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ASSESSMENT OF EFFICIENCY OF RURAL SEWAGE TREATMENT PLANT WITH BIOREACTOR

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ABSTRACT

Research aims
The aim of the conducted research was to assess efficiency of sewage treatment in rural areas in a sewage treatment plant with a sequencing batch reactor (SBR).

Materials and methods
Assessment of effectiveness of wastewater disposal in a treatment plant was carried out using elements of reliability theory. Research covered a period from March 2014 to December 2015. The content of pollution indicators in treated wastewater was compared with limit values included in the Regulation of the Minister of the Environment of November 18, 2014. Reliability analysis was performed for the following pollution indicators: BOD_5, COD_{Cr} and total suspended solids. Reliability coefficient RF was assumed as a basis for reliability calculations. Next, technological treatment efficiency index (P_{so}) was calculated.

Results and conclusions
An analysis of treated wastewater in relation to three tested parameters proved that the treatment plant works properly. Limit values of examined indicators – included in the Regulation (Dz. U. 2014 poz. 1800) – have not been exceeded. Also, all the analysed parameters have shown high percentage of pollutant reduction, ranging between 96% for COD_{Cr} and 99% for BOD_5. Obtained values of reliability indicators for the analysed treatment plant confirm its good condition.

Keywords: sewage, sewage treatment plant, reliability

INTRODUCTION

Rural areas constitute 93.2% of Poland's territory and are inhabited by 14.9 million people giving approximately 39% of the total population (GUS, 2014). Increasing number of inhabitants in countryside and rising standard of sanitary facilities lead to fast of development of rural water supply systems, and thus cause a steady growth in volume of discharged sewage from rural settlements. At the same time, infrastructure development determines attractiveness of a given area, as well as being an opportunity for improving quality of life (Krakowiak-Bal, 2004; Krzanowski and Wałęga, 2006) Accession of Poland to the European Union, for which environmental protection issues have always been a subject of extensive legal regulations, had a great impact on sewage system.

Due to the nature of sewage discharged from rural areas, there are considerable difficulties in maintaining its proper treatment. Therefore, it is necessary to look for solutions that lead to an effective reduction of pollutant load contained in sewage before it is dis-

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charged to a receiver. For this reason, treatment plants characterized by significant resistance to flow variation and pollutant load in discharged sewage, low capital consumption, operational reliability, high purification and simplicity of construction and exploitation are preferred in these areas (Kaczor, 2002; Krzanowski and Wałęga, 2006; Chmielowski and Ślizowski, 2009; 2010; Chmielowski et al., 2015, 2016). It should also be borne in mind that wrong selection of technological solution may be connected with operational problems and possible financial penalties imposed for poor quality of sewage discharged, breaching the required regulations (Oliviera and von Sperling, 2008, Kaczor, 2011; Bugajski, 2014; Al-Zahiri, 2015; Bugajski et al., 2016b; Łagożny et al., 2015; Castellet and Molinos-Senante, 2016; Kaczor et al., 2017). This means that there is a need for assessing the operation of existing treatment systems, both in terms of the effectiveness of pollutants reduction in sewage, as well as technological reliability of the process and statistical control of its quality. Such analysis allows recognising irregularities during exploitation, which can be eliminated in future projects or in existing facilities (Krzanowski and Wałęga, 2006; Bugajski et al., 2015; Arnell, 2016). For this purpose, it is necessary to determine reliability indicators that characterize quantitative properties of reliability of a given system. Selecting indicators is not easy, due to lack of unambiguous rules and guidelines. The basis for indicators selected to assess reliability of sewage facilities is mainly an analysis of the conditions and the process of their operation, while for most of facilities, such as sewage treatment plants, these are specific in terms of both functioning and operating (Kwietniewski et al., 1993).

AIM, SCOPE AND METHODOLOGY OF RESEARCH

The aim of the research was to assess efficiency of sewage treatment in rural areas in a sewage treatment plant with a sequencing batch reactor (SBR). The studied facility is located in the Małopolskie Voivodeship. Wastewater from residential and public buildings is discharged into treatment plants using sanitary sewers. Planned capacity of the treatment plant is 770 $m^3 \cdot d^{-1}$, while the RLM is 4800. Sewage treatment plant comprises following devices: rare grating, raw sewage pumping station, step grating, distribution chamber with sand trap, sand dewatering station and SBR reactor. The reactor consists of two technological lines. Each includes pressure chamber and open non-pressure chamber. Pressure chamber is connected to non-pressure chamber through slots on a wall above the bottom. Non-pressure chamber has a ventilation grill. Pressure chamber is equipped with membrane diffusers. Also, both chambers have a pump for removal of excess sediment. Pursuant to the Regulation of the Minister of the Environment on the conditions required for sewage drain-off to waters or ground, and on substances particularly harmful for aquatic environment (Dz. U. 2014 poz. 1800), maximum pollutant concentrations cannot exceed: for total suspension 35 $mg \cdot dm^{-3}$, BOD_5 25 $mgO_2 \cdot dm^{-3}$ and COD_{Cr} 125 $mgO_2 \cdot dm^{-3}$.

