the samples before biological treatment was high (alkaline) which was associated with the specificity of the influent sewage (mainly urine). Urine, in the case of the sewage generated in MRA may constitute over 80% of total nitrogen, which causes high concentrations of ammonium nitrogen (on average 273.9 – 334.5 mg $N\text{-}NH_4/dm^3$). Such a high concentration of ammonium nitrogen (maximum 529.14 mg $N\text{-}NH_4/dm^3$) affects the rate of nitrifying bacteria growth [Van Hulle et al. 2010, Mo et al. 2018, Pronk and Kone 2009, Fux et al. 2002]. The pH increase caused by high concentrations of ammonium nitrogen causes a simultaneous increase of free ammonia concentration, which is manifested by a reduction or even inhibition of the nitrification process. The ammonia concentration of 150 mg NH_3/dm^3 is assumed as the limit value at which both phases of nitrification are already inhibited [Fux et al. 2002]. Nitrate and nitrite forms were found in the samples taken from the primary settling tank, which may indicate the possibility of nitrifying bacteria occurrence in the installation supplying sewage to the tank.

Due to the lack of catering facilities, the load of organic matter fed to the reactor was low. The BOD values were in the average range of 109.92 – 213.1 mg/dm^3 with minimum values of 6.7 and 13.0 mg/dm^3, respectively, while the average COD concentrations were in the range of 387.57 – 938.01 mg/dm^3. One of the most critical parameters of the nitrification process is the COD/N ratio in the influent wastewater [Carrera

Table 1. Ranges and average values of individual forms of nitrogen in the wastewater flowing into the bioreactor for the analyzed treatment plants (MRA1-MRA4)

Parameter		MRA 1	MRA 2	MRA 3	MRA 4
pH	range	7.9 – 9.0	7.9 – 9.1	8.2 – 8.9	8.1 – 8.8
Total nitrogen [mg/dm^3]	range	193.04 – 725.34	103.21 – 569.67	146.31 – 551.60	193.11 – 686.28
	average	370.97	365.25	346.48	193.11
Ammonium nitrogen [mg NNH_4/dm^3]	range	169.00 – 406.59	99.40 – 416.63	117.44 – 529.14	163.85 – 497.11
	average	273.90	302.39	322.85	334.55
Nitrate nitrogen [mg NNO_3/dm^3]	range	0.23 – 14.21	0.25 – 11.96	0.23 – 0.52	0.33 – 20.00
	average	2.85	2.42	0.41	6.81
Nitrite nitrogen [mg NNO_2/dm^3]	range	0.00 – 1.83	0.00 – 1.18	0.00 – 9.33	0.00 – 2.07
	average	0.33	0.24	1.69	0.74
Basicity [mval/dm^3]	range	6.4 – 22.0	5.0 – 30.0	2.8 – 38.0	5.8 – 64.4
	average	16.4	19.7	14.1	26.6

et al. 2004]. It directly influences the increase of competition between the populations of auto and heterotrophic organisms. The organic matter in wastewater, described by the BOD and COD values, can be removed by decomposing carbon compounds in an aerobic environment using bacteria if it contains the compounds susceptible to this decomposition. With the simultaneous reduction of carbon compounds, the nitrogen removal processes are carried out [Radetic et al. 2018, Zhou et al. 2015]. The right proportion of compounds determining the organic matter indicates susceptibility to biological decomposition. In the case of the wastewater flowing into the settling tank, both the BOD/N and BOD/COD ratios (Tab. 2) showed an increased amount of non-biodegradable substance. The presence of organic matter not susceptible to biological degradation may cause inhibition of the biological decomposition processes [Abou-Elela et al. 2016, Chen et al. 2015, Siwiec et al. 2018]. The amount of suspended solids contained in the wastewater flowing from the sanitary facilities to the settling tank was mostly low. Increased suspension values were observed only in the case of temporary, increased sewage inflows.

