ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 2/2022

doi: 10.2478/ACEE-2022-0020

ANALYSIS OF THE EFFECTIVENESS OF WASTEWATER TREATMENT IN ACTIVATED SLUDGE TECHNOLOGY WITH BIOMASS RECIRCULATION

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Received: 15.02.2022; Revised: 19.04.2022; Accepted: 20.04.2022

Abstract
In the operation of a wastewater treatment plant, the key challenge for the operator is to obtain parameters of the treated wastewater required by relevant legal acts. Meeting these requirements is possible through the use of an appropriate technology and real-time automation of control and monitoring processes. The paper examines the results of laboratory tests of selected wastewater parameters in terms the content of organic substances and nutrients in order to determine the efficiency of wastewater treatment in a biological bioreactor using the sludge recirculation process. The performed analysis demonstrated that all levels involving the reduction of pollutants, concentrations and load are in compliance with the applicable legal requirements. Ensuring a continuous monitoring of the quality of treated wastewater and the optimization of this process is crucial for the aquatic environment and human health.

Keywords: **Biological reactor; Pollution reduction efficiency; Sludge recirculation, Wastewater treatment.**

1. INTRODUCTION

The production of municipal waste and sewage is an inherent feature of human economic and living activity, and its management is a challenge for all societies and economies. The requirement for wastewater treatment and waste management results from the need to protect the natural environment, especially water resources. The necessity to implement innovative solutions resulting from technological progress and growing requirements involving the quality of drinking water are becoming a challenge for the municipal sector, including water and sewage companies [1, 2, 3]. An organized system of municipal wastewater treatment comprises all activities and processes whereof the primary goal is to remove harmful pollutants contained in wastewater flowing into the treatment plant, so that after the treatment it poses no threat to the purity of surface waters [4, 5]. In the process of wastewater treatment, primarily biological methods are used, and their development has been facilitated by the negative impact of nitrogen compounds on the environment as one of the biogenic elements responsible for the increasingly observed phenomenon of eutrophication of water reservoirs. Currently, specific groups of bacteria capable of transforming nitrogen forms are used to remove nitrogen compounds from wastewater. For this purpose, two basic processes are most frequently used: nitrification and denitrification. To obtain partial nitrification, the value of dissolved oxygen concentration is of paramount importance. Currently, this process is carried out on the basis of the mathematical models of sewage treatment reactors with activated sludge, whereof the most important models are from the ASM family (Activated Sludge Model) [6, 7].

In the biological part of the majority of municipal wastewater treatment plants, the activated sludge method dedicated to two types of wastewater treatment plants is applied, i.e. sequential and flow-through ones. Currently, most of municipal sewage treatment plants built and modernized in Poland use biological reactors with activated sludge for the integrated removal of the compounds of carbon, nitrogen and phosphorus. This technology was introduced by the invention of James Barnard in the mid-1970s. The improved solution has been used successfully in many countries around the world, and in Poland it has been applied since the 1990s [8, 9, 10]. As to the technologies with multistage wastewater treatment with the use of activated sludge, two systems are most frequently used: the UCT (University Cape Town) system developed at the University of Cape Town and the SBR system (Sequencing Batch Reactor) [11].

