TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
ENVIRONMENT ENGINEERING | ŚRODOWISKO

1-Ś/2015

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THE PRZEGINIA DUCHOWNA WASTEWATER TREATMENT PLANT– AN EVALUATION OF TREATMENT PROCESS EFFICIENCY

OCENA SKUTECZNOŚCI DZIAŁANIA OCZYSZCZALNI ŚCIEKÓW W PRZEGINI DUCHOWNEJ

A b s t r a c t

The paper determines the reliability of the wastewater treatment plant (WWTP) at the Czernichów Municipality. The study was carried out from February 2010 to March 2011. The following physic-chemical sewage quality parameters were analyzed: BOD_5, COD and total suspended solids (TSS). While assessing the plant reliability, two indicators were considered: a reliability indicator and an indicator of technical plant efficiency. The number of violations of the effluent limit values, specified in the Regulation of the Minister of the Environment of 24 July 2006 [9] was established.

Keywords: *wastewater*, *wastewater treatment plant*, *wastewater treatment plant reliability*

S t r e s z c z e n i e

W artykule określono efektywność działania oczyszczalni ścieków w Gminie Czernichów. Badania przeprowadzono w okresie od lutego 2010 do marca 2011 roku. Analizie fizyczno-chemicznej poddano następujące wskaźniki zanieczyszczenia ścieków: BZT5, ChZT oraz zawiesinę ogólną. Przy ocenie skuteczności działania oczyszczalni posłużono się następującymi charakterystykami: wskaźnikiem niezawodności i wskaźnikiem technicznej sprawności oczyszczalni.

Słowa kluczowe: *ścieki*, *oczyszczalnia ścieków*, *niezawodność pracy oczyszczalni*

DOI: 10.4467/2353737XCT.15.180.4385

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1. Introduction

The introduction of excessive pollution loads into the environment results in, among other factors, the poor operation of the wastewater treatment plant. The deterioration of water quality in the incoming waters depends on the type of plant failure and its duration [7]. Malfunctions of treatment plants also have an impact upon its surroundings – this poses a threat to inhabitants nearby and to others who use the water for consumption or recreation.

Raw sewage contains a lot of toxic and pathogenic micro-organisms that may be harmful for biological life in water, i.e. aquatic flora and fauna. The proper operation of wastewater treatment plants should eliminate these hazards.

Reliability, in technical terms, is defined as a set of properties that characterise the readiness of the object and affect it is some way. The properties include: failure resistance, maintainability and the provision of means and ways to operate an object. The term 'reliability' is often associated with the analysis of an object's efficiency and its ability to function in a satisfactory way. The analysis is associated with the occurrence of partial damage that limits the objects' performance but does not necessarily result in breakdown [5]. Reliability can be understood as the percentage of time at which the expected effluent concentrations comply with specified discharge standards or treatment targets. [4]. A wastewater treatment plant can be described as completely reliable if the process performance response has no failure, that is to say, if the limits established by the targets or environmental legislation are not violated. The treatment process fails when the required effluent discharge standards or targets are exceeded [6].

Whether the assumed wastewater treatment efficiency can be achieved strongly depends upon the design and execution of a good system in accordance with technical design guidelines [2].

Other factors determining the treatment level include: maintaining the treatment process parameters within recommended limits and ensuring the competent operation of wastewater treatment facilities.

In cases where there is a poor quality of effluent, it is important to determine the origin of operation problems and eliminate them in order to prevent risks associated with environmental pollution. Thus, the reliability study is one of the methods used to determine failures or malfunctions of the wastewater treatment process.

The aim of the study was to evaluate the treatment process stability at the Przeginia Duchowna WWTP. When assessing the wastewater treatment plant reliability, the indicators used were a reliability indicator and an indicator of plant technical efficiency.