Wastewater samples from bioreactor

The pH of the wastewater after biological treatment, as in the case of wastewater flowing into the system, was high – alkaline (Tab. 3). The bacteria involved in the transformation of ammonium nitrogen need a sufficiently long time to grow (long activated sludge age). The growth rate of these organisms is primarily affected by the concentration of ammonium nitrogen and dissolved oxygen, temperature, as well as the pH in the environment and the BOD/TN ratio. The ratio within 0.5–3.0 is typical for a separate nitrification process. This indicates a high proportion of nitrifying bacteria in the overall biomass. For the

Table 2. Ranges and average values of organic matter parameters in the wastewater flowing into the bioreactor for the analyzed treatment plants (MRA1-MRA4)

Parameter		MRA 1	MRA 2	MRA 3	MRA 4
COD [mg O_2/dm^3]	range	213.7 – 548.1	187.0 – 822.2	254.6 – 929.0	254.6 – 2007.2
	average	387.57	588.18	344.5	938.01
BOD [mg O_2/dm^3]	range	6.7 – 354	13.0 – 434	47.0 – 324.0	54.0 – 521.0
	average	109.92	153.84	180.73	213.1
TSS [mg/dm^3]	range	27.0 – 116.0	17.0 – 200.0	7.0 – 340.0	10.0 – 1490.0
	average	82.0	92.3	129.67	456.17
COD/TN	range	0.75–1.42	0.74–5.44	1.1–2.53	1.0–2.92
	average	1.11	2.08	1.76	1.92
BOD:TN	range	0.03–0.45	0.051–1.1	0.22–0.63	0.16–0.75
	average	0.23	0.5	0.47	0.43
COD/BOD	range	1.54–31.9	1.89–14.4	1.87–8.55	2.84–6.40
	average	10.42	6.45	4.39	4.87

Table 3. Ranges and average parameter values in the wastewater flowing from the bioreactor for the analyzed treatment plants (MRA1-MRA4)

Parameter		MRA 1	MRA 2	MRA 3	MRA 4
		reactor	reactor	reactor	reactor
pH	range	6.4 – 8.8	5.8 – 8.5	7.7 – 9.2	7.0 – 8.6
Total nitrogen [mg/dm^3]	range	169.3 – 547.4	114.1 – 450.1	112.7 – 781.7	141.7 – 602.1
	average	314.2	235.2	475.4	394.3
Ammonium nitrogen [mg NNH_4/dm^3]	range	78.8 – 541.8	52.5 – 417.8	109.9 – 626.5	22.7 – 447.9
	average	243.2	140.8	397.2	279.7
Nitrate nitrogen [mg NNO_3/dm^3]	range	0.24 – 80.5	0.81 – 130.5	0.13 – 1.65	0.27 – 12.5
	average	6.6	43.5	0.6	1.5
Nitrite nitrogen [mg NNO_2/dm^3]	range	1.46 – 52.17	0.12 – 135.1	0.0 – 67.9	0.06 – 42.2
	average	17.7	12.9	6.4	9.3
COD [mg O_2/dm^3]	range	82.5 – 2064.7	71.2 – 681.7	106.2 – 671.6	124.3 – 1044.0
	average	352.8	313.2	396.2	444.4
BOD [mg O_2/dm^3]	range	6.2 – 128.0	1.7 – 88.0	11.4 – 252.0	7.3 – 256.0
	average	32.7	27.9	82.8	72.6
TSS [mg/dm^3]	range	5.0 – 1040.0	5.0 – 828.0	5.0 – 300.0	6.0 – 545.0
	average	171.9	147.3	87.3	126.4
BOD:TN	range	0.02 – 0.35	0.01 – 0.46	0.02 – 0.53	0.04 – 0.7
	average	0.10	0.12	0.18	0.16
COD/BOD	range	1.0 – 51.6	2.9 – 70.8	1.6 – 15.4	1.41 – 25.1
	average	14.8	21.1	6.6	8.7

observed objects, the values did not indicate the correctness of the nitrification process (low proportion values). The characteristic COD/BOD relationship indicates a low susceptibility of organic matter to biological degradation with a high concentration of ammoniacal nitrogen (Fig. 2). Insufficient amount of organic matter that can be used by activated sludge for the synthesis of new cells, which will subsequently participate in the nitrification process, is also manifested in persistent high concentrations of ammonium nitrogen in the wastewater at the outflow [Chen et al. 2015, Van-Hulle et al. 2010, Siwiec et al. 2018].