To assess the effectiveness of wastewater disposal in a treatment plant it was necessary to apply elements of reliability theory. Research covered the period from March 2014 to December 2015. The content of pollution indicators in treated wastewater was compared with limit values included in the Regulation of the Minister of the Environment of November 18, 2014 (Dz. U. 2014 poz. 1800), for RLM from 2000 to 9999. Reliability analysis was performed for the following pollution indicators: BOD_5, COD_{Cr} and total suspended solids. To this end, basic statistical characteristics such as arithmetic mean, standard deviation, variation coefficient, minimum and maximum value were defined. Reliability factor RF from formula (1) was adopted for reliability calculations (Andraka, 1997)

$$RF = \frac{\dot{m}_x}{X_{acc}} \, [-] \tag{1}$$

given that:

- m_x – average value of a given indicator in treated wastewater [$mg \cdot dm^{-3}$],
- X_{acc} – acceptable value of an indicator in treated wastewater [$mg \cdot dm^{-3}$].

Next, technological purity index was calculated (P_{so}) from the formula (2) (Kwietniewski et al., 1993):

$$P_{so} = \frac{n_z}{(N+1)} \tag{2}$$

given that:

- n_z – number of test results compliant with limit values,
- N – number of all test results for a given indicator.

This indicator defines technological reliability of sewage treatment plants and can be used as a simple tool to assess the proper functioning of a facility. It also allows to forecast the reliability of the facility's operation and to estimate risk of non-compliance with formal requirements as to the quality of treated wastewater, in association with an analysis of probability distribution of a random variable (Andraka and Dzienis, 2013).

In the paper, the percentage of reduction of the tested pollutants was also determined (3):

$$\eta = \frac{S_r - S_t}{S_r} \cdot 100\% \qquad (3)$$

given that:

- S_r – content of pollutant index in raw sewage [$mg \cdot dm^{-3}$],
- S_t – content of pollutant index in treated wastewater [$mg \cdot dm^{-3}$].

In addition, an analysis of the amount of sewage flowing into the treatment plant was performed.

RESULTS AND DISCUSSION

Dynamics of changes in volume of raw and treated wastewater from the analysed sewage treatment plant are presented in Tab. 1.

The data from Table 1 shows that minimum, average and maximum volumes of raw and treated wastewater, in both analysed years, were similar to each other. There is also a significant difference in volume of wastewater flowing into the sewage treatment plant – in the analysed period more sewage flowed in than it drained away. This may indicate accidental waters present in an inflow (almost 60%). Excess wastewater is discharged into a retention tank. Such a large amount of accidental waters is probably caused by poor technical condition of the sewerage network, which contributes to a significant inflow of rainwater or snowmelt. According to Kaczor (2009), there are two main causes of large inflow of accidental waters – location of manhole sewers beneath the level of a roadway or sidewalk, as well as a possibility of damaging the top of a manhole by heavy vehicles and local street and pavement repairs. Thus, a dip is created, where rainwater or snowmelt gather, which then penetrate inside a manhole through ventilation openings or slots used to lift the manhole cover. An increased amount of sewage inflow with foreign water has a negative impact on the functioning of sewage treatment plants in both economic and technological terms – it can lead to excessive dilution of sewage during rainy weather and reduce pollution disposal efficiency (Bugajski et al., 2016a).

In the case of the analysed sewage treatment plant, an efficiency of wastewater treatment was measured for three pollution indicators: BOD_5, COD_{Cr} and total suspended solids. Basic statistical characteristics of analysed pollution indicators included raw and treated wastewater, in the 2014–2015 research years, are presented in Table 2.