The objective of the biological wastewater treatment process is to deliver the required amount of air (oxygen) to the bioreactor, which determines the optimal development of bacteria that decompose organic substances contained in wastewater. In the solution of aeration control system used so far, the concentration of dissolved oxygen was adopted as the reference value. In the proposed solution of control system, a highly non-linear characteristic of the bioreactor's operation is taken into account as a control object. The non-linear nature of the object, variable operating conditions of the wastewater treatment plant, the impact of disturbances, including non-uniform wastewater inflow to the bioreactor, changing load of pollution, temperature and compactness of mineral substances enforce the change of reference quantity of oxygen concentration over time. This results in the rise of mechanical load for the installations in the process of mechanical treatment of municipal wastewater [12, 13, 14]. An appropriate quantity of oxygen demand in such bioreactors is a key factor to ensure efficiency of the process and the required final parameters for the treated wastewater. Additionally, the aeration process of the bioreactor and sludge recirculation process are the largest expenditure items in the energy balance of the wastewater treatment plant. However, the use of sludge recirculation process improves the removal efficiency of the concentrations and pollution loads in the treated sewage [15, 16]. The solution used in the wastewater treatment process, in the form of internal and external recirculation of sludge as well as the aeration process of wastewater, leads to the rise of electricity consumption. Such a situation positively translates into higher level of pollution reduction in sewage, e.g. in the case of BOD_5, COD, nitrogen, phosphorus [17, 18, 19]. Yet, this process can be optimized, e.g. in the treatment of wastewater in the deammonification process, up to 62.5% of oxygen demand and up to 100% of carbon demand can be saved. Consequently, the wastewater treatment process is less energy-consuming, especially during the aeration process of the reactor. The use of locally available renewable energy sources (e.g. solid biomass, biogas, solar energy, water) is an alternative to the supply from the grid. Scattered power industry, including the units applied in sewage treatment plants, reinforces energy security of the facility and increases the impact on the environment. Along with energy security, it is necessary to ensure the reliability of mechanical parts operating in difficult conditions or having a direct impact on safety, such as agitator systems in secondary settling tanks [20, 21, 22].The treatment of wastewater is not confined solely to energy-consuming processes, but it also offers a possibility to recover resources. This mainly involves the generation of energy and the production of energy carriers (biogas, biomethane, hydrogen) as well as the production of materials from wastewater (phosphorus for the production of fertilizers), which is becoming a factor that brings about a significant change in the way a sewage treatment plant operates [23, 24, 25]. The control of oxygen level dissolved in the bioreactor can be realized with the use of a decentralized control system including e.g. fuzzy controllers. Such a solution allows to meet the global directions involving the reduction of energy consumption and the improvement of energy effectiveness of the wastewater treatment process by using control algorithms in the aeration process, including predictive algorithms [26, 27]. Currently, the municipal wastewater treatment plants being in operation need to be modernized or expanded by introducing new solutions in the area of the realized technological processes in terms of quality and quantity. In effect of such measures, a sewage treatment plant should be viewed as a facility with innovative solutions which support the operators in maintaining the required quality parameters of treated wastewater. This can be achieved, e.g. by using reference devices (in the form of probes, sensors) with the application of algorithms in the control process of treatment plant. The process of expansion and modernization of wastewater treatment plants should be carried out based on building materials and technologies dedicated to this type of investment. This also applies to the waste management process at the construction site, storage methods of the wastes as well as methods of their recycling [28, 29, 30]. The growing interest of the scientific community in the optimization methods of technological processes in WWTP (Waste Water Treatment Plants) and in the events of crisis character caused by external factors and by systemic factors inside the plant is a response to the existing state of affairs. They mainly involve changes in the requirements contained in legal acts in terms of the improvement of the quality of treated wastewater, energy efficiency of wastewater treatment processes and safety assurance of these processes in the event of threat to the functioning of critical infrastructure. Mechanical wear of installations largely involves corrosion of components which undergo plastic deformation and oxidation during the operation [31, 32, 33]. A wastewater treatment plant as a critical infrastructure facility requires the use of control systems engineering to monitor and control the processes and the facility. Due to great significance of such facilities in the functioning of municipal economy, it is advisable to use appropriate algorithms to protect the facilities and to ensure continuity of wastewater treatment process [34, 34, 36].

2. OBJECT OF STUDY

The sewage treatment plant, which is the object of the research, serves the agglomeration with a population of over 170,000 residents. The average daily sewage flow in the treatment plant is 33,000 m^3. The sewage treatment plant has its own installation for the generation of electricity and heat from biogas, which satisfies its own needs in terms of electricity at the level of 70% and in terms of heat – 100%. The Benchmarking results compiled by the Waterworks Chamber of Commerce demonstrated that large water and sewage companies serving more than 100,000 inhabitants had the energy consumption incurred by sewage collection and treatment process in the range from 0.32 to 1.1 $kWh \cdot m^{-3}$. And the treatment plant being the object of the study showed the energy consumption incurred by sewage collection and treatment process at the level of 0.45 $kWh \cdot m^{-3}$, which places the treatment plant in question below the national average value, which is 0.71 $kWh \cdot m^{-3}$ [37].

The wastewater which enters the plant via a manifold collector is subjected to treatment in the mechanical and biological processes. The technology of nitrogen and phosphorus removal used in the biological part of the sewage treatment plant is based on the activated sludge bed, in the UCT flow-through reactor. After thetreatment on the grid, the sewage is passed to a sand trap, and then the sewage is directed to two preliminary sedimentation tanks. The sludge that builds up at the bottom of the preliminary sedimentation tanks is pumped to the hydrolysis tank, where it is subjected to the preliminary acid pre-fermentation process. The sludge processed in this way is partly returned to biological reactors as a source of organic carbon. The biological treatment of sewage in the treatment plant takes place in two UCT biological reactors. The reactor is a place for the processes of denitrification and nitrification, removal of organic carbon compounds and the final stage of excess phosphorus removal. This process takes place with the use of sewage aeration system, agitation in bioreactors by means of mixers, and with the use of sludge recirculation between the bioreactor and the secondary sedimentation tank. The treated wastewater is discharged to the watercourse receiver. Figure 1 shows the system of bioreactor and secondary sedimentation tank with the aeration and recirculation system.

