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## ANALYSIS AND EVALUATION OF SEWAGE TREATMENT PLANT OPERATION

### ANALIZA I OCENA FUNKCJONOWANIA OCZYSZCZALNI ŚCIEKÓW

**Abstract:** The paper presents the analysis and evaluation of six sewage treatment plants. The effectiveness of wastewater treatment was assessed for the following treatment facilities: Barcza (O1), Opatow (O2), Ostrowiec (O3), Starachowice (O4), Sandomierz (O5) and Piaseczno (O6). The evaluation of plant operation was based on the amount of reduction of five selected pollution indicators: BOD<sub>5</sub>, COD, total suspension, total nitrogen and total phosphorus. In addition, COD/BOD<sub>5</sub> ratios were determined, the reliability coefficient (RC) was calculated and the degree of use of sewage treatment plant capacity, in relation to pollutant loads, was assessed. The paper also analyzes the non uniformity coefficient that characterizes variation in sewage flow.

**Keywords:** waste water treatment plant, BOD<sub>5</sub>, biological treatment, removal efficiency

### Introduction

Wastewater introduced into a water body should not cause any physical, chemical and biological changes [1]. The task of wastewater treatment plants is, among others, to ensure proper functioning of the environment and to protect clean water resources. This can be done only by a correctly operating sewage treatment plant [2]. The reliability of a sewage treatment plant is defined as its ability to dispose of the estimated amount of sewage. The latter need to be purified to the extent required by the wastewater receiver, under specified conditions of the plant operation, during the intended period of the plant service, and at random changes in the characteristics of the plant functional components [3]. When sewage composition and properties are altered (removal of pollutants such as nutrients, refractory compounds, pathogenic microorganisms, easily falling and col-loidal suspensions, organic compounds), it is possible to discharge sewage into the receiver with a minimal risk to human and animal health [4]. According to the data [5], approx. 24.6 thousand dam<sup>3</sup> liquid waste was collected in 2010, which constitutes an

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increase of 5 % on the previous year. Besides, the Treaty of Accession provides that the European Union legislation on the disposal and treatment of urban wastewater will fully come into effect in Poland from 31 December 2015 [6]. Consequently, sewage treatment plants will not only have to comply with more restrictive EU regulations, but also to cope with an increasing amount of sewage. It is likely that not all facilities will be able to meet new requirements, and some irregularities in the operation sewage plants may occur. Incorrectly operating treatment plants can pose a threat to the safety of the people living in the vicinity of the plant, and also to recreational use of wastewater receivers, lakes and rivers, by the public [7]. The paper presents the evaluation of five sewage treatment plants in the Swietokrzyskie Province and one in the Mazowieckie Province. Sewage treatment plants under consideration are located in: Barcza (O1), Opatow (O2), Ostrowiec (O3), Starachowice (O4), Sandomierz (O5) and Piaseczno (O6).

## General characteristics of the objects O1–O6

The sewage treatment plant O1 is located in the south-eastern part of the Zagnańsk Commune, in the grounds of Gruszka village. It is intended for treatment of domestic sewage from the villages: Barcza, Gruszka, Jaworze, Kajetanow, Lekomin, Zablocie. The plant O1 was put into service in 2003, and its target capacity is expected to reach 520 m<sup>3</sup>/d. Because of the degree of sewerage in the catchment, the plant has been designed to operate in two stages. Currently, the sewage treatment plant operation is described as stage I ( $Q_{davg.} = 250 \text{ m}^3/\text{d}$ ). The object O1 is a mechanical-biological treatment plant intended for integrated removal of carbon, nitrogen and phosphorus compounds. It is based on EvU-Pearl technology, which combines a three-phased activated sludge method with separate anaerobic, anoxic, aerobic zones and whirled biological sludge – moving-bed biofilter methods. Biofilter which fills the biological reactor are EVU-Pearl cylindrical hollow forms of bulk volume specific surface 800 m<sup>2</sup>/m<sup>3</sup>. Biological phosphorus removal process may be assisted by chemical precipitation with ferric sulfate (PIX) coagulant. Treated effluent is discharged into the receiver, which is the river Lubrzanka. The plant is equipped with a sludge treatment line, where aerobically stabilized sludge is subjected to gravitational compaction and mechanical dewatering.

