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COMPARISON OF POLLUTANT REMOVAL EFFECTIVENESS IN SELECTED RURAL SEWAGE TREATMENT PLANTS IN NOWY TARG DISTRICT

The aim of the research was to compare the effectiveness of pollutant removal in five chosen mechanical-biological treatment plants located in rural communes of Nowy Targ district. The selected treatment plants used biological reactors with activated sludge and had a designed capacity of 315–600 $m^3 \cdot d^{-1}$. The treatment plants were compared in three categories using a 5-point evaluation system. The research showed that the Bardenpho-type reactor in Czarny Dunajec was most effective in removing pollutants. The Kluszkowce treatment plant, achieving the best value in two categories and based on the UCT reactor, fared only 3.6% worse (in point valuation) than the Bardenpho-type reactor in Czarny Dunajec. The low operational effectiveness of the Łopuszna and Maniowy treatment plants may be caused by illegal sewage discharge from a tannery company.

1. INTRODUCTION

During the last decade in Poland, approximately 165 new treatment plants have been commissioned every year [1]. The majority of these are based on different designs of biological reactors, currently recognized as the most effective means for municipal sewage treatment [2], [3].

A large percentage of newly constructed treatment plants are intended to treat household sewage from rural settlements. In Poland, there is still an unfavourable ratio between the municipal wastes and the systems available for treating discharged sewage [4]. The operation of rural wastewater treatment plants is inhibited by significant variability in sewage inflow as well as in pollutant loading. Additional problems arise from rainwater and water infiltration into sewage canals [5], [6]. This phenome-

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non is especially evident in rural areas, since they often lack a proper rainwater collection-disposal system. The presence of rain and infiltration water can lead to excessive raw sewage dilution. Under maximal inflow conditions, this can cause the removal of activated sludge from the biological reactor [7]. Another problem is the illegal discharge to the sewerage system of manure and sewage from small industries such as meat processing facilities, tanneries, among others. Generally, rural sewage treatment plants depend to a large extent on human controllers; thus only staff experience may prevent problems encountered during treatment.

Sewage treatment plants operating in rural areas should therefore be able to tolerate dynamical variations in the quantity and quality of raw sewage, often occurring within a single day.

Wide variability in structure design, operating conditions, process parameters, and maintenance significantly reduces communication and collaboration between researchers, operators and designers. Moreover, in Poland, independent designing, commissioning, and implementation further make collaboration less effective. Thus, research results showing the most effective, verified technological solutions for given conditions are becoming more meaningful.

Comparing the operating effectiveness of different sewage treatment plants is difficult because treated sewage quality is influenced by multiple factors, often random ones. Thus, sewage treatment plant operation can be evaluated using different methods. For treatment plant operators, the most important task is to fulfill the requirements for the defined pollutant ratios in water. Comparing the different treatment operations by defining their pollutant removal efficiency in relation to raw sewage can help in evaluating the treatment plant. Another important piece of data is the number of average daily sewage samples taken throughout a year in violation of the operating permit for BOD_5, COD and total suspended solids.

2. RESEARCH PROCEDURES

2.1. RESEARCH AIM

The aim of the research was to compare the effectiveness of pollutant removal in five selected mechanical-biological sewage treatment plants located in the communes of Nowy Targ district. Treatment plants using biological activated sludge reactors and having a capacity from 315 to 600 $m^3 \cdot d^{-1}$ were chosen. It was possible to determine the most effective treatment plants by conducting measurements under comparable weather conditions and by selecting treatment plants with similar raw sewage characteristics. This allows rational and sensible decision-making about the selection and design of a new sewage treatment plant.

2.2. RESEARCH AREA DESCRIPTION

Nowy Targ district is located in the southern part of Lesser Poland voivodeship bordering Tatra district to the south and Limanowa, Myślenice and Sucha Beskidzka districts to the north. This district consists of 11 rural communes: Czarny Dunajec, Czorsztyn, Jabłonka, Krościenko nad Dunajcem, Lipnica Wielka, Łapsze Niżne, Nowy Targ, Ochotnica Dolna, Raba Wyżna, Spytkowice and Szaflary. Nowy Targ district has 437.5 km of sewerage system serving 9887 habitable buildings. This district discharges 3 hm^3 of sewage annually, of which 46% is treated in sewage treatment plants with higher biogenic compounds removal. 46.6% of inhabitants in Nowy Targ district are served by a sewerage system [1].