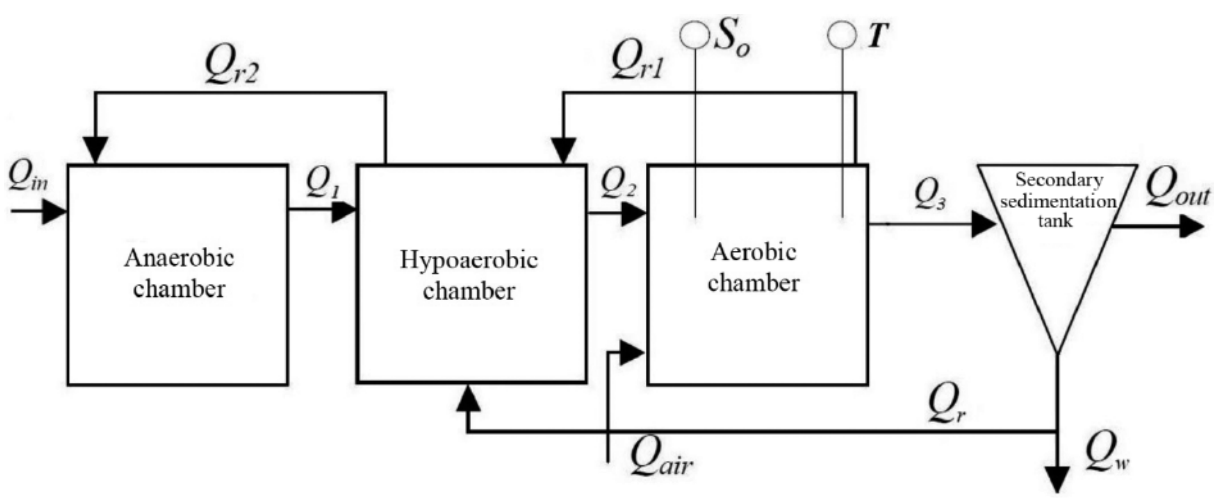

Figure 1.
Biological reactor with the system of internal and external

Different oxidoreduction conditions prevail in the individual chambers. In this technological system, external recirculation of sludge is used, as well as internal recirculation of sludge and sewage, which has impact on the flows (Q_1, Q_2, Q_3) between individual zones. The external recirculation of sludge (Q_{re}) is defined as a stream of sludge returned from the secondary sedimentation tank to the hypoaerobic chamber. As a result of external recirculation, the activated sludge chamber and the secondary sedimentation tank are mutually interacting due to the relationship between the content of dry matter (sludge concentration) in the chamber, the content of dry matter in the return sludge and the recirculation degree. The use of various oxidoreduction conditions in the activated sludge chamber and the use of internal recirculation allow for the biological removal of C, N, and P compounds within one technological system. In the UCT technological system, two streams of internal recirculation were used. The first stream (Q_{ri1}), from the aerobic chamber to the chamber, to supply nitrates. And the second stream of internal recirculation (Q_{ri2}), from the hypoaerobic chamber to the anaerobic one, contributes to the rise of removal level of phosphates from wastewater [38]. There are two UCT bioreactors operating in the wastewater treatment plant, and their task involves the treatment of wastewater, including the removal of nitrogen and phosphorus compounds. The activated sludge method is the basic technology applied in this process. Bacteria, the so-called activated sludge, convert organic compounds into gases, other organic compounds and new bacteria. It takes place in a system of interconnected chambers, where phosphorus is released thanks to the so-called phosphorus bacteria of bio-P type (anaerobic chamber), and where the processes of denitrification (hyperaerobic chamber), nitrification and phosphorus uptake by bio-P bacteria (aerobic chamber) take place [39, 40]. The use of the sludge recirculation system between the secondary settling tank and the bioreactor makes the dilution process faster and, consequently, better use of substrate (lower concentrations) is obtained, which in the case of wastewater treatment translates into a higher degree of pollution removal.