2. Wastewater treatment plant characteristic

The Przeginia Duchowna WWTP is located in the municipality of Czernichów, near Kraków (Fig. 1a, b). The wastewater treatment plant accepts municipal sewage as well as wastewater from small local enterprises e.g. slaughterhouses and meat processing plants. Additionally, some pollution loads from areas that are not equipped with a sewage system as well as storm water and infiltration water are collected at the plant.

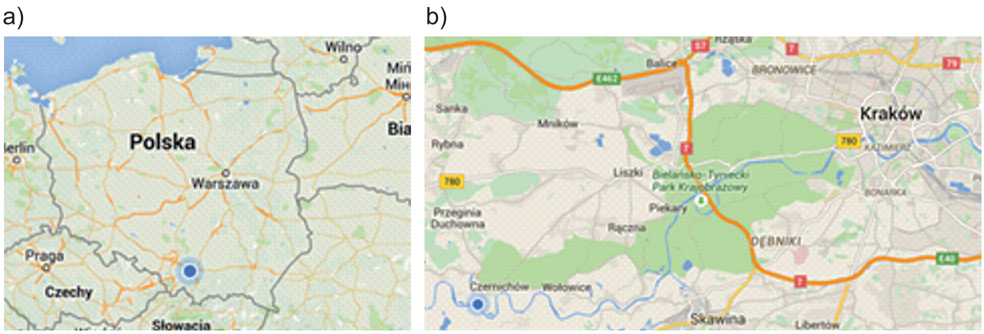

Fig. 1a), b) Location of Przeginia Duchowna village

The treatment plant is designed for an average daily flow ($Qd_{śr}$) of 450 $m^3 \cdot d^{-1}$, and a maximum daily flow (Q_{dmax}) of 540 $m^3 \cdot d^{-1}$; PE = 3392. Currently, during dry periods, the wastewater treatment plants treats about 450–500 m^3 of wastewater daily; during periods with a lot of precipitation, the amount goes up to approximately 1000–1200 $m^3 \cdot d^{-1}$. The wastewater treatment plant consists of the following treatment units (Fig. 2): a well with a bar screen and pumps, the Pomiltek integrated unit for grit and screenings removal, two continuous flow reactors with activated sludge, a secondary clarifier and the sludge thickening/dewatering unit manufactured by Pomiltek. In addition, the original project included a hydroponic lagoon that has never been completed.

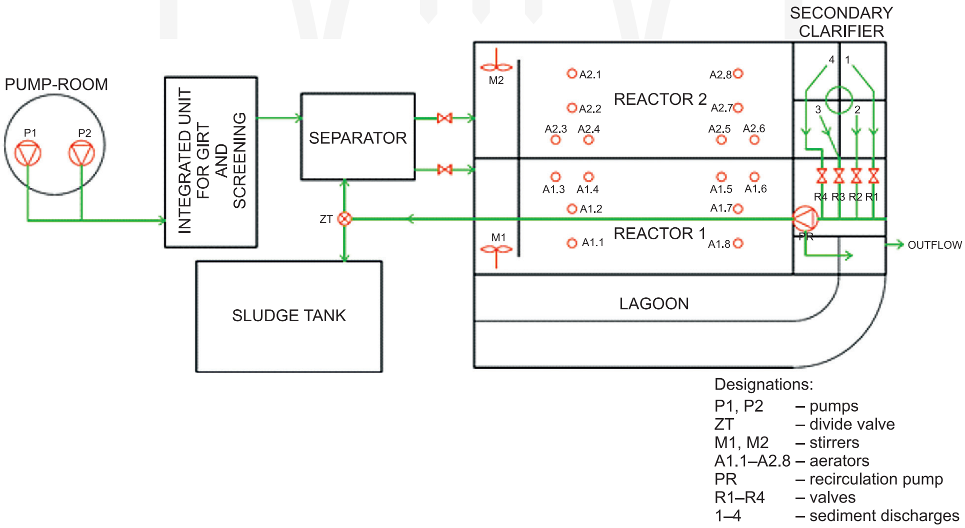

Fig. 2. Flow diagram of Przeginia Duchowna WWTP

3. Methods

The study was based on the analysis of physic-chemical parameters of raw sewage and plant effluent, such as: BOD_5, COD and TSS, performed by the SGS EKO-MOTION lab in Pszczyna. BOD_5, COD and TSS analysis were conducted according to ISO 17025; BOD_5 was determined by the electrochemical method, COD by titration, while TSS was analysed by using a gravimetric method. The analyzes included 17 samples that were collected once per month in 2010 and 2011.