The nitrate concentrations that change the conditions for biomass development in the reactor are also changing widely. At increased concentrations of ammonium nitrogen, a weak increase in the activated sludge biomass is visible.

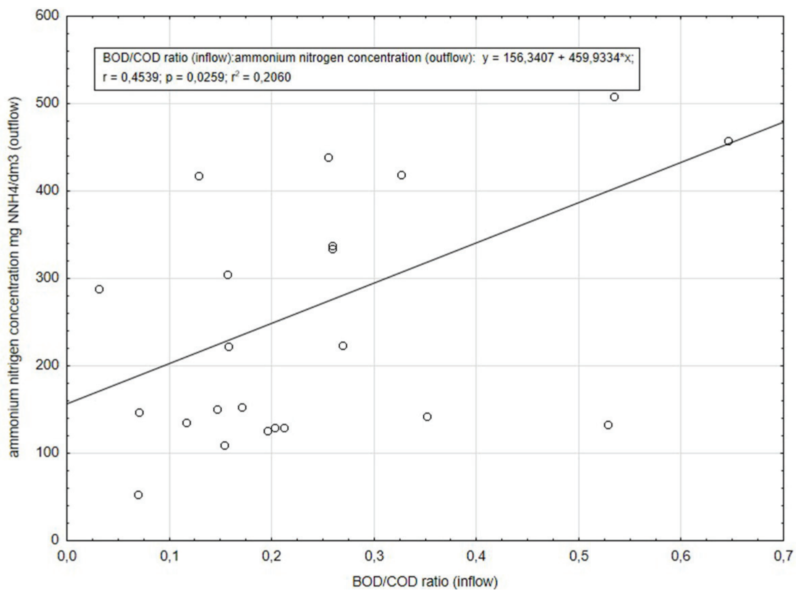

Figure 2. Correlation between the BOD/COD ratio in the wastewater flowing into the system and the ammonium nitrogen concentration in the treated wastewater flowing from the treatment plant

In this case, the inhibition of nitrification may be caused by the unstable inflow of sewage with variable composition to the reactor chamber [Makowska and Mazurkiewicz 2016]. The high alkalinity of the wastewater in the preliminary settling tank, which results from the nature of the influent wastewater, correlates with the concentration of ammonium nitrogen in the reactor (Fig. 3), which may indicate a slowdown in transformation processes [Mo et al. 2018]. The proportions between the organic matter generated in the reactor due to the activity of activated sludge microorganisms have also not improved (Table 3). The main component of organic matter flowing into the reactor was, among others, cellulose (paper towels, toilet paper), not susceptible to biological decomposition. The concentration of total suspended solids in the reactor chamber was in a very wide range of max. 1040 mg/dm^3 and were the result of temporary high sewage inflows to the tank.

The classic system (two-stage with activated sludge) used for treatment of wastewater with increased concentrations of ammonium nitrogen shows measurable efficiency in the case of organic matter reduction (Fig. 4). The average efficiency of reduction was 53–56% for COD and BOD and 39% for total suspended solids. However, this is primarily due to the sedimentation process and not the biological transformation of ammonium. Under the conditions of variable inflows, high unevenness of the nitrogen load and specific sewage character (high pH and high concentration of ammonium nitrogen) systems with activated sludge show low work effects, on average 9%. During the experiment, higher concentrations of ammonium nitrogen at the outflow from the system were observed comparing to the concentrations of $N\text{-}NH_4$ in raw sewage.