3. MATERIALS AND METHODS

3.1. Laboratory tests and calculations

The paper presents the results of the research on the concentration and load of pollution in the inflowing (raw) sewage and in the treated sewage discharged to the receiver on an annual basis. The following wastewater parameters were tested: total nitrogen (total Kjeldahl nitrogen (N_{Norg} + N_{NH4}), total phosphorus, total suspended solids, biological oxygen demand (BOD_5) determined with the addition of nitrification inhibitor, and chemical oxygen demand (COD_{Cr}) determined by the dichromate method. Based on the obtained test results, calculations of the reduction scope of the concentration of substances contained in untreated and treated sewage and their loads were carried out. In effect of the calculations, the efficiency of wastewater treatment (pollution reduction efficiency) in terms of load and concentration reduction was obtained. The obtained results were compared with the highest permissible values specified in the legal act in force.

3.2. Development of research results

The results of laboratory tests and calculations were used as input parameters for the analysis of the quality of untreated and treated wastewater, which were statistically analyzed using the Statistica software, v 13.3 TIBCOI Software Inc. [41]. To compare the effectiveness of the wastewater treatment process, a cluster analysis was performed using the Ward agglomeration method. This method is used to estimate the distance between clusters, and it uses the analysis of variance approach that results in minimizing the sum of squared deviations of any two clusters. And as a measure of distance in this method, the Euclidean distance was used, which is the geometric distance in a multidimensional space. The results of the analysis were presented in the form of a dendrogram, i.e. a binary tree. Additionally, in order to analyze the interrelationships between individual wastewater parameters, 3D surface plots were used for three variables: X, Y, Z.

4. RESULTS AND DISCUSSION

The quality of raw sewage at the inflow to the treatment plant as well as that of sewage treated in a mechanical and biological process, collected at the outflow to the receiver, was defined based on the analysis of the test results for total nitrogen, total phosphorus, suspended solids, BOD_5 and COD. The research was aimed at checking whether the sewage parameters do not exceed the maximum permissible values of pollutants specified in the Regulation of the Minister of Maritime Economy and Inland Navigation of July 12, 2019 [42]. The treated sewage is

Table 1.
Monthly concentrations of pollutants in untreated and treated sewage in

Month	Total nitrogen mgN·dm^{-3}			BOD$_5$ mgO$_2$·dm^{-3}			COD$_{Cr}$ mgO$_2$·dm^{-3}			Total phosphorus mgP·dm^{-3}			Total suspension [mg·dm^{-3}]		
	UW	PTE	TW	UW	PTE	TW	UW	PTE	TW	UW	PTE	TW	UW	PTE	TW
January	69.54	63.26	7.10	407	293	4.78	940	614	25.2	13.64	12.68	0.38	383	187	9.77
February	66.49	61.41	7.30	397	299	4.67	853	578	44.7	10.16	7.18	0.37	363	194	10.25
March	61.68	60.14	8.81	267	209	4.49	1109	829	42.5	8.51	7.39	0.39	435	178	10.92
April	76.33	72.10	8.54	322	276	4.09	1079	824	55.0	6.72	6.52	0.46	334	167	6.25
May	73.53	70.15	7.34	545	263	5.36	1123	796	49.5	5.39	4.83	0.43	472	192	7.15
June	44.76	39.73	4.75	310	245	3.23	521	301	23.8	3.89	2.81	0.14	337	140	6.89
July	65.28	63.77	6.44	286	263	5.72	583	466	48.1	6.35	5.08	0.23	371	158	7.53
August	62.05	59.23	6.62	390	252	4.62	1458	801	39.0	7.46	7.10	0.36	316	194	10.42
September	60.39	59.90	5.63	330	284	4.14	720	531	32.2	6.78	6.07	0.41	343	203	10.65
October	70.62	60.49	8.62	356	268	5.11	820	528	49.3	9.24	7.70	0.62	454	190	7.11
November	77.11	75.53	8.10	368	287	2.78	1160	832	49.0	9.04	7.89	0.35	343	131	9.75
December	78.58	76.82	8.23	383	291	3.04	985	793	47.8	9.14	8.04	0.36	325	124	8.76

UW – untreated sewage, PTW – sewage after pre-treatment, TW – treated sewage

discharged from the secondary sedimentation tanks to the receiver via a measurement flume. The parameters of raw sewage, treated in a mechanical process and treated after the biological treatment process, presented in Table 1, are exclusively the results of tests carried out in accredited laboratories. Sewage samples are collected at three technological points in line with the sampling procedure based on the standard PN-ISO 5667-10: 1997. The tests of the collected samples are carried out in the laboratory based on the scope of accreditation and on the resulting applicable test methods for individual substances. And in order to monitor and optimize the sewage treatment process, the treatment plant has an internal technological laboratory, which ensures the correctness of the carried out processes by testing the parameters of sewage in the course of its treatment [43].

