INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/3/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1547–1557
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.4.3.115

RELIABILITY OF SEWAGE TREATMENT PLANTS PROCESSING SEWAGE FROM SCHOOL BUILDINGS LOCATED IN NON-URBAN AREAS

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Abstract

The aim of this study was to assess the reliability of two on-site sewage treatment facilities (BCT S-12 and TJ EP-4) serving two school buildings located in rural communes in Małopolska region. The reliability was determined using Weibull reliability method. The research was conducted for 24 months and it involved the collection and analysis of 48 samples of raw and treated sewage from each facility. The analyses included organic and biogenic pollution, i.e. BOD_5, COD, and total nitrogen. Reliability assessment revealed the following effectiveness for BCT S-12 facility: 77% for BOD_5, 96% for COD and 25% for total nitrogen. For TJ EP-4 facility, the effectiveness was 81%, 88% and 72% for BOD_5, COD and total nitrogen, respectively. Both facilities used the activated sludge process and experienced periodic disturbances in the treatment flow that resulted in reduced sewage treatment efficiency. Considering the above, the processes of nitrification and denitrification in the biological reactor should be streamlined to provide more effective removal of organic and nitrogen-based compounds in the investigated facilities.

Key words: sewage, reliability, on-site sewage treatment facility

INTRODUCTION

Sewage treatment is currently one of the top priorities among the investment projects aimed at improving the quality of surface and ground waters. The projects involving construction and operation of sewage treatment plants (STP) in rural areas of Poland are extremely expensive due to scattered development of these areas (Bielińska et al. 2014, Pawełek 2016, Mikosz 2013). Collective sewage treatment facilities may be supplemented by small, on-site systems that enable treatment of the sewage where it is generated without the need to transport it. This lowers the operating costs (Jawecki et al. 2016, Pryszcz and Mrowiec, 2015). Recent years witnessed a high growth in the number of on-site sewage treatment facilities in Poland, with around 150 000 systems installed by 2015 (Chmielowski, 2015). However, once the facility is put in place and registered at the Commune Office, there is no further monitoring of its performance. Current Polish regulations on the collection and analysis of sewage from on-site sewage treatment facilities provided in the Regulation of the Minister of the Environment as of November 2014 (Regulation 2014) do not specify who and how shall control the facility performance once it is installed. Therefore, many of these facilities are STP only by name, as the lack of control prevents their proper evaluation. The analysis carried out and described in this publication is aimed at enhancing our knowledge on the efficiency and reliability of on-site sewage treatment plants based on the activated sludge, in the context of a large number of facilities using this technology in Poland.

AIM, SCOPE AND METHODS OF THE STUDY

The aim of the study was to assess the reliability of the removal of organic and biogenic compounds by means of Weibull reliability (Bugajski et. al. 2012) method in two on-site sewage treatment facilities collecting sewage from school buildings and teacher houses. The analyses included BOD_5, COD, and total nitrogen. The research was carried out at both facilities between January 2012 and December 2013. During this period, 48 samples (two samples of two liters a month) of each raw and treated sewage were collected from either facility and they were subjected to physical and chemical analysis, which are recommended in the current Regulation (Regulation 2014). The efficiency of pollution removal was determined by employing some elements of Weibull reliability theory. Weibull distribution is characterized by a probability density function (1) with parameters b, c and θ:

$$f(x) = \frac{c}{b} \cdot \left(\frac{x-\theta}{b}\right)^{(c-1)} \cdot e^{-\left(\frac{x-\theta}{b}\right)^{c}} \tag{1}$$

where:
x – variable indicating the concentration of a specific pollution indicator in the treated sewage,
b – scale parameter,

c – shape parameter,
θ – location parameter.
Assumptions: $\theta < x$, $b > 0$, $c > 0$

Weibull distribution parameters were estimated by means of maximum likelihood method. The quality of fit of Weibull distribution to the empirical data was assessed using Hollander-Proschan test. The results were analyzed with STATISTICA 8 software.

DESCRIPTION OF THE INVESTIGATED FACILITIES

The first facility was denoted as BCT S-12. It included a preliminary sedimentation tank from which the sewage flew into a biological reactor based on activated sludge. Biological reactors are of the type of flow Then, the sewage was clarified in a secondary sedimentation tank. Mean design capacity was 12 $m^3 \cdot d^{-1}$, and during the study period, the actual sewage supply was 5.0 $m^3 \cdot d^{-1}$. This facility was used for treating sewage from a primary and junior secondary school. The school serviced on average 320 students and 15 members of the persons teaching. To treatment plant discharged wastewater they were also the teacher's home inhabited by 15 teachers. The object is designed to serve 60 PE.