In order to analyse the reliability of the process, the basic statistical characteristics of both raw sewage and the effluent were established, this included: mean, standard deviation, minimum, maximum, spread, coefficient of variation, kurtosis and skewness. Subsequently, reductions of specific pollutants were calculated. The calculation of the wastewater treatment plant efficiency was based on a technical efficiency indicator (P_{sw}), a reliability index (WN) and a reliability coefficient ($WN_{1-\alpha}$).

The technical efficiency indicator (P_{sw}) for the plant was assumed from the formula [1]:

$$P_{sw} = \frac{n}{N+1} \cdot 100\,[\%] \tag{1}$$

where:

n – number of samples with a value lower than the limit effluent value,
N – total number of effluent samples.

The reliability index (WN) was then determined based on the following equation:

$$WN = \frac{\bar{X}}{X_{\text{dop}}}\,[-] \tag{2}$$

where:

$\bar{X}$ – average concentration in the plant effluent [$mg \cdot dm^{-3}$],
X_{dop} – the concentration limit of the plant effluent [$mg \cdot dm^{-3}$].

While studying the reliability of a wastewater treatment plant, it is very important to determine the statistical distribution of pollutant concentrations in the plant effluent. When the statistical distribution is available, one can determine reliability and attempt to model it [8]. Niku [3] developed the concept of the reliability coefficient $WN_{1-\alpha}$, which combines the mean pollutant concentration in the effluent with the limit values in the effluent, taking into account the probability of their occurrence. The average pollutant concentration in the effluent which can be achieved at a given probability is expressed by the formula:

$$m_x = WN_{1-\alpha} \cdot X_{\text{dop}} \tag{3}$$

For a normal distribution:

$$WN_{1-\alpha} = \frac{1}{1 + Z_{1-\alpha} \cdot C_v} \tag{4}$$

where:

$Z_{1-\alpha}$ – standardised variable of a normal distribution for α reliability level,
C_v – coefficient of variation.

Value of $Z_{1-\alpha}$ for a normal distribution is:

$$Z_{1-\alpha} = \frac{(X_{\text{dop}} - m_x)}{\delta_x} \tag{5}$$

where:

δ_x – standard deviation of a particular pollutant.

For a log-normal distribution:

$$WN_{1-\alpha} = (C_v^2 + 1)^{0.5} \cdot \exp\{-Z_{1-\alpha}[\ln(C_v^2 + 1)]^{0.5}\} \tag{6}$$

$Z_{1-\alpha}$ for a log-normal distribution can be written as:

$$Z_{1-\alpha} = \frac{[\ln(X_{\text{dop}}) - (\ln(m_x) - 0.5\ln(C_v^2 + 1))]}{[\ln(C_v^2 + 1)]^{0.5}} \tag{7}$$

When calculating $WN_{1-\alpha}$, one should define a variable distribution using, for example, the Shapiro-Wilk test. The hypothesis of a normal sample distribution was verified at a 0.05 level of significance. The results of the analysis are presented in Table 1. Since COD and TSS both have a normal distribution, formulas [4] and [5] were used in calculations; for BOD_5 (a log-normal distribution) formulas [6] and [7] were used. The reliability level 1–α. Was found in the tables for a calculated variable $Z_{1-\alpha}$ for both normal and log-normal distributions.