The wastewater treatment plant (WWTP) O2 is located in the Sempolowskiej street in Opatow. Sewage from the town of Opatow flow through gravity sewers into the raw sewage pumping station, from where it is pumped into the expansion chamber, situated within the facility. Then the wastewater flows by gravity through the mechanical and manual screens, and also through a vertical grit chamber, where wastewater is cleaned mechanically. In the next stage, wastewater is directed to the activated sludge chamber, where under varying substrate and aerobic conditions, it receives full biological treatment. In addition, phosphorus removal can be fostered by dosing PIX 113 formulation. A mixture of treated sewage and the activated sludge is further transferred to the vertical secondary settlement tanks, in which sedimentation takes place. After sedimentation, the sludge is pumped through the recirculated sludge chamber back to

the activated sludge chamber. Cleaned effluent flows by gravity through measurement flume into the receiver, which in this case is the river Opatowka.

The municipal wastewater treatment plants O3 is located at Mostowa Street 72, within the administrative boundaries of the town of Ostrowiec, in the south-east of the town. Municipal sewage from the town is delivered by the municipal collecting sewer to the wastewater treatment plant. The facility O3 is a mechanical-biological treatment plant. The mechanical component of the facility starts with a coarse screen mounted in a collection well, from where the sewage flows down by gravity to the raw sewage pumping station I°. The latter is equipped with submersible pumps, which force the sewage through two channels into the stilling chamber, and further to the step grates. A sand separator receiving sand pulp from the vortex grit chamber is also located in the screening building. From the grit chamber, sewage flows by gravity to the pumping station II, and then it is forced into the flow splitting chamber situated before primary circular sedimentation basin. Clarified effluent from preliminary settling tanks is piped by the gravity through overflows and overflow troughs to the multifunctional reactors in two parallel treatment lanes. Each of the reactors consists of four chambers, namely those of: dephosphatation, predenitrification, denitrification and nitrification. From the biological reactor, effluent flows through an overflow to the secondary settling tanks. Treated effluent from the wastewater plant is discharged through the measurement flume to the river Kamienna.

The WWTP O4 has been in service since 1962. For the first time, the expansion and modernization of the wastewater treatment was carried out in the 80s. The next upgrading of the facility took place in 1999–2002 and was aimed at increasing the efficiency of wastewater treatment and removal of nutrients. The separation of floating and dragged pollutants is carried out in the screening building on the mechanical screen. The material retained (screenings) is transported to the press-rinse; pressed screenings are emptied to the container. The removal of sand takes place in two vertical sand traps. The sand collected in the hopper is removed periodically by pumping through a sand separator and scrubber into an above-ground tank located in the pumping station. The separation of suspended solids is performed in the primary circular sedimentation basin. Clarified effluent is discharged into the sewage pumping station II, and the drained sludge is passed to the sludge pumping station, and further to the existing sludge management facilities. Floating parts are removed to the pumping station and to the existing sludge facilities. The process of biologically activated sludge treatment in the O4 is performed on two process lines, each consisting of a biological reactor, secondary settling tank, recirculation pumping station, and the blowers station. The biological reactor is a three-chamber tank with activated sludge, in which the process of biological removal of carbon compounds, nitrogen and phosphorus takes place. The separation of activated sludge from treated wastewater is performed in the circular secondary clarifier. Clarified effluent is discharged by gravity through a measuring device into the receiver. The sludge separated in the secondary clarifier is recirculated through the sludge recirculation pumping to the biological reactor and the excess of the sludge is transferred, after mechanical compaction, to the existing sludge facilities. It is possible to promote the removal of total phosphorus by dosing the solution of iron (III) sulphate (VI).

The sewage treatment plant O5 provides treatment services to a larger part of the town, the wastewater is carried there, by gravity, from the left and right bank of the river. In addition, approx. 900 tanks without drainage are located in the city. The O5 is a mechanical-biological treatment plant, located on the left bank of the Vistula River and its nominal capacity is 7500 m<sup>3</sup>/d. The plant operation has continued without interruption since 1998. The technological system of the wastewater treatment plant comprises mechanical and biological parts. The mechanical part employs the processes of separation of floating and dragged pollutants trailing on the step grate, as also the mechanical plane grating and sedimentation of sand in the vortex grit chamber. The grit chamber installed in a separate room in the screening building is used for sand separation. The biological method is based on activated sludge with the enhanced removal of nutrients. The basic elements of this part are two integrated multi-function circular bioreactors, which comprise a centrally located secondary clarifier and activated sludge chambers located along the circumference.