CONCLUSIONS

In classic activated sludge systems used for the treatment of specific wastewater with an increased content of ammonia nitrogen, in the case of insufficient amount of organic matter, the nitrification process is a complicated task. The main component in the wastewater stream flowing into the systems used in the Motor Rest Area (without additional catering points) is urine (uric acid and urea), which determines the elevated concentrations of ammonium nitrogen and high pH. The lack of organic matter susceptible to biological decomposition hinders the development of activated sludge biocenosis, and the high concentrations of ammonium nitrogen inhibit the nitrification processes. The sewage inflow which is difficult to equalize and extreme conditions of hydraulic as well as pollution load do not favor the use of conventional wastewater treatment solutions in MRA. According to the authors, a proper solution for wastewater treatment in MRA would be to connect them to the central sewage system or to use urine separation systems that would be treated as an additional nitrogen source (fertilizer value).

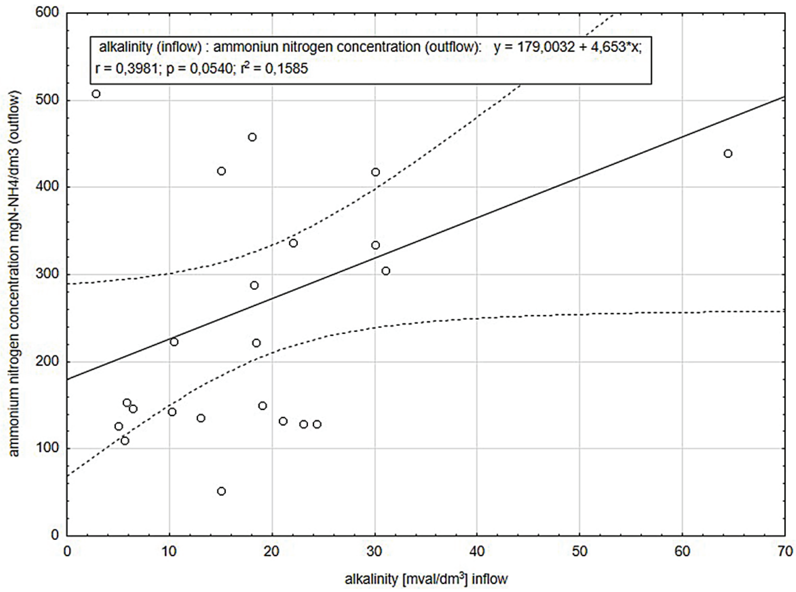

Figure 3 Correlation between alkalinity in the wastewater flowing into the system and the ammonium nitrogen concentration in the treated wastewater flowing from the treatment plant

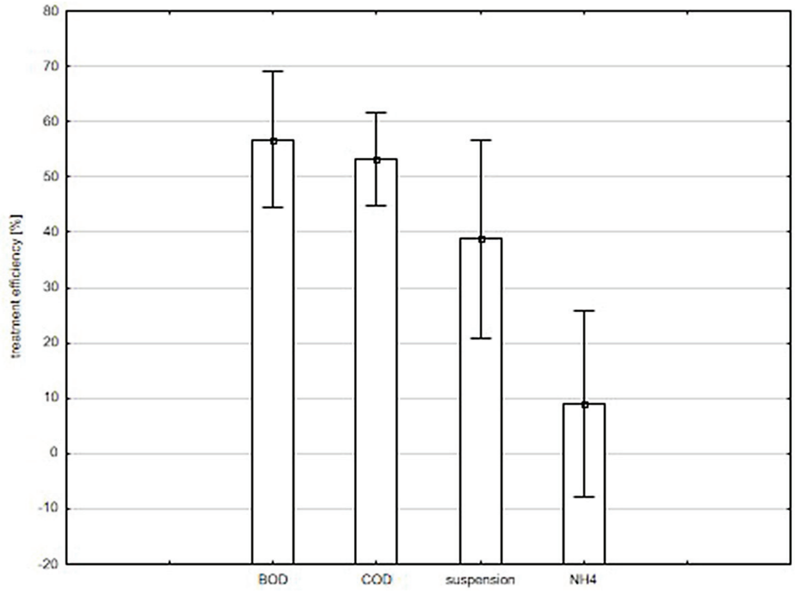

Figure 4 Efficiency of basic pollution indicators removal in a conventional activated sludge system for wastewater with higher ammonium nitrogen concentration

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