The results of the tests, being monthly averages, are presented in Table 1.

The analysis of the test results (Table 1) showed that the content of BOD5 in untreated sewage was in the range of 286÷545 mg O$_2$·dm^{-3}, while COD was in the range of 521÷1148 mg O$_2$·dm^{-3}. Such concentration values in untreated sewage indicate that the sewage was highly concentrated. The nitrogen content ranged from 44.76 to 76.33 mg N·dm^{-3}, and it was also classified as highly concentrated sewage. But the annual content of phosphorus concentration was in the range of 3.89÷10.16 mg P·dm^{-3}, which qualifies this sewage as having an average concentration of phosphorus. These values correlate with the data presented by Henze el al, (2002), who presented the classification of pollutants with organic substances and nutrients [44]. Oxygen demand (COD) in treated sewage may pose a potential threat to watercourses of reservoirs to which they are discharged. The tests performed by Al-Sulaiman & Khudair (2018), showed that the average annual BOD$_5$/COD value for untreated municipal wastewater was 0.54, while for treated sewage it was 0.37. The results of the research carried out as part of this study showed that the average annual BOD$_5$ /COD ratio for untreated sewage was 0.44, which proves a moderate (average) susceptibility of sewage to biodegradation [45]. At the design stage of each wastewater treatment plant, the selection of wastewater treatment technology determines the acquisition of parameters of treated sewage required by law for each substance contained in it. A key element in the operation of treatment plants is the monitoring of treated wastewater in order to confirm its quality in terms of legal requirements. The use of wastewater monitoring is also an element which optimizes the technological process, connected with the variability of sewage composition during the year, which enforces the need to make some process changes [46]. A comparative analysis for the substance contained in wastewater, which is biological oxygen demand (BOD$_5$), for untreated wastewater (U_BOD$_5$), wastewater treated in a mechanical process (M_BOD$_5$) and wastewater treated after the biological process (T_BOD$_5$), is presented in Fig. 2.

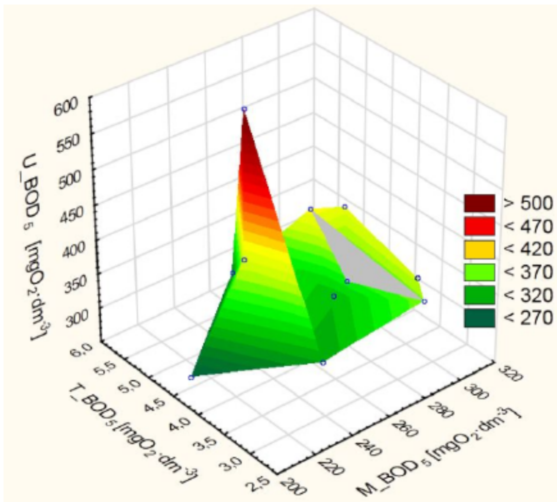

Figure 2.
Mutual correlations for BOD$_5$ in the wastewater treatment process

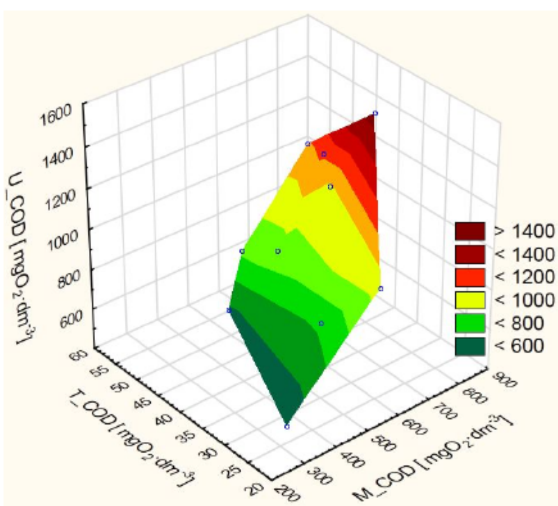

Figure 3.
Mutual correlations of COD parameters in the wastewater treatment process

