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CONCENTRATIONS OF ORGANIC AND BIOGENIC POLLUTANTS IN DOMESTIC WASTEWATER AFTER MECHANICAL TREATMENT IN THE ASPECT OF BIOLOGICAL REACTOR DESIGN

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Abstract

The aim of the study was to determine the value and concentration indicators of BOD_5, COD and general nitrogen in domestic wastewater after mechanical treatment, which should be considered in the design of the activated sludge reactor. Ninety-nine samples of raw wastewater and after mechanical treatment were then collected and physicochemical analysis was carried out. The quantity of pollutants in the raw wastewater was verified to determine if this was domestic wastewater. The next stage of the analysis included the definition of the characteristic quantity of the analysed indicators in wastewater after mechanical treatment, which should be taken into account while calibrating computer programs supporting the design of biological reactor chambers. A detailed analysis led to the conclusion that mean values for BOD_5 – 300 $mgO_2 \cdot dm^{-3}$, for COD – 500 $mgO_2 \cdot dm^{-3}$and for total nitrogen 50 $mgN \cdot dm^{-3}$ should be applied. The work also determined the susceptibility of wastewater after mechanical treatment to the decomposition of organic and biogenic compounds.

Key words: wastewater, organic and biogenic pollutants, mechanical treatment, bioreactor design.

INTRODUCTION

Designing a new or modernising the existing wastewater treatment plant is a complex process that requires a designer thorough knowledge (Arnold *et al.* 2000, Barnard 2000, Stańko *et al*.2016). The errors made by the designer at this stage will result in malfunctioning of the facility and on top of that they are often challenging to eliminate at a later stage of the operation of a wastewater treatment plant (Dymaczewski *et al.* 2011, Łomotowski and Szpindor 1999, Bergel *et al.* 2017). At present, the execution of projects concerning the technological process of wastewater treatment plants is enhanced by various types of computer programs, which help and facilitate the work of the designer (Klaczyński 2016, Heidrich and Witkowski 2010). However, even the best computer program requires pre-calibration that is putting in the data. The most problematic in the design of individual wastewater treatment plants is the biological reactor as the volume of treated wastewater as well as the quality expressed by organic and biogenic pollutants should be taken into consideration. Bearing in mind that in Poland in the non-urbanized areas there is a remarkable development of sewage management and plenty of new wastewater treatment plants are being built, it is necessary for designers to take into account their up-to-date data while designing (Pawełek 2016). It is vital to properly use and utilise large financial investments in this area of the economy. The issue discussed in this article should complement the knowledge of both designers and wastewater treatment plant operators of the quantity of pollutants in wastewater before and after mechanical treatment.

OBJECTIVE, SCOPE AND METHODOLOGY OF RESEARCH

The aim of the study was to determine the concentration of organic pollutants expressed by BOD_5 and COD as well as the concentration of biogenic pollutants expressed by total nitrogen in wastewater after mechanical treatment that is then subject to biological treatment. The obtained results should contribute to calibration of computer programs that support the design of biological reactors that use activated sludge technology. In addition, the quantities of the analysed indicators in raw wastewater were determined in order to calculate their reduction rate in the mechanical treatment process. Additionally, the susceptibility of wastewater after mechanical treatment process to biological degradation of organic and biogenic pollutants was analysed. The study was conducted during period of 24 months. In the given period, 99 samples of raw wastewater and after mechanical treatment were collected and subjected to physicochemical analysis. Pollutants in wastewater were determined by the following indicators: BOD_5, COD and total nitrogen. Raw wastewater samples were taken from a well before the technological sequence and the wastewater samples after mechanical treat-

ment were collected from the sewer that discharged wastewater from the primary settling tank. The wastewater analysis was carried out in accordance with the reference methods defined in the Regulation of the Minister of the Environment.