The second facility was labelled as TJ EP-4. It consisted of three tanks, of which the first served as a preliminary sedimentation tank, the second as a biological reactor with the activated sludge, and the third was a secondary sedimentation tank. Mean design capacity was 3.5 to 5.0 $m^3 \cdot d^{-1}$, and in the study period it was supplied with 0.81 $m^3 \cdot d^{-1}$ of sewage. The facility received sewage from a school building servicing 120 students and 8 members of the teachers. It also collected the sewage from a teacher's house inhabited by 6 teachers. Design capacity of the facility was 25 to 30 PE.

RESULT ANALYSIS

The values and concentrations of pollution indicators in the raw sewage for both facilities were typical for domestic sewage reported in the literature (Kaczor 2009; Heidrich and Kozak 2009). Raw and treated sewage characteristics for BCT S-12 are presented in Table 1, and for TJ EP-4 in Table 2. Information in tables for raw sewage are in the counter and the treated sewage in denominator.

The values and concentrations of pollution indicators in the treated sewage were highly variable in both investigated facilities. In BCT S-12, BOD_5 ranged from 2.7 to 134.6 $mgO_2 \cdot dm^{-3}$, with the mean of 28.2 $mgO_2 \cdot dm^{-3}$. Coefficient of variation for BOD_5 was high and amounted to 0.90. COD concentration ranged from 20.5 to 189.6 $mgO_2 \cdot dm^{-3}$, with the mean of 74.4 $mgO_2 \cdot dm^{-3}$. The coefficient of variation for this parameter was 0.51. The concentration of total nitrogen in the treated sewage was between 10.8 and 98.8 mgN·dm^{-3}, and its mean value was 30.8 mgN·dm^{-3}. The coefficient of variation for total nitrogen concentration in the treated sewage was 0.59. High coefficient of variation for both the organic and biogenic indicators suggests instability of the sewage treatment processes at BOD S-12 facility.

The analysis of treated sewage from TJ EP-4 showed that BOD_5 ranged from 12.0 to 58.5 mgO_2·dm^{-3}, and its mean value was 29.3 mgO_2·dm^{-3}. COD concentration ranged from 29.7 to 273.0 mgO_2·dm^{-3}, with the mean of 94.6 mgO_2·dm^{-3}. The coefficient of variation was 0.40 and 0.47 for BOD_5 and COD, respectively. The concentration of total nitrogen in the treated sewage was between 8.6 and 77.1 mgN·dm^{-3}, with the mean concentration in the study period of 23.1 mgN·dm^{-3}. The values of the coefficients of variation in the treated sewage again indicated instability of the treatment processes at this facility.

Table 1. Characteristics of the pollutants in the raw and treated sewage at BCT S-12 facility.

Index	Statistics					
	Mean (mg·dm^{-3})	Median (mg·dm^{-3})	Min. (mg·dm^{-3})	Max. (mg·dm^{-3})	Standard of deviation (mg·dm^{-3})	Coefficient of variation [-]
BOD_5	279.5	246.2	104.7	690.0	137.3	0.49
	28.2	24.0	2.7	134.6	25.3	0.90
COD	502.5	461.0	252.4	995.6	196.3	0.39
	74.4	67.5	20.5	189.6	37.9	0.51
Total nitrogen	78.4	75.1	23.6	173.4	29.5	0.38
	30.8	25.8	10.8	98.8	18.0	0.59

At the next stage of the study, reliability of the facilities was assessed using Weibull reliability method. The reliability profile was prepared based on the results of physical and chemical analyses of the treated sewage.

For both investigated facilities, the determined distribution parameters were used to verify a hypothesis assuming the usefulness of Weibull distribution for the approximation of empirical data. Statistical analysis of the probability test p for all the indicators confirmed that the empirical data may be described by Weibull distribution and assumed as a null hypothesis. Results of distribution fit based on Hollander-Proschan test together with estimated parameters are presented in Table 3.

Table 2. Characteristics of the pollutants in the raw and treated sewage at TJ EP-4 facility.