Table 1. Quantitative characteristics of raw and treated wastewater outflowing from analysed plant in years 2014–2015

Characteristics	Unit	Year			
		2014		2015	
		raw wastewater	treated wastewater	raw wastewater	treated wastewater
Mean daily outflow	$m^3 \cdot d^{-1}$	655.3	260.2	655.7	275.8
Maximum daily outflow	$m^3 \cdot d^{-1}$	910	313	840	320
Minimum daily outflow	$m^3 \cdot d^{-1}$	490	230	500.5	239
Standard deviation	$m^3 \cdot d^{-1}$	151.8	24.7	114.4	28.5
Total annual outflow	$m^3 \cdot 10^3$	7.9	3.12	7.9	3.31

Table 2. Basic statistical characteristics of analysed pollutants in raw and treated wastewater in years 2014–2015

Parameter	Wastewater	Statistics				
		Mean [mg · dm^{-3}]	Maximum [mg · dm^{-3}]	Minimum [mg · dm^{-3}]	Stand. dev. [mg · dm^{-3}]	Variation coefficient [-]
BOD_5	raw	307.4	573.0	133.0	137.6	0.45
	treated	3.4	7.9	0.9	2.2	0.66
COD_{Cr}	raw	831.4	1510.0	155.0	474.2	0.57
	treated	29.5	44.0	19.0	9.6	0.33
Total suspension	raw	500.8	1088.0	67.0	350.2	0.69
	treated	6.9	20.0	1.9	4.9	0.71

Raw sewage (see: Table 2) flowing into the analysed sewage treatment plant was defined by concentration of organic pollutants typical for domestic wastewater and did not differ from composition confirmed by other authors (Krzanowski and Wałęga, 2004, Chmielowski, 2008, Chmielowski and Ślizowski, 2008, 2010). BOD_5 content in raw sewage ranged from 133.0 to 573.0 mg $O_2 \cdot dm^{-3}$. Whereas variation coefficient was 0.45, indicating wide dispersion. The next parameter – COD_{Cr} – ranged from 155.0 to 1510.0 mg $O_2 \cdot dm^{-3}$, with an average value of 831.4 mg $O_2 \cdot dm^{-3}$. In this case, similarly as for BOD_5, it was characterized by high variability (variation coefficient amounted to 0.57). As to total suspended solids, a very high variability of the parameter is observed in raw sewage, as demonstrated by a high variation coefficient of almost 0.71. The range of indicator in raw sewage amounted to 1021.0 mg · dm^{-3} (average value was 500.8 mg · dm^{-3}).

For treated wastewater the average content of BOD_5 was 3.4 mg $O_2 \cdot dm^{-3}$ (value range 7 mg $O_2 \cdot dm^{-3}$). The acceptable value of the indicator included in the Regulation (Dz. U. 2014 poz. 1800), amounting to 25 mg $O_2 \cdot dm^{-3}$, was not breach at any moment of measurement. The average percentage of reduction of BOD_5 content for both analysed years was similar and amounted to almost 99% (see: Fig. 1).

In turn, the content of COD_{Cr} in treated wastewater in the examined period ranged from 19 to 44 mg $O_2 \cdot dm^{-3}$ (see: Table 2), with an average value of 29.5 mg $O_2 \cdot dm^{-3}$. As it was for BOD_5, the content of COD_{Cr} in the studied period did not exceed limit value (125 mg $O_2 \cdot dm^{-3}$). The average rate of indicator reduction was high, approximately 96% (see: Fig. 1).

For total suspended solids an average concentration of the indicator in treated wastewater oscillated between 1.9 mg · dm^{-3} and 20 mg · dm^{-3}, with an average value of almost 7 mg · dm^{-3}. Similarly to raw sewage, treated wastewater demonstrated a wide variation of the indicator, as evidenced by variation coefficient of 0.71. Permissible concentration of the indicator (35 mg $O_2 \cdot dm^{-3}$) was not exceeded throughout the research period. An average percentage of reduction for total suspension was 98%.

On the basis of an analysis of treated wastewater, in reference to three parameters – BOD_5, COD_{Cr} and total suspended solids – it was concluded that the studied treatment plant works properly. Limit values of the examined indicators – included in the Regulation (Dz. U. 2014 poz. 1800) – have not been exceeded.

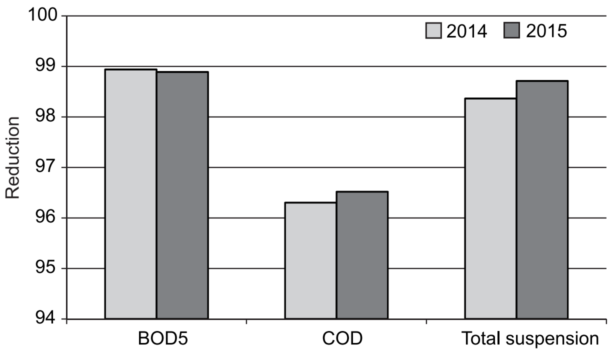

Fig. 1. Reduction of analysed pollution indicators in years 2014 and 2015

Also, all the analysed parameters have shown high percentage of pollutant reduction, ranging between 96% for COD_{Cr} and 99% for BOD_5.