DESCRIPTION OF THE TESTED OBJECT

The investigated wastewater treatment plant in Biłgoraj was designed for typical daily inflows: $Q_{av.d}$=8000 $m^3 \cdot d^{-1}$ and $Q_{max.d}$=10 000 $m^3 \cdot d^{-1}$ and it is a building classified as the average quantity wastewater treatment plant belonging to the group of structures from 15000 to 100,000 ENI. Domestic wastewater from the city area and neighbouring boroughs is supplied to the facility by the sewage system of the total length of 139.3 km. The technological line of the treatment plant in question consists of a mechanical part and a biological one. The mechanical sewage treatment equipment includes a thick grille made of 5 mm stainless steel. The grille is equipped with a system of pressing and washing the screenings that is automatically controlled by the use of measuring probes located in front of and behind the grille. Then the wastewater flows into the vortex grit and further to two radial preliminary settling tanks of 18 m in diameter each. After the mechanical part, the wastewater reaches the biological reactors with activated sludge. The analysed facility consists of two biological reactors with a total capacity of 5360 m^3. The chambers in the denitrification part are equipped with the Flygt stirrers and in the nitrification part with the Schumacher's fine-bubble aeration system. The wastewater from the biological reactors goes to secondary radial settling tanks of 24 m in diameter. The treated wastewater receiver is the Czarna Łada river.

ANALYSIS OF RESEARCH RESULTS

In the analysed period, raw wastewater entering the wastewater treatment plant in question had concentration of organic and biogenic pollutants at the level corresponding to domestic effluents (Kaczor 2009, Heidrich and Kozak 2009, Bugajski and Bergel 2008, Bugajski 2012). The mean value of BOD_5 amounted to 465.7 $mgO_2 \cdot dm^{-3}$, while the median of this parameter added up to 440.0 $mgO_2 \cdot dm^{-3}$. Fluctuations of the parameter ranged from 220.0 to 1150.0 $mgO_2 \cdot dm^{-3}$.

The difference between the minimum and maximum values for BOD_5 was 930.0 $mgO_2 \cdot dm^{-3}$. The coefficient of variation of BOD_5 in wastewater was at an average level and amounted to C_v=0.37 indicating a moderate variation in this parameter in individual wastewater samples entering the treatment plant. In the case of another organic indicator, COD, it was found that the mean value of this parameter came to 806.2 $mgO_2 \cdot dm^{-3}$ and the median equalled to 761.0 $mgO_2 \cdot dm^{-3}$. The minimum COD value reached 314 $mgO_2 \cdot dm^{-3}$ and the maxi-

mum value amounted to 2050 $mgO_2 \cdot dm^{-3}$. That means that the difference between the minimum and maximum added up to 1734 $mgO_2 \cdot dm^{-3}$. The coefficient of variation of COD in raw wastewater equalled to C_v=0.35 and as was the case with the previous indicator it was at an average level. In relation to the third indicator, which is total nitrogen, it was found that the average concentration of this parameter in raw wastewater equated to 64.4 $mgN \cdot dm^{-3}$, while the median amounted to 62.0 $mgN \cdot dm^{-3}$. The minimum concentration of total nitrogen in the effluent equalled to 30.7 $mgN \cdot dm^{-3}$and the maximum to 146.2 $mgN \cdot dm^{-3}$. In comparison to organic indicators, the coefficient of variation of total nitrogen concentrations in raw wastewater was lower and amounted to C_v =0.25. Characteristic values and concentrations of the analysed pollutants in raw wastewater are presented in Table 1.

Table 1. Statistical characteristics of concentration indicators of contamination in raw wastewater

Parameters	Statistics					
	Average $g \cdot m^{-3}$	Median $g \cdot m^{-3}$	Min. $g \cdot m^{-3}$	Max. $g \cdot m^{-3}$	Standard deviation $g \cdot m^{-3}$	Coefficient of variation
BOD_5	465.7	440.0	220	1150	171.1	0.37
COD	806.2	761.0	314	2050	285.6	0.35
Total Nitrogen	64.4	62.0	30.7	146.2	16.3	0.25