Index	Statistics					
	Mean ($mg \cdot dm^{-3}$)	Median ($mg \cdot dm^{-3}$)	Min. ($mg \cdot dm^{-3}$)	Max. ($mg \cdot dm^{-3}$)	Standard of deviation ($mg \cdot dm^{-3}$)	Coefficient of variation (-)
BOD_5	210.0	195.9	103.7	418.6	64.8	0.31
	29.3	24.6	12.0	58.5	11.8	0.40
COD	384.9	377.5	172.2	997.1	149.9	0.39
	94.6	84.8	29.7	273.0	44.0	0.47
Total nitrogen	80.3	75.4	29.7	134.1	24.4	0.30
	23.1	18.9	8.6	77.1	13.3	0.58

Table 3. Results of estimation of Weibull distribution parameters with goodness of fit to empirical data

Index	Facility	Distribution parameters			Hollander-Proschan test	
		b	c	Θ	Test value	p
BOD_5	BCT S-12	30.568	1.2816	1.7272	0.314446	0.75318
	TJ EP-4	33.088	2.6896	9.4747	0.399387	0.68961
COD	BCT S-12	84.303	2.1061	13.182	0.306075	0.75955
	TJ EP-4	106.98	2.2732	21.869	0.322880	0.74679
Total nitrogen	BCT S-12	34.940	1.8662	9.5960	0.412131	0.68024
	TJ EP-4	26.234	1.9049	7.6869	0.443316	0.65754

Maximum permissible values of individual indicators for both the facilities were 40 $mgO_2 \cdot dm^{-3}$ for BOD_5, 150 $mgO_2 \cdot dm^{-3}$ for COD, and 30 $mgN \cdot dm^{-3}$ for total nitrogen. These limits for the treated sewage were exceeded at BCT S-12 eight times for BOD_5 and three times for COD. At TJ EP-4, they were exceeded also eight times for BOD_5 and four times for COD. According to the guidelines set out in the Regulation of the Minister of the Environment (Regulation 2014), eutrophic parameters are not considered when assessing the performance of this type of facility, but total nitrogen concentration was taken into account in this study to make the analysis more comprehensive. Permissible concentration of total nitrogen was exceeded 16 times at BCT S-12 facility and 9 times at TJ EP-4.

Reliability analysis for BCT S-12 revealed that BOD_5 limit in the treated sewage was not adhered to at BCT S-12 in about 23 % of cases. Therefore, the concentration of BOD_5 may be higher than permitted for nearly 84 days per year. For COD, the limit was exceeded in 4 % of cases. This means that the values may be above the limit for 14 days per year. Reliability analysis for total nitrogen removal showed that its permissible concentration was exceeded in 48 % of cases. This translates into as many as 175 days per year when the determined concentration may be higher than the limit. The outcomes of Weibull reliability method for BOD_5, COD and total nitrogen in the treated sewage from BCT S-12 are presented in Figures 1, 2, and 3.

The reliability assessment for TJ EP-4 indicated that the permissible value of BOD_5 in the treated sewage was exceeded in 19 % of cases that is for 69 days per year. COD values were above the limit in 12 % of cases, i.e. for 44 days per year. For total nitrogen, the concentration limit may be broken in 28 % of cases that comes up to 102 days per year. The outcomes of Weibull reliability method for BOD_5, COD and total nitrogen in the treated sewage from TJ EP-4 are presented in Figures 4, 5, and 6.

The guidelines by Andraki and Dzienis (2003) stated that the reliability of sewage treatment plants of this size should be around 97.3%, i.e. the permissible limits of pollution indicators may be exceeded in up to 9 days per year. For BCT S-12 facility, the reliability of BOD_5, COD and total nitrogen removal was lower than that outlined in the guidelines. Also for TJ EP-4, the reliability of performance was below the norm for all the investigated parameters.

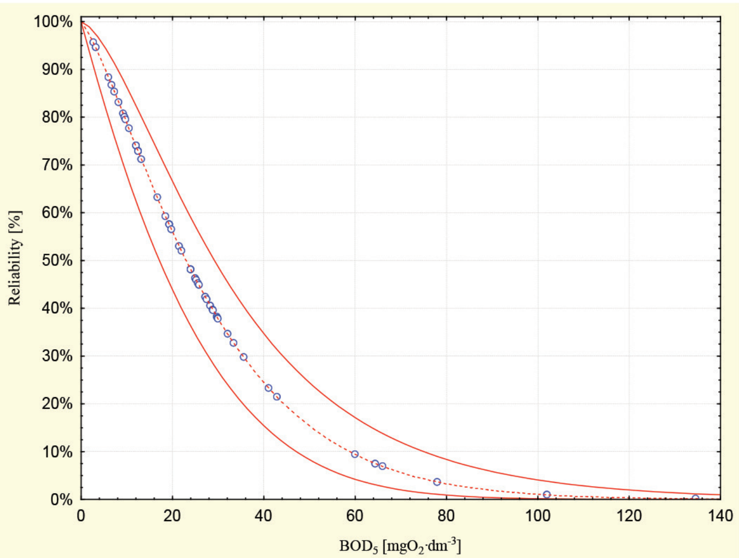

Figure 1. Results of Weibull reliability analysis for BOD_5 concentrations in the treated sewage for BCT S-12 facility