2.3. DESCRIPTIONS OF RESEARCH OBJECTS

There was evaluated the operation of five mechanical-biological sewage treatment plants located in the follwing Nowy Targ district towns: Łopuszna, Maniowy, Nidzica, Kluszkowce and Czarny Dunajec.

The wastewater treatment plant in Łopuszna of a designed capacity of 600 $m^3 \cdot d^{-1}$ was commissioned in 1998. Presently, approximately 550 $m^3 \cdot d^{-1}$ of raw sewage flows to the sewage treatment, resulting in a hydraulic loading of 92%. The PE (population equivalent) computed for this system is 3800. The main treatment devices include: mechanical grates (stair grates), vertical grit chamber, flow biological reactor (with separate chambers for predenitrification, denitrification, and nitrification), and vertical secondary tanks. Chemicals to assist with phosphorus removal are applied in the form of a PIX dosage. Treated sewage is then discharged into the Dunajec River.

The sewage treatment plant in Kluszkowce was commissioned in 1994 with a design capacity of 400 $m^3 \cdot d^{-1}$. The PE currently equals 1900 and in the absence of precipitation, the inflow amounts to approximately 265 $m^3 \cdot d^{-1}$, resulting in a hydraulic loading of 66%. The sewage treatment plant consists of basket grates, a vertical grit chamber, an average chamber, a flow biological reactor UCT (with separate chambers for dephosphatation, denitrification and nitrification), vertical secondary tanks, and a pump for applying doses of the PIX coagulant. Treated sewage is subsequently discharged into Kluszkowianka stream.

The wastewater treatment plant in Maniowy has been operating since 1999 with a hydraulic capacity of 315 $m^3 \cdot d^{-1}$. Presently, the system inflow is approximately 250 $m^3 \cdot d^{-1}$, resulting in a hydraulic load of 79% and a PE of 1800. The treatment plant consists of manual grates, horizontal two-chamber grit, modified flow Bardenpho biological reactor (with separate chambers for predenitrification, dephosphatation, denitrification and nitrification), a vertical tank, and a PIX station.

The wastewater treatment plant EKO-CLEAR in Nidzica was commissioned in

1995 and has a designed capacity of 430 $m^3 \cdot d^{-1}$. Inflow of household sewage is approximately 400 $m^3 \cdot d^{-1}$ with the system hydraulically loaded at 93% and having a PE of 2050. The main treatment plant systems are manual grates, a vertical grit chamber, the biological reactor EKO-CLEAR, a PIX station, and a biological pond with marsh-root flora. Treated sewage is deposited in the Sromowce Wyżne reservoir.

The commissioning of the sewage treatment plant in Czarny Dunajec having a designed capacity of 400 $m^3 \cdot d^{-1}$ was performed in 2001. Inflow is approximately of 330 $m^3 \cdot d^{-1}$, resulting in a hydraulic loading of 83% and a PE of 3643. The treatment plant consists of basket grates, a tank for removed sludge, the modified flow Bardenpho biological reactor (with separate chambers for predenitrification, dephosphatation, denitrification, and nitrification), a vertical secondary tank, and a PIX station. The treated sewage is then discharged into Czarny Dunajec stream.

2.4. RESEARCH METHODS

During a three year research period, samples of raw and treated sewage were taken from the selected wastewater treatment plants. Sewage composition was analyzed in terms of five basic pollutant indexes as defined in the operating permit for each treatment plant: BOD_5, COD, total suspended solids, total nitrogen and total phosphorus. From this analysis, basic statistical parameters including the minimum, maximum, mean, and standard deviation were determined for raw and treated sewage. Moreover, the pollutant removal efficiency in terms of the indexes was calculated according to the following equation [8]:

$$\eta_x = \frac{(S_{px} - S_{kx})}{S_{px}} \cdot 100\%, \tag{1}$$

where:

S_{px} – the concentration of x pollutant in the inflow to the treatment plant, $mg \cdot dm^{-3}$,

S_{kx} – the concentration of x pollutant in treated sewage, $mg \cdot dm^{-3}$.