Source: Own study

After analysing the quantity and concentration of pollutants in raw wastewater, a similar analysis was performed for these indicators in wastewater after mechanical treatment processes that directly flow into the biological rector. The mean BOD_5 value amounted to 317.5 $mgO_2 \cdot dm^{-3}$. It was then nearly 32% lower than the average value of the parameter in raw wastewater. The median of BOD_5 value in wastewater after mechanical treatment equated to 310 $mgO_2 \cdot dm^{-3}$ and was 30.5% lower than the value of this parameter in raw wastewater. The range of BOD_5 values in wastewater after mechanical treatment ranged from 140 to 520 $mgO_2 \cdot dm^{-3}$. The coefficient of variation of BOD_5 was lower compared to the coefficient in raw wastewater and amounted to C_v=0.33. In the case of the second indicator depicting organic pollutants, which is COD, it was found that the mean value in wastewater after mechanical treatment came to 532.9 $mgO_2 \cdot dm^{-3}$ and the median added up to 513 $mgO_2 \cdot dm^{-3}$ and these values were respectively lower by 34% and 32.5% than the values of this parameter in raw wastewater. The range of COD values in the effluents ranged from 133 to 1184 $mgO_2 \cdot dm^{-3}$. The coefficient of variation of the parameter amounted to C_v= 0.34. The analysis of

total nitrogen concentrations in wastewater after mechanical treatment allowed to state that the mean concentration of this indicator amounted to 47.9 $mgN \cdot dm^{-3}$ and was lower than the concentration in raw wastewater by an average of 25.5%. The median of total nitrogen concentration equalled to 46.1 $mgN \cdot dm^{-3}$ and was lower than the median of concentration of this parameter in raw wastewater by 25.5%. The minimum total nitrogen concentration in wastewater after mechanical treatment added up to 22.4 $mgN \cdot dm^{-3}$ while the maximum 92.8 $mgN \cdot dm^{-3}$. The coefficient of variation of this parameter was C_v=0.22. The characteristic values and concentrations of BOD_5, COD and total nitrogen in wastewater after mechanical treatment are presented in Table 2.

Table 2. Statistical characteristics of concentration indicators of contamination in wastewater after mechanical treatment

Parameters	Statistics					
	Average $g \cdot m^{-3}$	Median $g \cdot m^{-3}$	Min. $g \cdot m^{-3}$	Max. $g \cdot m^{-3}$	Standard deviation $g \cdot m^{-3}$	Coefficient of variation
BOD_5	317.5	310.0	140	520	105.6	0.33
COD	532.9	513.0	133	1184	178.9	0.34
Total Nitrogen	47.9	46.1	22.4	92.8	10.7	0.22

Source: Own study

In the next stage of the analysis concerning the quantity and concentrations of organic and biogenic pollutants in raw wastewater and after mechanical treatment, histograms were generated, which show the frequency of occurrence of characteristic values in both types of wastewater. In the case of BOD_5 in raw wastewater, it was found that the most common values of the parameter were in the range of 300 to 400 $mgO_2 \cdot dm^{-3}$ which accounted for 29% of 99 wastewater samples analysed. In the range of 400 to 500 $mgO_2 \cdot dm^{-3}$, 21% of cases were reported. In the next range of 500 to 600 $mgO_2 \cdot dm^{-3}$, the quantity of the analysed parameter appeared in 16% of cases. From the histogram shown in Figure 1, it can be seen that the BOD_5 values in raw wastewater were in a large range of variations that is from the value below 300 $mgO_2 \cdot dm^{-3}$ to the one above 700 $mgO_2 \cdot dm^{-3}$. This indicates the seasonal inflow of wastewater other than domestic wastewater. Presumably, it could have been rainwater and industrial wastewater.

Established three dominating ranges in raw wastewater entering the treatment plant were found where the COD values were present most often which is shown in Figure 2. In the range of 500 to 700 $mgO_2 \cdot dm^{-3}$ 35% of the cases were reported, in the range of 700 to 900 $mgO_2 \cdot dm^{-3}$ 29% of the cases and in the range of 900 to 1100 $mgO_2 \cdot dm^{-3}$ 17% of the cases were reported. During the

study period, there were incidental cases where the COD values were below 500 $mgO_2 \cdot dm^{-3}$ and above 1300 $mgO_2 \cdot dm^{-3}$. In the case of this parameter, as before, it can be stated that the high variability of the COD values is indicative of a temporary inflow of wastewater other than domestic wastewater.