The wastewater treatment plant O6 is located in the eastern part of the town of Piaseczno, between Żeromskiego Street and Mazurska Street. It purifies the sewage flowing through the separate sewer system and the sewage transported to the discharge point at the sewage treatment plant with road tanker vehicles. The facility uses mechanical-biological treatment of wastewater with the biological dephosphatation, denitrification and nitrification, and with simultaneous chemical precipitation of phosphorus. It has a technological line, where, in the first stage, wastewater is subjected to mechanical methods of purification. The second stage involves biological treatment in the dephosphatation chamber and four chambers of activated sludge with an option of simultaneous phosphorus removal. Two of those chambers, together with two secondary clarifiers constitute the emergency system of the treatment plant. From denitrification and nitrification chambers, wastewater is carried to the circular secondary clarifier, from where, when the sludge is settled and clarified, it is discharged into the receiver.

## Quantitative analysis of wastewater

The basic flow describing discussed treatment plants O1–O6 are summarized in Table 1.

Table 1

Characteristic wastewater flows in objects O1–O6

Treatment plant	$Q_{davg}$ [m <sup>3</sup> /d]	$Q_{dmax}$ [m <sup>3</sup> /d]	$Q_{hmax}$ [m <sup>3</sup> /h]
O1	250	300	25
O2	959	1 950	210
O3	13 137	20 200	630
O4	15 200	18 200 (dry weather) 24 000 (wet weather)	1 100
O5	7 500	10 000	625
O6	17 152	24 870	—

The facility O1 is the smallest of the plants discussed. Presently, the sewage load expressed as the population equivalent amounts to PE = 2250, but from the design data PE is expected to increase to 3833. In accordance with the design data, the O2 sewage load population equivalent is 21125, but the actual PE-based value of the maximum average weekly load for the calendar year 2010 was 15243. For the wastewater treatment plant O3, the design predicts the sewage load population equivalent to amount to 88060. The actual PE value for the O3 facility, based on the maximum average weekly load, is 50142. The wastewater treatment plant O4 [8], as well as the facilities O2–O4, belong to the fourth group with PE ranging from 15000 to 99999. As regards the treatment plant O5, the PE real data was 31933. The treatment plant O6 sewage load expressed with the population equivalent is currently 121779, and its target size is estimated at PE = 163500. Variability of wastewater flow is defined by the non-uniformity coefficient. It represents the ratio of the maximum daily flow of sewage to the average daily flow:

$$N_{dmax} = Q_{dmax} / Q_{davg} \quad (1)$$

The value of the coefficient of daily nonuniformity  $N_{dmax}$  depends on the number of inhabitants and according to [9] are:

- in large cities ( $R > 25000$ ) 1.2,
- in medium-sized cities ( $10000 < R < 25000$ ) 1.5,
- in small towns ( $5000 < R < 10000$ ) 1.75,
- in small settlements ( $R < 5000$ ) 2.0.

Summary of ratio values for each object  $N_{dmax}$  O1–O6 are presented in Fig. 1.

$N_{dmax}$  values according to Fig. 1 are in the range 1.20–1.58. High value refers to the object O4 and the lowest to the treatment O1. The calculations for the analyzed objects O1–O6 is clear that the values  $N_{dmax}$  according to the literature data are somewhat higher than those calculated for the actual values. This means that the treatment plants O1–O6 are not so vulnerable to changing flow conditions – so their work is more stable.