Table 1

Results of Shapiro-Wilk normality test for the effluent parameters

Parameter	Distribution	Value of the Shapiro-Wilk's test
BOD_5	log-normal	0.78
COD	normal	0.82
TSS	normal	0.92

4. Results and discussion

The Przeginia Duchowna WWTP treats wastewater discharged by the sewage system of the Czernichów Commune. The treatment plant is designed for an mean average of daily flow of 450 $m^3 \cdot d^{-1}$ and a maximum flow of 540 $m^3 \cdot d^{-1}$. Figure 3 presents the monthly flows to the plant during the analysed period. Comparing the monthly flows and the daily design flows, it can be seen that the values from only 6 months (April, May, June, July, October and November 2010) exceeded $Q_{dśr}$ (450 $m^3 \cdot d^{-1}$).

Monthly flows do not present a steady and even pattern, but they vary each month. The largest flow (550 $m^3 \cdot d^{-1}$) occurred in May 2010, when heavy rain was observed, this caused the infiltration of rainwater to the sewage system. The lowest flow (400 $m^3 \cdot d^{-1}$) took place in February 2010. The spread between the data is 150 $m^3 \cdot d^{-1}$ and the calculated mean average (456 $m^3 \cdot d^{-1}$) is similar to the design daily flow.

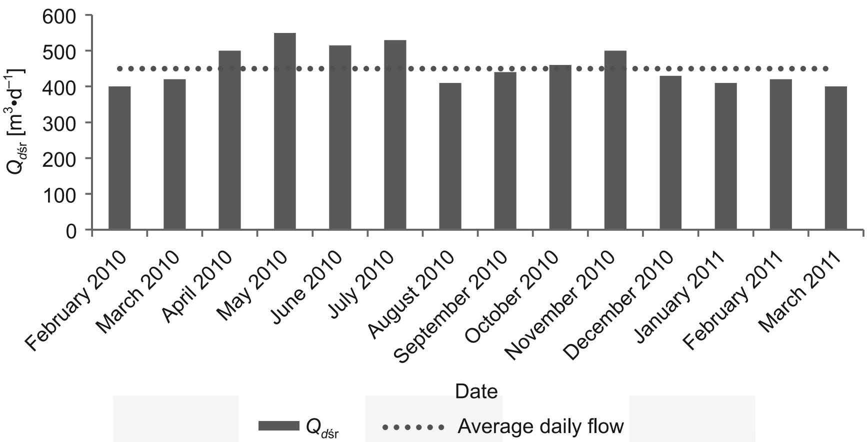

Fig. 3. Monthly flows to the Przeginia Duchowna WWTP

According to the Regulation of the Minister of the Environment of 24 July 2006 [Dz. Laws of 2005. No. 239, item. 2019, as amended], the BOD_5, COD and TSS concentration limits in the treatment plant effluent are respectively 25, 125 and 35 $mg \cdot dm^{-3}$. Tables 2 and 3 show the raw wastewater and the effluent quality parameters. Upon analysing the raw wastewater data, it can be seen that the highest BOD_5 value (1402 $mg \cdot dm^{-3}$) was observed in December 2010 while the lowest occurred in September 2010 – 59 $mg \cdot dm^{-3}$. The spread between the maximum and the minimum values was 1343 $mg \cdot dm^{-3}$, indicating high variability of the parameter. The mean average BOD_5 value in the raw wastewater was 426.60 $mg \cdot dm^{-3}$. The standard deviation of 352.72 $mg \cdot dm^{-3}$ shows a considerable scatter of samples with respect to the mean value. On the basis of the kurtosis (3.42) and skewness (1.52) it can be concluded that the variable distribution is slim and has a right-sided asymmetry.