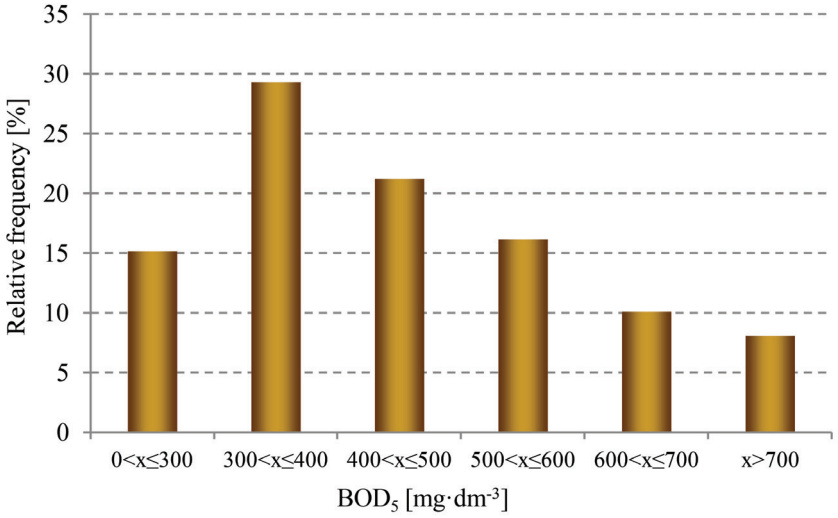

Figure 1. Histogram of distribution of BOD_5 in wastewater entering the wastewater treatment plant [Source: Own study]

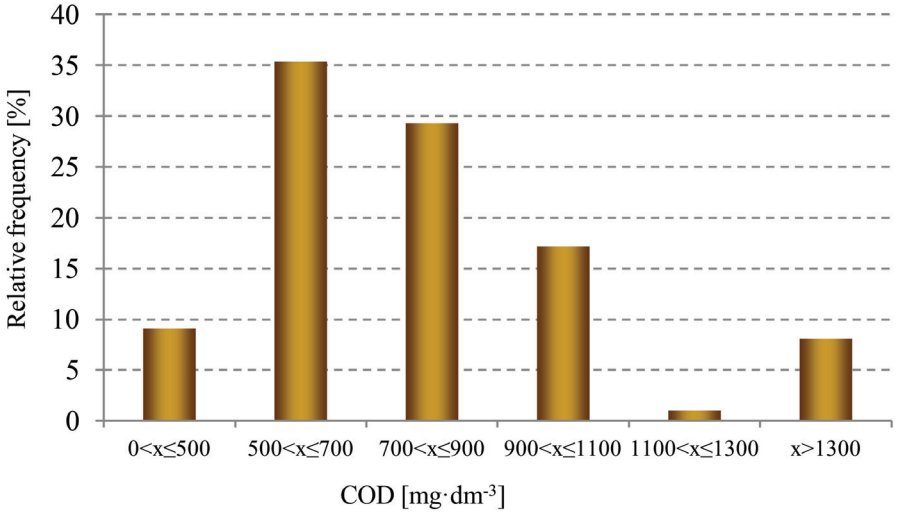

Figure 2. Histogram of COD distribution in wastewater entering the wastewater treatment plant [Source: Own study]