The mutual relations between the individual test results, for the three contents, showed the best fit of the BOD$_5$ value for the point with the parameters: (x = 209; y = 4.49; z = 267) and the dispersion values (x = -0.70; y = -1.0) in the month of March. And the smallest correlation was demonstrated by the point with the parameters: (x = 263; y = 5.36; z = 545) and the dispersion values (x = -0.40; y = 0.86) in the month of May. The analysis showed the differentiation of BOD$_5$ parameters throughout the year, but the maximum allowable value for this parameter in treated sewage, defined as 15 mgO_2·dm^{-3}, was met throughout the year, ranging from 2.78 to 5.72 mg O_2·dm^{-3}. The performed analysis for chemical oxygen demand (COD) in untreated sewage (U_COD), sewage treated in the mechanical process (M_COD) and sewage treated after the biological process (T_COD), is presented in Fig. 3.

The interrelationships between the obtained test results for COD showed the best fit of values for three tests at the point with the parameters: (x = 301; y = 23.8; z = 521) and the dispersion value (x = 0.002; y = -1, 25) in the month of June. And the smallest correlation for this substance had the following parameters: (x = 801; y = 39; z = 1458), and the values of the dispersion were: (x = 0.61; y = 0.86) in August. The analysis showed the differentiation of COD parameters in treated sewage per year, ranging from 23.8 to 55 mg O_2·dm^{-3}, which places these values below the maximum permissible value in treated sewage defined as 125 mg O_2·dm^{-3}. The results of the analysis for total suspended solids in the sewage, being the results of the tests of untreated sewage (U_TSS), sewage treated in the mechanical process (M_TSS) and sewage treated after the biological process (T_TSS), are presented in Fig. 4.

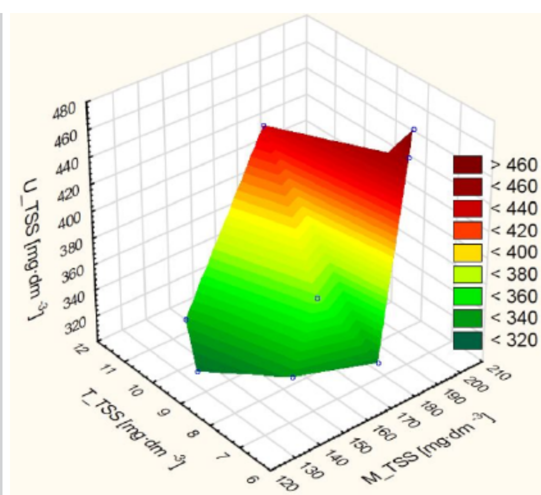

Figure 4.
Mutual correlations for total suspended solids in the wastewater treatment process

With reference to the substance of total suspension, the analysis of test results showed that the best fit of the concentration value of this substance is at the point with the parameters: (x = 140; y = 6.89; z = 337) and the dispersion value (x = 0.04; y = - 0.92) in June. And the smallest fit was found for the point with the parameters: (x = 472; y = 7.15; z = 472) and the dispersion values (x = 0.90; y = 0.76) in May. Total suspension per year was characterized by variable concentration in treated sewage and ranged from 6.25 to 10.92 mg·dm^{-3}, with the maximum allowable value in treated sewage being 35 mg·dm^{-3}. The comparative analysis for the concentration of total nitrogen contained in sewage, in untreated sewage (U_Total N), after the mechanical treatment (M_Total N) and in sewage treated after the biological process (T_Total N), is presented in Fig. 5.

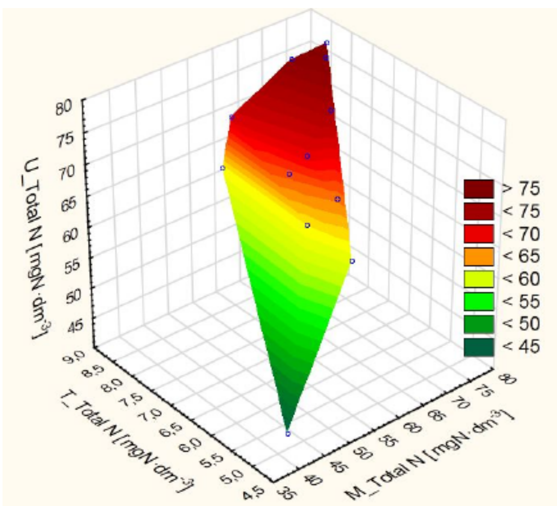

Figure 5.
Mutual correlations of total nitrogen parameters in the wastewater treatment process