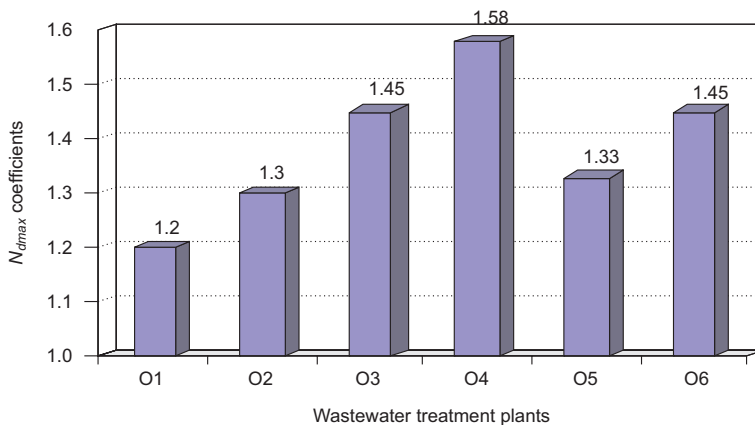


Fig. 1. Coefficient of nonuniformity  $N_{dmax}$  for objects O1–O6

## Qualitative analysis of wastewater

Malfunctioning of wastewater treatment plants usually leads to environmental pollution. The resultant deterioration of water quality in the receiver depends on the type of irregularities or failures and their duration [10]. The mere fact that a sewage treatment plant has been constructed does not relieve the operators from the obligation to maintain appropriate quality of the effluent. It is necessary to collect raw sewage and effluent samples and then to determine the values of pollution indicators on current basis. With these data, it is possible to assess the effectiveness of removing pollutants and to determine the reliability coefficients for the various indicators of sewage pollution [11]. On the basis of [8], it should be noted that, in terms of the PE size, sewage treatment plants under consideration can be categorized into three different groups. Therefore, the requirements for effluent quality are different, which is shown in Table 2.

Table 2

The highest permissible values of indicators and minimum percentages of pollutant reduction in accordance with [8]

Indicator	The highest permissible values of indicators and minimum percentages of pollutant reduction for PE		
	from 2000 to 9999 (O1)	from 15000 to 99999 (O2–O5)	100000 and above (O6)
BOD <sub>5</sub>	25 mgO <sub>2</sub> /dm <sup>3</sup> or 70–90 %	15 mgO <sub>2</sub> /dm <sup>3</sup> or 90 %	15 mgO <sub>2</sub> /dm <sup>3</sup> or 90 %
COD	125 mgO <sub>2</sub> /dm <sup>3</sup> or 75 %	125 mgO <sub>2</sub> /dm <sup>3</sup> or 75 %	125 mgO <sub>2</sub> /dm <sup>3</sup> or 75 %
Total suspension	35 mg/dm <sup>3</sup> or 90 %	35 mg/dm <sup>3</sup> or 90 %	35 mg/dm <sup>3</sup> or 90 %
Total nitrogen	15 mgN/dm <sup>3</sup>	15 mgN/dm <sup>3</sup> or 80 %	10 mgN/dm <sup>3</sup> or 85 %
Total phosphorus	2 mgP/dm <sup>3</sup>	2 mgP/dm <sup>3</sup> or 85 %	1 mgP/dm <sup>3</sup> or 90 %

Each of the sewage treatment plants has a valid sewage effluent disposal consent for effluent discharge into the receiver. In accordance with the document mentioned above, effluent discharged into a water body or soil can not exceed certain values. Actual values are at the same level (O4–O6), and in two cases they are lower (O2 and O3) than those stated by the regulation [8].

The criterion adopted to assess the plant efficiency is a percent to which the values of individual pollution indicators are lowered

$$\eta = (S_i - S_e) / S_i \cdot 100 \% \quad (2)$$

where:  $S_i$  – concentration of a particular pollutant type in wastewater flowing into the wastewater treatment plant [mg/dm<sup>3</sup>],

$S_e$  – concentration of a particular pollutant type in effluent treated and discharged to the receiver [ $\text{mg}/\text{dm}^3$ ].

As shown in Fig. 2, the percent of pollution reduction in the wastewater plants under consideration is within the following ranges:

- for  $\text{BOD}_5$ , from 93.2 % (O4) to 99.6 % (O1),
- for the COD, from 80.5 % (O3) to 97.9 % (O2),
- for suspended solids, from 81.3 % (O3) to 99.6 % (O6),
- for total nitrogen, from 57.2 % (O4) to 95.3 % (O6),
- and for total phosphorus, from 76.2 % (O1) to 98.3 % (O6).

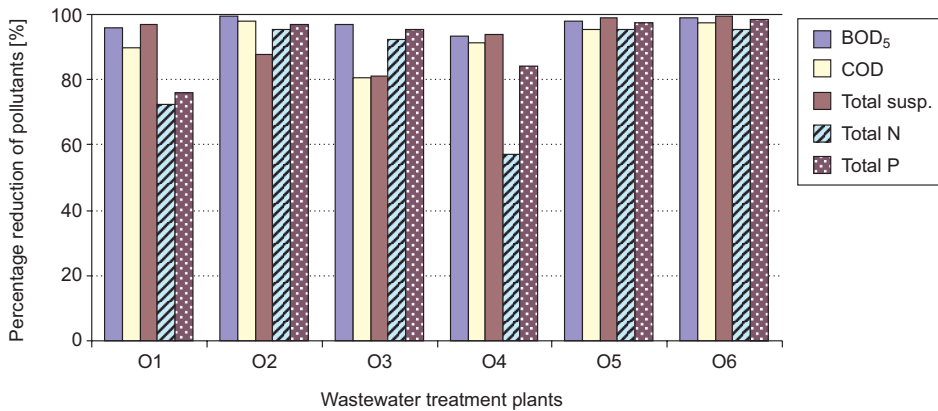


Fig. 2. The percentage reduction in the value of individual indicators of pollution