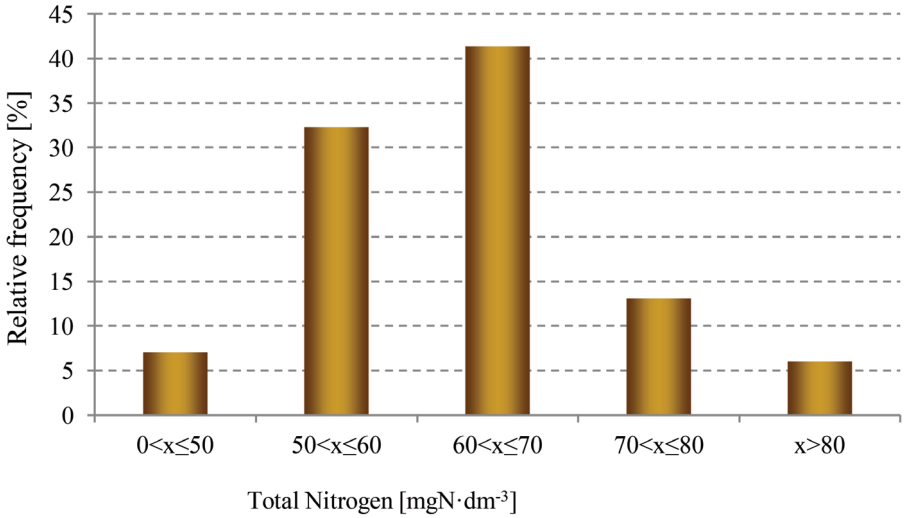

Figure 3. Histogram of distribution of total nitrogen concentration in wastewater entering the wastewater treatment plant [Source: Own study]

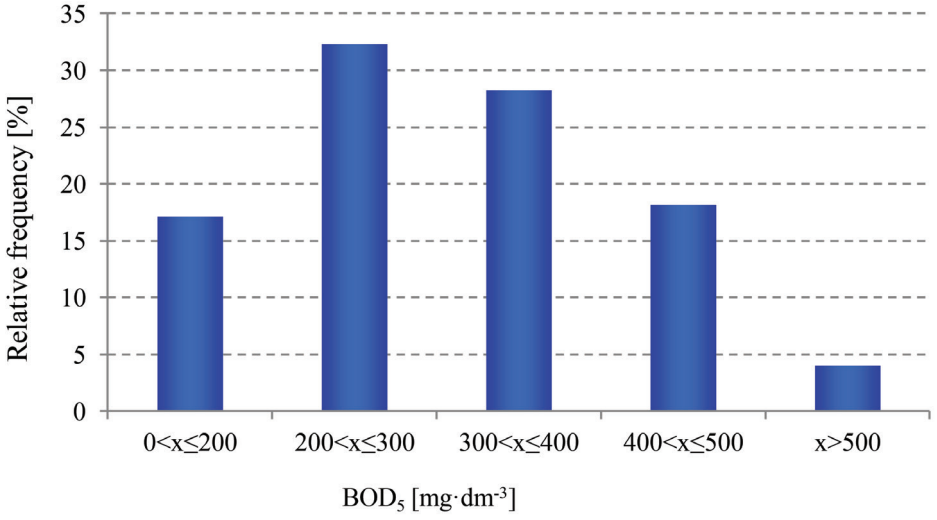

Figure 4. Histogram of BOD_5 distribution in wastewater after mechanical treatment [Source: Own study]

Analysing concentrations of total nitrogen in raw wastewater, it was found that the concentrations of this parameter ranged from 60 to 70 $mgN \cdot dm^{-3}$ (41.5% of cases) and from 50 to 60 $mgN \cdot dm^{-3}$ (32% of cases). In total, in the range of

50 to 70 mgN·dm^{-3}, there were 73.5% cases out of the 99 samples analysed as shown in Figure 3. Similarly, as in the case of organic indicators, there were extreme concentrations at a level below 50 mgN·dm^{-3} (7% of cases) and over 80 mgN·dm^{-3} (6% of cases).