The so-called reliability index *RI* was computed to relate sewage quality to admissible values in discharge permits [9]:

$$RI = \frac{\mu_x}{X_{\mathrm{adm}}}, \tag{2}$$

where:

μ_x – an average value of a given index in treated sewage,

X_{adm} – an admissible value of a specified pollutant index according to the operating permit.

The operational effectiveness of the sewage treatment plants was evaluated by comparing computed numerical values in three categories: an average value of pollutant index in treated sewage, an average effectiveness of pollutant removal expressed in %, and the value of the computed reliability index *RI*. In each category, the values of the five pollutants were compared individually. Since three different parameters were compared, a point evaluation system was used to interpret the results.

The wastewater treatment plant with the best results for a particular category gained 5 points, while the other treatment plants received 4, 3, 2 and 1 point according to their respective performances. In each category, a treatment plant could gain a maximum of 25 points and a minimum of 5 points. From this analysis, it was possible to determine which treatment plant achieved the best results in each category and overall.

3. ANALYSIS OF RESULTS

In the first stage of analysis, the composition of raw sewage in the different treatment plants was compared (table 1). The BOD_5, COD and total suspended solids concentration are similar to typical household sewage values [10], although a high total nitrogen concentration was found in raw sewage in the Maniowy and Czarny Dunajec treatment plants. In general, the mean total phosphorus concentration remained below 10 $mg \cdot dm^{-3}$, and only in Czarny Dunajec it was about two times higher, reaching 18.06 $mg \cdot dm^{-3}$. For the most part, the highest mean pollutant concentrations were found in the inflow sewage in Łopuszna, whereas the lowest concentrations were in Maniowy (excluding the total nitrogen concentration). While analyzing raw sewage composition, a high $COD:BOD_5$ ratio in the interval from 2.4 to 3.1 was found in the selected treatment plants. This indicates a relatively low biological treatment potential. Also, a low proportion of BOD_5 to N_{tot}, ranging from 2.2 to 2.9, was found in all sewage treatment plants with the exception of Łopuszna (the value of 4.9). This may be because it is difficult to increase the reduction of high concentrations of nitrates in the hypoxic chamber, possibly also to limit the amount of carbon available for biomass growth. The proportion of BOD_5 to $P_{tot} > 20$ is maintained, except in the Czarny Dunajec treatment plant. In summary, the composition of sewage that flows to the treatment plants may cause problems during the biological treatment process.

Table 1

Mean values of chosen contamination indexes in raw sewage that flows to the analyzed treatment plants

Treatment plant	Mean value of contamination index ($mg \cdot dm^{-3}$)				
	BOD_5	COD	Total suspended solids	Total nitrogen	Total phosphorus
Łopuszna	411.92	973.13	403.78	84.90	9.73
Kluszkowce	198.06	606.52	242.26	69.10	4.33
Maniowy	213.69	533.56	133.51	102.04	6.04
Nidzica	182.19	545.35	272.87	71.22	9.14
Czarny Dunajec	248.50	686.20	192.00	112.41	18.06

Table 2

Comparison of parameters characterizing the effectiveness of the analyzed treatment plants