Table 2

Characteristic of raw wastewater parameters at the Przeginia Duchowna WWTP

Characteristics	Unit	BOD_5	COD	TSS
Mean value	[$mg \cdot dm^{-3}$]	426.60	666.00	237.87
Standard deviation	[$mg \cdot dm^{-3}$]	352.72	352.62	164.21
Minimum	[$mg \cdot dm^{-3}$]	59	149	45
Maximum	[$mg \cdot dm^{-3}$]	1402	1259	546
Coefficient of variablility	[–]	0.83	0.53	0.69
Kurtosis	[–]	3.42	–0.77	–0.80
Skewness	[–]	1.81	–0.15	0.65

Table 3

Characteristic of the effluent parameters at the Przeginia Duchowna WWTP

Characteristics	Unit	BOD_5	COD	TSS
Mean value	[mg·dm^{-3}]	65.37	213.93	51.62
Standard deviation	[mg·dm^{-3}]	54.38	140.94	35.41
Minimum	[mg·dm^{-3}]	16.2	64	2
Maximum	[mg·dm^{-3}]	203	508	132
Coefficient of variablility	[–]	0.83	0.66	0.69
Kurtosis	[–]	1.72	–0.35	0.19
Skewness	[–]	1.52	0.87	0.92
Number of exceedances of the limit value	[–]	**13**	**10**	**9**

The mean BOD_5 concentration in the effluent had a value of 65.37 mg·dm^{-3} with a standard deviation of 54.38 mg·dm^{-3}. The maximum BOD_5 value of 203 mg·dm^{-3} was observed in October 2010, while the minimum value (16.2 mg·dm^{-3}) was observed in December 2010. The spread between the maximum and minimum values was 186.80 mg·dm^{-3}. On the basis of the kurtosis (1.72) and the skewness (1.52) values, it can be concluded that the parameter distribution has a flattened shape and a right-hand asymmetry.

The highest COD value in raw wastewater (1259 mg·dm^{-3}) was observed in February 2011. The lowest value occurred in May 2010 and was equal to 149 mg·dm^{-3}. The spread between the COD concentrations was 1110 mg·dm^{-3}, the mean concentration was 666 mg·dm^{-3} and the standard deviation was 354.62 mg·dm^{-3}. Kurtosis (–0.77) and skewness (–0.15) suggest that the distribution of COD was flattened and had a slight left-hand asymmetry.

On the other hand, the mean COD concentration in the plant effluent was 213.93 mg·dm^{-3} and the standard deviation was 140.94 mg·dm^{-3}. The maximum COD value (508 mg·dm^{-3}) occurred in November 2010 and the minimum value (64 mg·dm^{-3}) occurred in May of the same year. The spread between the maximum and the minimum was 444 mg·dm^{-3}. The kurtosis value of –0.35 indicated that the distribution of the analyzed sample was flattened, while the skewness value of 0.87 showed that the distribution had a right-sided asymmetry.

In the case of TSS in raw sewage, the highest concentration value (546 mg·dm^{-3}) was observed in February 2011 and the lowest value (45 mg·dm^{-3}) was observed in September 2010. The spread between the maximum and the minimum values was 501 mg·dm^{-3} which proved a high level of variability with regard to this parameter. The mean TSS concentration in the raw wastewater was 237.87 mg·dm^{-3}. The standard deviation of 164.21 mg·dm^{-3} showed a considerable scatter of samples around the mean value. Values of kurtosis and skewness proved that the distribution is flattened and had a right-sided asymmetry.

The average TSS concentration in the effluent was 51.62 mg·dm^{-3}, and the standard deviation was 35.41 mg·dm^{-3}. The maximum TSS value occurred in October 2010 and was 132 mg·dm^{-3}, while the minimum value was observed in August 2010 and was 2 mg·dm^{-3}.

The spread between these values was equal to 130 mg·dm^{-3}. On the basis of the values of kurtosis (0.19) and skewness (0.92) it can be concluded that the distribution had a shape similar to that observed for TSS in raw sewage.

In the case of TSS in the raw sewage, the highest value (546 mg·dm^{-3}) was observed in February 2011, while the lowest TSS value of 45 mg·dm^{-3} was found in September 2010. The spread between the maximum and the minimum values was 501 mg·dm^{-3} – this showed a large variability of the parameter. The average TSS concentration in the raw wastewater was 237.87 mg·dm^{-3}. The standard deviation of 164.21 mg·dm^{-3} showed a considerable scatter of samples around the average value.