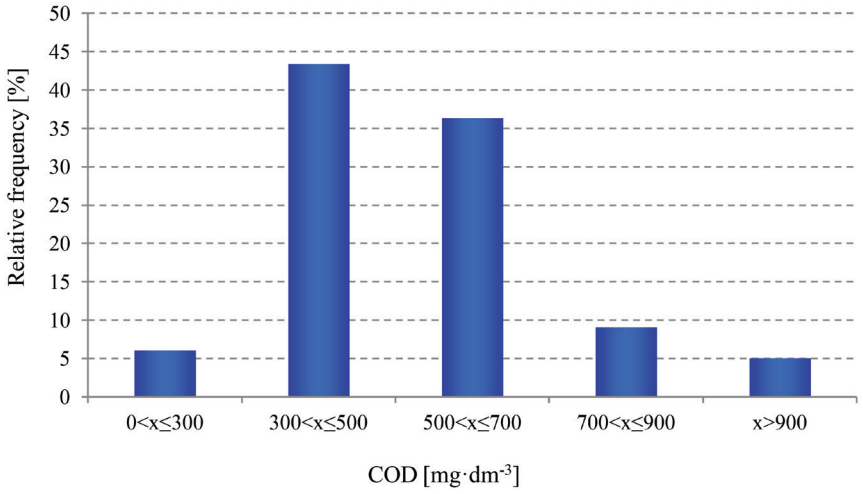

Figure 5. Histogram of COD distribution in wastewater after mechanical treatment [Source: Own study]

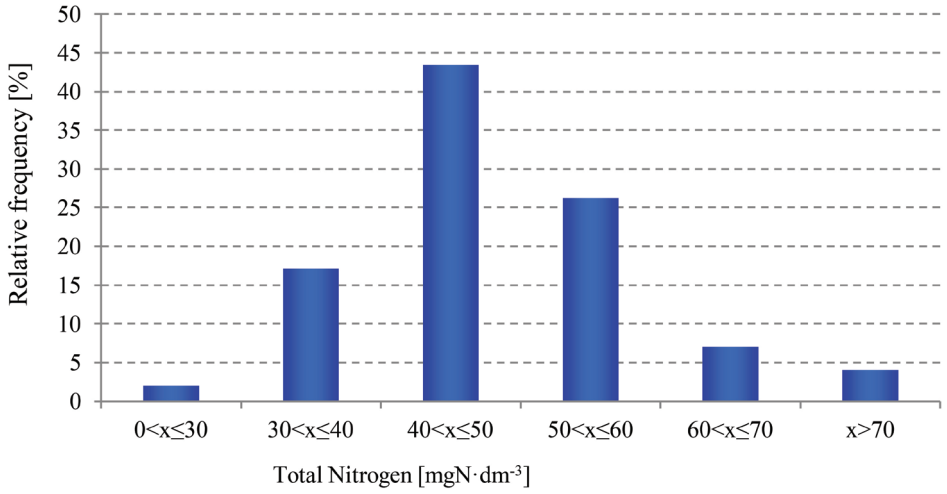

Figure 6. Histogram of total nitrogen concentration in wastewater after mechanical treatment [Source: Own study]

In the wastewater after mechanical treatment, it was noted that the average BOD_5 values were lower by 32% compared to the value of the parameter in raw wastewater. In the wastewater, the BOD_5 values mostly ranged from 200 to 300 $mgO_2 \cdot dm^{-3}$ (32% of cases) and from 300 to 400 $mgO_2 \cdot dm^{-3}$ (28% of cases). In total, 60% of cases of BOD_5 values in the range of 200 to 400 $mgO_2 \cdot dm^{-3}$ out of the 99 wastewater samples collected and analysed were observed. In addition, in this type of effluents there were low values below 200 $mgO_2 \cdot dm^{-3}$ (17% of cases) and high that is above 400 $mgO_2 \cdot dm^{-3}$ (in total 22% of the cases). The characteristic values of BOD_5 in wastewater after mechanical treatment are shown in Figure 4.