Contamination index	Parameter		Unit	Parameter value for given treatment plant				
				Łopuszna	Kluszkowce	Maniowy	Nidzica	Czarny Dunajec
BOD_5	Value in treated sewage	maximal	$mg\ O_2 \cdot dm^{-3}$	70.68	21.10	17.18	28.69	8.30
		mean		19.38	9.00	11.65	10.70	4.65
		minimal		7.00	3.92	6.46	1.28	2.70
	Certainty ratio *CR*		–	1.29	0.60	0.78	0.43	0.31
	Mean removal effectiveness		%	94.42	94.88	93.84	88.42	97.83
COD	Value in treated sewage	maximal	$mg\ O_2 \cdot dm^{-3}$	119.60	52.10	61.10	68.50	65.10
		mean		64.36	37.71	46.59	43.45	44.98
		minimal		39.00	26.63	25.70	3.88	26.40
	Certainty ratio *CR*		–	0.86	0.50	0.56	0.33	0.60
	Mean removal effectiveness		%	93.04	91.86	88.12	85.64	92.15
Total suspended solids	Value in treated sewage	maximal	$mg \cdot dm^{-3}$	38.80	31.00	24.40	34.00	26.00
		mean		17.48	12.14	17.26	15.26	14.40
		minimal		9.00	2.00	6.00	2.80	9.60
	Certainty ratio *CR*		–	0.70	0.49	0.69	0.61	0.58
	Mean removal effectiveness		%	95.34	90.11	86.7	96.02	86.46
Total nitrogen	Value in treated sewage	maximal	$mg\ N_{tot} \cdot dm^{-3}$	60.00	26.60	38.20	34.45	25.23
		mean		39.01	18.52	24.01	23.13	13.99
		minimal		11.00	13.25	17.12	12.82	7.50
	Certainty ratio *CR*		–	1.30	0.62	1.20	0.93	0.47
	Mean removal effectiveness		%	50,1	72.2	74.19	65.2	77.56
Total phosphorus	Value in treated sewage	maximal	$mg\ P_{tot} \cdot dm^{-3}$	0.90	2.94	6.42	2.64	2.40
		mean		0.57	1.07	1.48	0.93	1.16
		minimal		0.10	0.51	0.13	0.08	0.20
	Certainty ratio *CR*		–	0.57	1.07	0.30	0.93	1.16
	Mean removal effectiveness		%	93.84	75.2	77.76	81.07	89.04

Table 2 compares sewage treatment parameters in the treatment plants of interest. Maximums, minimums and means of the analyzed pollutant indexes in treated sewage were defined. Furthermore, each index and the reliability index *RI* were presented at various stages of treatment.

An evaluation of treatment effectiveness was conducted for the selected plants based on three criteria: achieving a low value of the pollutant indexes in treated sewage, reaching the highest possible sewage treatment, and obtaining the lowest value of the reliability index *RI*. The results of the point valuation comparison are shown in table 3.

Table 3

Comparison of pollutant removal in five chosen treatment plants in Nowy Targ district (point valuation)

Comparison category	Contamination index	Treatment plant				
		Łopuszna	Kluszkowce	Maniowy	Nidzica	Czarny Dunajec
The lowest mean value of contamination index in treated sewage	BOD_5	1	4	2	3	5
	COD	1	5	2	4	3
	susp. sol.	1	5	2	3	4
	tot. nitr.	1	4	2	3	5
	tot. phosp.	5	3	1	4	2
Sum		**9**	**21**	**9**	**17**	**19**
The highest effectiveness of pollutant removal in relation to a given index	BOD_5	3	4	2	1	5
	COD	5	3	2	1	4
	susp. sol.	4	3	2	5	1
	tot. nitr.	1	3	4	2	5
	tot. phosp.	5	1	2	3	4
Sum		**18**	**14**	**12**	**12**	**19**
Reliability index (*RI*) value	BOD_5	1	3	2	4	5
	COD	1	4	3	5	2
	susp. sol.	1	5	2	3	4
	tot nitr.	1	4	2	3	5
	tot. phosp.	4	2	5	3	1
Sum		**8**	**18**	**14**	**18**	**17**
Total		**35**	**53**	**35**	**47**	**55**

The lowest pollutant index values of treated wastewater were reached in Kluszkowce (21 points out of 25 possible) and in Czarny Dunajec (19 points), while the Łopuszna and Maniowy treatment plants had the highest pollutant index values. In relation to biogenic compounds, the highest index values occurred in the Maniowy treatment plant. The remaining four treatment plants all had similar results.