In the case of the treatment plant O1, although high percents of reduction in COD and total nitrogen have been achieved, the other indicator values in the effluent are higher than those recommended by the regulation [8]. The sewage plant O3 has been highly effective in nutrient removal (Fig. 2), which makes it possible to abandon using coagulants to assist the dephosphatation process, resulting in lower sludge production. Alarmingly low levels of total nitrogen reduction present in the case of O4 may result in penalties for failure to comply with the sewage effluent disposal consent. That can also lead to the accumulation of nitrogen compounds in the receiver, which in turn, can cause the intensification of eutrophic processes.

To determine the reliability of the wastewater treatment plants, a reliability ratio (WN) [11] was used, presented in Table 3. It was calculated for pollution indicators in all objects using the formula [11]:

$$WN = \mu_x / X_{lim} \quad (3)$$

where:  $\mu_x$  – mean value of pollution indicator in treated effluent [ $\text{mg}/\text{dm}^3$ ],

$X_{lim}$  – permissible value of pollution indicator in treated effluent [ $\text{mg}/\text{dm}^3$ ].

Low values of the reliability coefficient for the analyzed pollutants indicate effective operation of sewage treatment plants. Excessively high values of the coefficient occur in

Table 3

Reliability coefficient for sewage treatment plant O1–O6

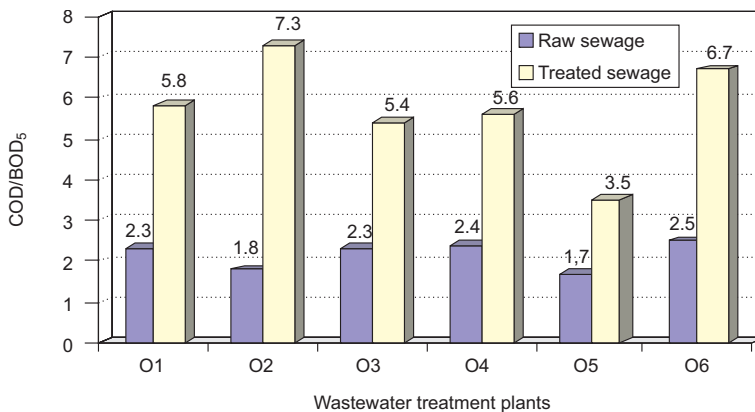
Indicator, for which reliability coefficient is calculated	O1	O2	O3	O4	O5	O6
BOD <sub>5</sub>	0.9	0.3	0.4	0.8	0.8	0.3
COD	1.0	0.3	0.2	0.4	0.3	0.2
Total suspension	0.7	0.2	0.2	0.5	0.1	0.1
Total nitrogen	1.9	0.4	0.6	1.7	0.3	0.4
Total phosphorus	2.5	1.1	0.4	0.6	0.1	0.4

the following treatment plants: O1 (for COD, total N, and total P), O2 (for total P), and also O4 (for total N). Despite high values of the reliability coefficient, relatively high values of pollution reduction are obtained in all the treatment plants, which is shown in Fig. 2.

To test the quality of the analysis of raw and treated wastewater, the correlations between indicators of pollution, *ie* COD and BOD<sub>5</sub>, are established. For raw sewage, two cases are considered:  $COD/BOD_5 < 2$  (readily biodegradable wastewater) and  $COD/BOD_5 > 2$  (hard biodegradable wastewater) [12]. For the effluent  $COD/BOD_5 = 5-6$ .

In sewage plants O2 and O5 (Fig. 3), raw sewage is easily biodegradable ( $COD/BOD_5 < 2$ ). In the remaining four cases, the ratio of COD to BOD<sub>5</sub> is greater than 2, which means the wastewater is hard biodegradable. In objects O2 and O6, the COD/BOD<sub>5</sub> ratio in treated sewage is higher (7.3 and 6.7, respectively) than those described in the literature, also in the O5, the value is lower than in the literature and amounts to only 3.5.