Analysing the characteristic values of COD in wastewater after mechanical treatment, it was found that the most common values of the parameter were in two ranges that is from 300 to 400 $mgO_2 \cdot dm^{-3}$ (43.5% of cases) from 400 to 500 $mgO_2 \cdot dm^{-3}$ (36% of cases) which together amounts to 79.5% of cases. Low values of less than 300 $mgO_2 \cdot dm^{-3}$ (6% of cases) and high values above 700 $mgO_2 \cdot dm^{-3}$ (14% of cases in total) were also reported. The characteristic values of COD in wastewater after mechanical treatment are shown in Figure 5.

In the case of analysis of the frequency of characteristic total nitrogen concentrations in wastewater after mechanical treatment, it was found that the concentration of this parameter ranged from 40 to 50 $mgN \cdot dm^{-3}$ and it was evident in 43.5% of cases. The presence of total nitrogen concentrations in the range of 50 to 60 $mgN \cdot dm^{-3}$ was found in 26% of cases. In nearly 18% of cases, the total nitrogen concentration ranged from 30 to 40 $mgN \cdot dm^{-3}$. As in the case of organic indicators, the low and high concentrations were observed here. Namely, 2% of the occurrence of concentrations below 30 $mgN \cdot dm^{-3}$ were reported, and in total in 11% of cases the total nitrogen concentration exceeded 60 $mgN \cdot dm^{-3}$. The typical concentrations of total nitrogen in wastewater after mechanical treatment are shown in Figure 6.

The knowledge of the susceptibility of wastewater to the biodegradation of organic and biogenic pollutants is a very important factor in the design of nitrification and denitrification chambers in activated sludge technology (Płuciennik-Koropczuk and Jakubaszek 2012, Bugajski and Kaczor 2012). The susceptibility of wastewater to biodegradation is determined by the ratio of organic pollutants expressed by BOD_5 and COD to total nitrogen concentration. The guidelines in the literature indicate that wastewater is susceptible to the decomposition of organic and biogenic pollutants by maintaining the ratio of COD/ $BOD_5 \leq 2$ and $BOD_5/N \geq 4$ (Łomotowski and Szpindor 1999; Dymaczewski et al. 2011, Bugajski and Kaczor 2012, Abdalla and Hammam 2014 Sukumara *et al*. 2015, Anusha and Jayatunga 2017). In the case of wastewater after mechanical treatment that enter the biological reactor, it was found that COD/ BOD_5 ratio below 2 was present in 76 wastewater samples which accounted for nearly 77% of cases. In the remaining 23 wastewater samples (nearly 23% of cases) the COD/ BOD_5 ratio was higher than two. In the case of wastewater susceptibility to bio-

logical degradation of nitrogen compounds, it was found that in 91 wastewater samples the BOD_5/N ratio was higher than 4 which accounted for almost 92% of cases. In conclusion, it can be stated that wastewater after mechanical treatment is moderately susceptible to the decomposition of organic pollutants and highly susceptible to the decomposition of biogenic pollutants. To increase the susceptibility of wastewater to the susceptibility of the disposal of organic and biogenic pollutants, it is necessary to periodically add wastewater containing high organic carbon to increase the BOD_5 to the required quantity.

CONCLUSIONS

1. The organic and biogenic pollutants expressed by BOD_5, COD and total nitrogen indicators in raw wastewater flowing into the analysed wastewater treatment plant were at the level of typical values for domestic wastewater.
2. A significant average decrease of organic values was observed in facilities used for mechanical wastewater treatment that is 32% for BOD_5 and 34% for COD respectively. With respect to total nitrogen, a concentration reduction of 25.5% was observed in mechanical treatment.
3. The following values of BOD_5 – 300 $mgO_2 \cdot dm^{-3}$ and COD – 500 $mgO_2 \cdot dm^{-3}$ as well as a total nitrogen concentration of 50 $mgN \cdot dm^{-3}$ are proposed while designing nitrification and denitrification chambers in the activated sludge bioreactor.
4. In the period when the susceptibility of wastewater to organic and biogenic pollutants is limited, it is advisable to add industrial effluent or other compounds with a high concentration of organic compounds expressed in BOD_5 to the wastewater before the biological reactor. However, this should be done periodically and in justified periods (cases) so as not to increase the cost of wastewater treatment.

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