The mutual relations between the individual test results showed the best fit of the total nitrogen value for the point with the parameters: (x = 39.75; y = 4.75; z = 44.76) and the dispersion value (x = 0.02; y = - 1.2) in June. And the smallest correlation was found for the point with the parameters: (x = 76.82; y = 8.23; z = 78.59) and the dispersion values (x = 0.26; y = 1.32) in December. The analysis of concentrations for total nitrogen demonstrated a differentiation of this parameter per year, but the required maximum allowable value in treated sewage, defined as 10 mgN·dm^{-3} , was met throughout the year, ranging from 4.75 to 8.81 mg N·dm^{-3}. The results of the analysis of laboratory tests for phosphorus contained in untreated sewage (U_Total P), sewage treated in the mechanical process (M_Total P), and sewage treated after the biological process (T_Total P), are presented in Fig. 6.

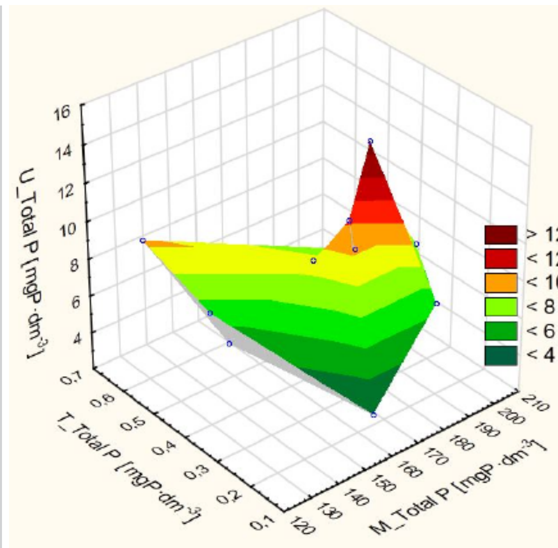

Figure 6.
Mutual correlations of total phosphorus concentrations in the wastewater treatment process

For the substance of total phosphorus, the analysis of the test results showed the best fit of the concentration value of this substance at the point with the parameters: (x = 65.08; y = 0.23; z = 6.35) and the dispersion value (x = 0.33; y = -1.04) in July. And the smallest fit was demonstrated by the point with the parameters: (x = 12.68; y = 0.38; z = 13.64) and the dispersion values (x = 0.42; y = 0.66) in January. The concentration of total phosphorus per year was characterized by variability in treated sewage, and it ranged from 0.14 to 0.62 mgP·dm^{-3}, with the maximum permissible value in the treated sewage being 1.0 mg P·dm^{-3}. The performed analysis of the concentrations of total nitrogen, total phosphorus, total suspended solids, biological oxygen demand (BOD_5) and chemical oxygen demand (COD) in the treated sewage showed that the requirements for these parameters were met in relation to the highest permissible values for this type of sewage treatment plant.

In view of the above, the analysis of the efficiency of wastewater treatment was also carried out in the study in terms of meeting the requirements for the minimum reduction percentage of the concentration and load in wastewater, for wastewater treatment plants above 100,000 PE [47]. For this purpose, the treatment efficiency of sewage (pollution reduction efficiency) was calculated on the basis of the formula (1):

$$\eta = \frac{S_u - S_t}{S_u} \cdot 100\% \qquad (1)$$

where:

η - pollution reduction efficiency (%),

S_u – index value inuntreated sewage [mg·dm^{-3}],

S_t – value of the index in treated sewage[mg·dm^{-3}].

The results of the calculations performed for the concentration values of the given substances contained in untreated and treated sewage are presented in Table 2.

The calculated scope of pollution reduction for all five substances which require monitoring meets the requirements specified in the applicable regulation, and it is above the required values. In order to compare the reduction scope of the concentration value of a given substance during the wastewater treatment process with the minimum required percentage of concentration reduction for 5 substances, the cluster analysis was performed using the Ward agglomeration method. The performed analysis of distance estimation between the clusters, in the form of bond distance between individual groupings, is presented by the dendrogram, i.e. the binary tree as shown in Figure 7.