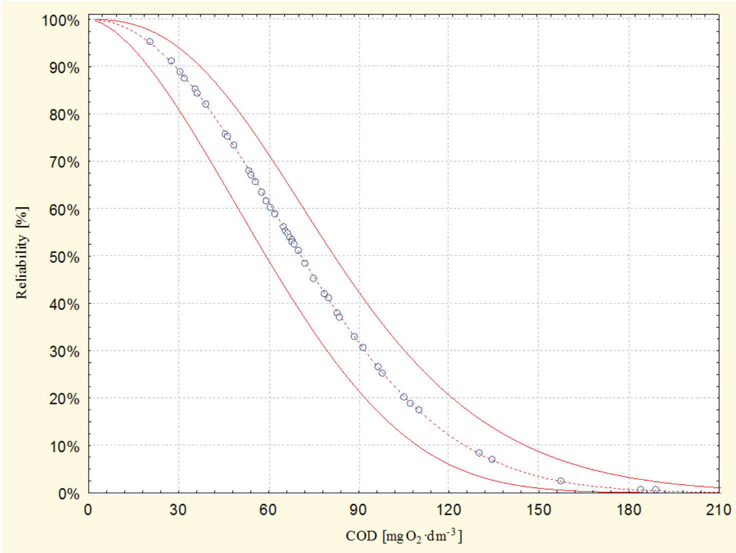

Figure 2. Results of Weibull reliability analysis for COD concentrations in the treated sewage for BCT S-12 facility

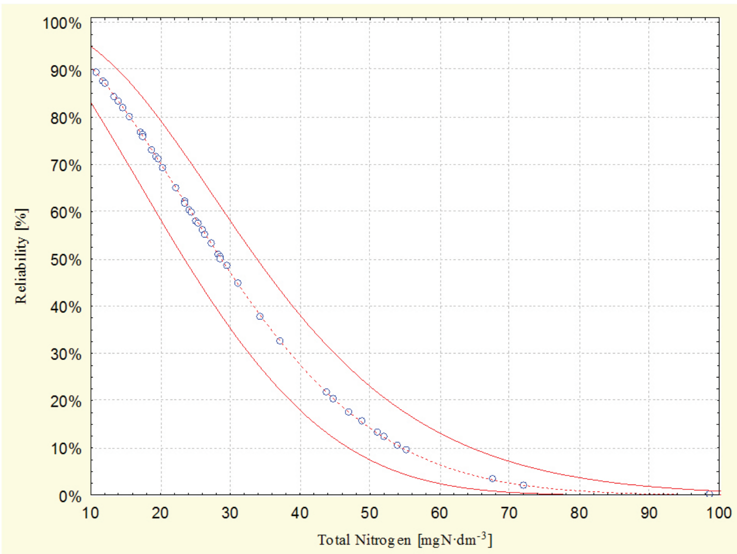

Figure 3. Results of Weibull reliability analysis for total nitrogen concentrations in the treated sewage for BCT S-12 facility

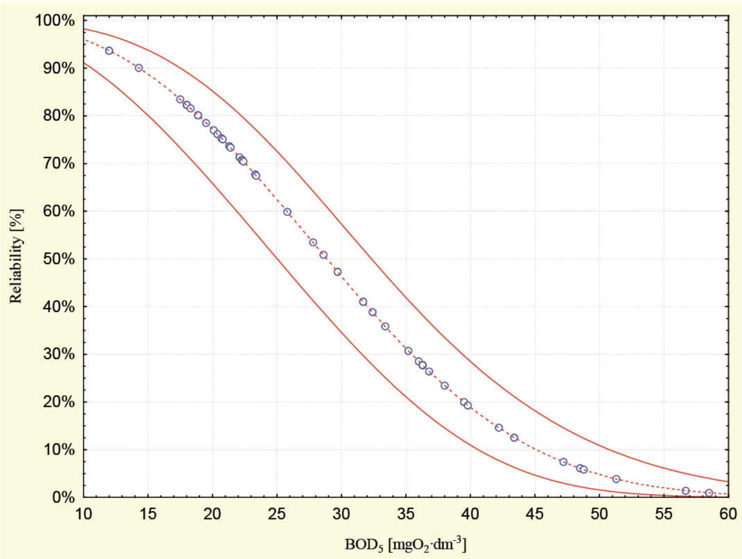

Figure 4. Results of Weibull reliability analysis for BOD_5 concentrations in the treated sewage for TJ EP-4 facility