Table 3 presents the results of calculations of reliability indicators for the analysed sewage treatment plant. Obtained values of reliability indicators for the analysed treatment plant confirm its good condition.

Table 3. Indicators of reliability for analysed wastewater treatment plant

Parameter	Indicator		
	RF	P_{so}	□
BOD_5	0.13	0.93	0.98
COD_{Cr}	0.24	0.93	0.96
Total suspension	0.19	0.93	0.98

Values of calculated reliability indicators, summarized in Table 3, prove its good condition. The reliability coefficient RF delivered low values for each analysed indicator (from 0.13 for BOD_5 to 0.24 for COD_{Cr}), which proves that the treatment plant operates properly. In turn, for technological efficiency indicator (P_{so}), for each analysed indicator, values equal to 0.93 were recorded, which proves its proper functioning. The obtained results of reliability coefficient RF, P_{so} and for BOD_5, COD_{Cr} and the total suspended solids are similar to those obtained by Młyński et al. (2016) for the sewage treatment plant in Jasło. P_{so} has shown slightly higher values – 1.0 (for COD_{Cr} and total suspended solids) and 0.99 (BOD_5). Wąsik and Chmielowski (2013) obtained similar values of P_{so} indicator (0.96) for the sewage treatment plant in Skala-Nowa Wieś. Młyński et al. (2016) indicate that RF indicator values for BOD_5 and COD_{Cr} were slightly higher than presented in this paper (0.24 and 0.28, respectively). For total suspended solids the RF value obtained in this study was slightly higher than that presented by Młyński et al. (2016) (i.e. at the level of 0.13).

CONCLUSIONS

The performed tests on effectiveness of wastewater treatment in rural areas in a sewage treatment plant with a SBR reactor provide with following conclusions:

1. Raw sewage flowing into the analysed treatment plant, in terms of the examined pollutant indicators, was similar to typical domestic sewage.
2. Average reduction of pollutants in sewage treatment plants in 2014 and 2015 was very high, about 99% for BOD_5, about 96% for COD_{Cr}, and 98% for total suspended solids.
3. In the studied period, in all tested samples of treated wastewater, the content of organic compounds (BOD_5, COD_{Cr}) and total suspended solids were below the limits specified in the Regulation of the Minister of the Environment of November 18, 2014.
4. The calculated values of reliability indicators for the tested treatment plant confirm its high efficiency.

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Rozporządzenie Ministra Środowiska z dnia 18 listopada 2014 r. w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego (Dz. U. 2014 poz. 1800).

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OCENA SKUTECZNOŚCI PRACY WIEJSKIEJ OCZYSZCZALNI ŚCIEKÓW Z REAKTOREM BIOLOGICZNYM

ABSTRAKT

Cel pracy

Celem przeprowadzonych badań była ocena skuteczności oczyszczania ścieków wiejskich w oczyszczalni z reaktorem o działaniu sekwencyjnym (SBR).

Materiał i metody

Ocenę efektywności usuwania zanieczyszczeń w oczyszczalni określono przy wykorzystaniu elementów teorii niezawodności. Badania obejmowały okres od marca 2014 do grudnia 2015 roku. Zawartości wskaźników zanieczyszczeń w ściekach oczyszczonych porównano z wartościami granicznymi zawartymi w Rozporządzeniu Ministra Środowiska z dnia 18 listopada 2014 roku . Analiza niezawodności została przeprowadzona dla następujących wskaźników zanieczyszczeń: BZT5, ChZTCr i zawiesiny ogólnej. Jako podstawę do obliczeń niezawodnościowych przyjęto współczynnik niezawodności WN Następnie obliczono wskaźnik technologicznej sprawności oczyszczania (Pso).

Wyniki i wnioski

Na podstawie analizy ścieków oczyszczonych, w odniesieniu do badanych trzech parametrów stwierdzono, że analizowana oczyszczalnia pracuje prawidłowo. Zawarte w Rozporządzeniu (Dz. U. 2014 poz. 1800) graniczne wartości badanych wskaźników nie zostały przekroczone. Również w przypadku wszystkich badanych parametrów obserwowano wysoki procent redukcji zanieczyszczeń, który wyniósł od 96% w przypadku ChZTCr, do 99% dla BZT5. Uzyskane wartości wskaźników niezawodności analizowanej oczyszczalni potwierdzają jej bardzo dobre funkcjonowanie.

Słowa kluczowe: ścieki, oczyszczalnia ścieków, niezawodność