A comparison between the values of treatment capacity showed that the Czarny Dunajec and Łopuszna treatment plants (19 and 18 points respectively out of 25 possible) achieved the highest pollutant removal effectiveness, whereas the Maniowy and Nidzica treatment plants (12 points each) were the least effective. The Czarny Dunajec treatment plant had the highest effectiveness in biogenic compound removal, whereas the Kluszkowce treatment plant had the lowest effectiveness.

The Kluszkowce and Nidzica treatment plants received the highest ratings for the reliability index *RI* (the relation of the values of pollutant indexes to the admissible values). They gained 18 points each. The Czarny Dunajec treatment plant had just one point less. The Łopuszna treatment plant received a very low rating for the reliability index *RI*, namely 8 points out of 25 possible. This indicates a high likelihood of pollutant indexes exceeding permissive limits, which was confirmed by the results of physicochemical analyses.

Taking into account the three categories analyzed, the Czarny Dunajec treatment plant received the best rating (55 points out of 75 possible), while the Kluszkowce treatment plant fared just 2 points worse. The operation of the Łopuszna and Maniowy treatment plants was considered to be the worst, with them only receiving 35 points each. In the point evaluation, these treatment plants failed to even receive 50% of the possible points.

4. SUMMARY

The analysis of five sewage treatment plants in Nowy Targ district showed that the Bardenpho-type reactor in Czarny Dunajec was most effective in pollutant removal. This is demonstrated by very high pollutant removal efficiencies as well as low overall pollutant concentrations in treated sewage. The results of the Kluszkowce treatment plant, based on UCT reactor, were only 3.6% worse; this treatment plant even had the best rating in two categories. The low rating of the Maniowy sewage treatment plant, based on the Bardenpho reactor similar to that in Czarny Dunajec, may be caused by two factors: a high attenuation of sewage (periodical inflow of accidental and infiltration water to the sewerage system was found) and illegal pollutant discharges from a nearby tannery company. A high concentration of a total nitrogen in raw sewage (table 1) may be due to the discharge of animal waste from agriculture. The periodical inflow of tannery sewage might have also influenced the operational effectiveness of the Łopuszna treatment plant. This was confirmed by an increase in the chromium concentration in raw sewage. Chromium compounds have a negative influence on the processes in a nitrification chamber. Tannery sewage is often a major factor destabilizing the operation of rural sewage treatment plants located in submontane districts of Lesser Poland voivodeship.

The point evaluation of treatment plant effectiveness used in this work seems to be useful in comparing multiple treatment facilities. This analysis may be broadened by including additional comparative categories such as those connected with exploitation costs or with the threat of pollutant loading.

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PORÓWNANIE EFEKTYWNOŚCI USUWANIA ZANIECZYSZCZEŃ W OCZYSZCZALNIACH WIEJSKICH W POWIECIE NOWOTARSKIM

Celem badań było porównanie efektywności usuwania zanieczyszczeń w pięciu wybranych mechaniczno-biologicznych oczyszczalniach ścieków, zlokalizowanych w gminach wiejskich powiatu nowotarskiego. Do badań wytypowano obiekty o przepustowości projektowej od 315 do 600 $m^3 \cdot d^{-1}$, oparte na reaktorach biologicznych z osadem czynnym. Obiekty porównywano w trzech kategoriach, dokonując oceny w skali 5-punktowej. Przeprowadzone badania wykazały, że najlepsze efekty w usuwaniu zanieczyszczeń osiągnięto w reaktorze typu Bardenpho w Czarnym Dunajcu (bardzo dobre wyniki zarówno w aspekcie redukcji zanieczyszczeń, jak i niskiej wartości wskaźników zanieczyszczeń w ściekach oczyszczonych). Jedynie o 3,6% gorsze wyniki (w ocenie punktowej) uzyskała oczyszczalnia w Kluszkowcach (najlepsza ocena w dwóch kategoriach), oparta na reaktorze UCT. Niska skuteczność działania oczyszczalni w Łopusznej i Maniowach może być powodowana nielegalnymi zrzutami do kanalizacji w tych miejscowościach ścieków z zakładów garbarskich.