According to the regulations of the Minister of the Environment of 24th July 2006, the minimum removals of BOD_5, COD and TSS at the wastewater treatment plant should be: 70–90%, 75% and 90%, respectively. Table 4 shows the removal of three analysed pollutants as percentages. It can be seen that not all test samples meet these requirements. In the case of BOD_5, a reduction below the limit value was observed in September, October and November. Since a low level of BOD_5 removal occurred in a few consecutive months, it may be concluded that during this period, the treatment plant operation was disrupted in some way.

Table 4

Removal of pollutants at the Przeginia Duchowna WWTP

Sample	BOD_5	COD	TSS
	[%]	[%]	[%]
17.02.2010	93	90	66
25.03.2010	93	94	66
24.04.2010	76	44	69
24.05.2010	80	57	75
26.06.2010	76	58	78
26.07.2010	70	53	57
28.08.2010	74	59	96
05.09.2010	31	16	32
27.10.2010	48	50	63
12.11.2010	60	39	49
21.11.2010	58	41	48
10.12.2010	99	98	99
16.12.2010	95	95	99
18.01.2011	91	87	91
07.02.2011	92	84	93
09.02.2011	93	90	94
16.03.2011	95	84	86
Mean value	**78**	**67**	**74**

A very low treatment efficiency was observed in the case of COD; an exceptionally low removal of COD took place in the spring and autumn seasons and during summer. An even worse removal performance was observed for TSS, as eleven samples did not reach the recommended percentage of removal.

Table 5 shows the reliability levels for BOD_5, COD and TSS. The results confirmed a very poor level of efficiency of the wastewater treatment plant. The $NW_{1-\alpha}$ index for all analysed pollutants stayed below 50%; this means that the treatment plant was functioning correctly for less than 183 days per year.

Table 5

Reliability values for the Przeginia Duchowna WWTP operation

Indicator	BOD_5	COD	TSS
Distribution	log-normal	normal	normal
X_{dop}	25	125	35
Average	65.37	213.93	51.62
Standard deviation	54.38	140.94	35.41
$Z_{1-\alpha}$	–1.1077	–0.6479	–0.4693589
Coefficient of variability	0.98	0.84	0.69
$WN_{1-\alpha}$	< 50%	< 50%	< 50%
WN	3.4744	2.19768	1.474857
P_{sw}	16.7%	27.8%	44.4%

Similar conclusions can be drawn based on the analysis of a P_{sw} indicator. The values of BOD_5, COD and TSS were 16.7%, 27.8% and 44.4%, respectively. According to Andraki and Dzienis [2003] wastewater treatment plants of similar sizes should operate with a technical efficiency index not lower than 89.89%, and the number of days per year with effluent limit violations should not exceed 36.

The results of the analysis showed that the Przeginia Duchowna WWTP does not work properly, so to make its modernisation effective, it is necessary to identify the origin of the problems.

5. Conclusions

Based on the data analysis, the following conclusions can be formulated:

1. While assessing the operation of the Przeginia Duchowna WWTP, it should be noted that the plant did not work properly over the studied time period;
2. The mean value of daily flow at the wastewater treatment plant was 456 $m^3 \cdot d^{-1}$;
3. The mean value of BOD_5 removal was 78% and thirteen violations of the limit concentration were reported. The average COD and TSS removals were 67% and 74%, respectively; the numbers of violations of the limit values for these parameters were ten and eleven, respectively;

4. The $WN_{1-\alpha}$ indicator for all pollutants stayed below 50%; this means that the plant had no operating problems for less than 183 days per year. Similar conclusions about the plant's operation can be drawn based on the P_{sw} indicator; its values for BOD_5, COD and TSS were 16.7%, 27.8% and 44.4%, respectively. Analysis of the plant removal efficiency using statistic methods allows to accurate examine wastewater treatment processes.

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