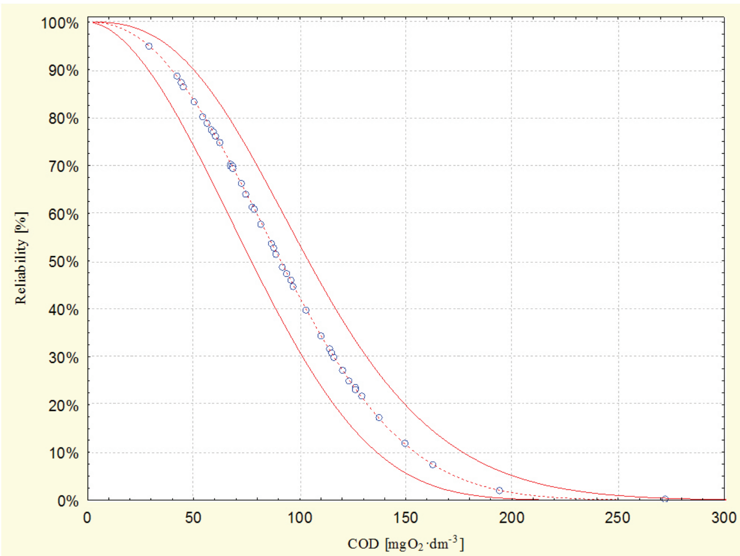

Figure 5. Results of Weibull reliability analysis for COD concentrations in the treated sewage for TJ EP-4 facility

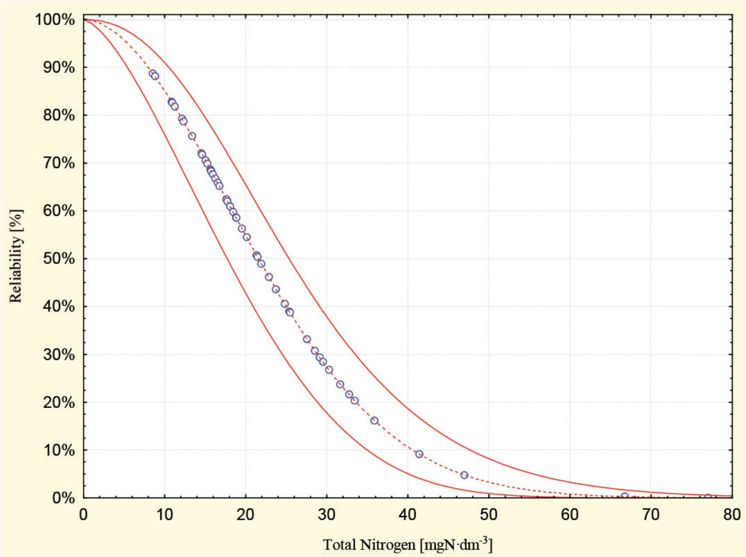

Figure 6. Results of Weibull reliability analysis for total nitrogen concentrations in the treated sewage for TJ EP-4 facility

In summary, the study results clearly indicated the need for improvement of the treatment processes in both analyzed facilities.

CONCLUSIONS

1. Values and concentrations of the analyzed pollution indicators in the raw sewage entering the investigated facilities were typical of domestic sewage.
2. Mean removal rates for BOD_5 were 89.9 % at BCT S-12 and 86 % at TJ EP-4, for COD they amounted to 85 % and 75 %, and for total nitrogen to 61 % and 71 %, respectively.
3. Reliability of the removal of organic compounds in BCT S-12 and TJ EP-4 facilities assessed with Weibull reliability model was 77 % and 81 % for BOD_5 and 96 % and 88 % for COD.
4. Reliability of the removal of total nitrogen was 52 % for BCT S-12 and 72 % for TJ EP-4.
5. Considering the study outcomes, the processes of nitrification and denitrification in the biological reactors of the investigated facilities should be streamlined to provide more effective removal of organic and nitrogen-based compounds.

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Received: 12.09.2016
Accepted: 04.11.2016