Typically, while designing objects such as sewage treatment plants, prognostic data on wastewater quantity and quality are relied on. Consequently, when the facility has

Fig. 3. Correlations between COD and BOD<sub>5</sub> pollution indicators



started operating, it may turn out that the actual data differ significantly from the design data. Discrepancies between the design and real data may result in irregularities in the operation of wastewater treatment plants [13].

The utilization percent of sewage treatment capacity with respect to pollution loads was calculated from the dependence [13]:

$$\omega_i = L_R / L_P \cdot 100 \% \quad (4)$$

where:  $L_R$  – the actual average daily load of pollutants contained in wastewater influent to the treatment plant expressed in kg/d;

$L_P$  – the average daily load of pollutants contained in wastewater influent to the treatment plant according to the design data.

Table 4 clearly indicates that all these facilities operate under extremely changeable conditions varying from underload to overload with various pollution types. The lack of stability in influent loads may significantly affect the quality of treated wastewater and sewage treatment plant operation. Therefore, it is necessary to control the inflowing loads, so that they were at a fairly constant level, and as close as possible to the design assumptions. It should also be emphasized that in spite of differences in  $\omega_i$  for individual pollutant, the objects achieved very high levels of pollution reduction. Also, in most cases, they did not exceed the pollutant limit for treated wastewater discharged into the receiver.

Table 4

The utilization percent of sewage treatment capacity in O1–O6

Indicator, for which $\omega_i$ is calculated	O1	O2	O3	O4	O5	O6
BOD <sub>5</sub>	74.9	101.7	58.9	66.3	59.6	—
COD	65.6	109.6	84.2	87.4	65.6	—
Total suspension	39.4	45.9	64.8	138.8	63.8	—
Total nitrogen	—	163.7	80.3	88.5	65.3	—
Total phosphorus	—	66.7	63.6	93.5	49.4	—

## Summary and conclusions

The sewage treatment plants O1–O6 can be categorized into three different groups with respect to load expressed by the population equivalent (from 2250 to 121779). Despite differences in load size, all facilities operate satisfactorily. They produce very good results in wastewater treatment and comply with the limit values and sewage effluent disposal consent. Only in the treatment plant O1, in spite of achieving high degrees of pollution reduction for COD and total nitrogen, effluent values are higher than those recommended by the regulation. In most cases, low reliability coefficients for the analyzed pollutants were obtained, which indicates correct operation of sewage

treatment plants. It should also be noted that although working under highly variable load conditions as regards individual pollutants, all treatment plants reached very high levels of reduction.

Lack of sewage treatment plants or sewerage would be a major barrier to the development of any region. That would lower the attractiveness of an area to potential residents and investors. Due to the operation of sewage treatment plants, uncontrolled wastewater discharge into water and soil has been substantially reduced. To conclude, positive effects produced by wastewater treatment plants fully balance their possible adverse impact on the environment.

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## ANALIZA I OCENA FUNKCJONOWANIA OCZYSZCZALNI ŚCIEKÓW

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**Abstrakt:** W pracy przedstawiono analizę oraz ocenę funkcjonowania sześciu oczyszczalni ścieków. Ocenie efektywności systemu oczyszczania poddano oczyszczalnie ścieków Barcza (O1), a także w Opatowie (O2), Ostrowcu Świętokrzyskim (O3), Starachowicach (O4), oraz w Sandomierzu (O5) i Piasecznie (O6). Oceny poprawności działania oczyszczalni oparto na wielkości redukcji 5 wybranych wskaźników zanieczyszczeń: BZT<sub>5</sub>, ChZT, zawiesina ogólna, azot ogólny i fosfor ogólny. Poza tym dokonano obliczeń stosunku

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ChZT/BZT<sub>5</sub>, jak i również obliczono współczynnik niezawodności WN oraz stopień wykorzystania przepustowości oczyszczalni ścieków ze względu na ładunki zanieczyszczeń. W pracy przeanalizowano również wartość współczynnika nierównomierności, który charakteryzuje zmienność dopływu ścieków.

**Słowa kluczowe:** oczyszczalnia ścieków, BZT<sub>5</sub>, biologiczne oczyszczanie ścieków, skuteczność usuwania zanieczyszczeń