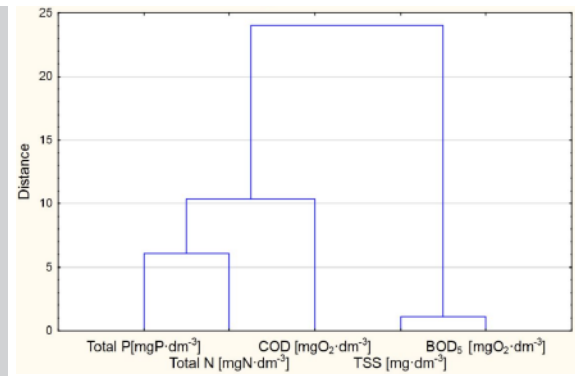

Figure 7.
Dendrogram of the effectiveness of concentration reduction to permissible values in the treated sewage

The analysis demonstrated that the objects form clusters as a result of which three main groups (clusters) can be distinguished. The first group contains biological oxygen demand (BOD_5) and total suspended solids, and the second one contains total nitrogen and total phosphorus, while the third group covers chemical oxygen demand (COD). The smallest bond distance occurs at the level of the first cluster for the agglomeration distance (x = 4.92; y = 1.07), for the second cluster it is the distance (x = 1.75; y = 6.16) between nitrogen and phosphorus, while the third cluster for COD represents the distance (x = 2.41;

Table 2.
Comparison of N-NH_4^+ loads at the corresponding points of the technological cycle

No	Name of substance	Unit	Concentration value in untreated sewage	Concentration value in treated sewage	Scope of concentration reduction of a given substance [%]	Minimum required percentage of concentration reduction of a given substance [%]
1.	Biochemical oxygen demand (BOD_5)	$mgO_2·dm^{-3}$	361.64	4.45	98.77	90
2.	Chemical oxygen demand (COD_{Cr})	$mgO_2·dm^{-3}$	942.36	1.66	99.82	75
3.	Total suspension	$mg·dm^{-3}$	377.36	8.79	97.67	90
4.	Total nitrogen	$mgN·dm^{-3}$	66.16	7.20	89.12	70-80
5.	Total phosphorus	$mgP·dm^{-3}$	7.93	0.38	95.21	80

Table 3.
Scope of load reduction for individual substances contained in untreated and treated sewage

No	Name of substance	Load in untreated sewage [kg/d]	Load in treated sewage [kg/d]	Reduction scope of load of a given substance [%]
1.	Biochemical oxygen demand (BOD_5)	9216	117	98.73
2.	Chemical oxygen demand (COD_{Cr})	23228	1065	95.41
3.	Total suspension	8966	295	96.70
4.	Total nitrogen	1691	168	90.06
5.	Total phosphorus	193	9.1	95.28

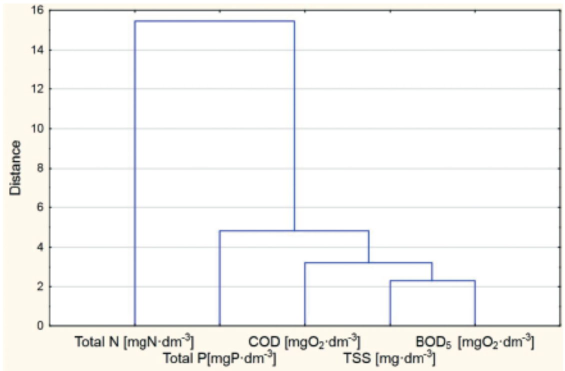

Figure 8.
Dendrogram for the effectiveness of concentration reduction and load reduction in treated sewage

y = 10.39). All clusters are linked by a bond with the parameters (x = 3.26; y = 24.03). Such a state of bonds within the dendrogram indicates a comparable scope of the reduction effectiveness of concentrations in the first cluster and slightly lower in the second cluster, but with a similar value. And the bond within the third cluster shows that there is an outlier value of COD in comparison with the other parameters (99.82%), which translates into the highest reduction effectiveness of this concentration and into the highest exceedance of the required minimum reduction percentage of the concentration of 75%.

The next stageof wastewater treatment efficiency analysis was to determine the reduction scope of the pollution load contained in untreated and treated wastewater. The level of load reduction in wastewater is not required in the monitoring process of the quality of treated wastewater, but such an analysis allows for the development of mutual correlation for these two processes. The scope of load reduction in untreated and treated sewage is presented in Table 3.

The reduction scope of the load value of a given substance is not required by the legislator, but the operators of the treatment plant make such a compilation in order to control and monitor the scope of load that enters the treatment plant and then is discharged to the receiver [48]. All monitored substances show over 90% scope of reduction of their loads, which proves very high efficiency of wastewater treatment in this respect by the sewage treatment plant. In order to compare the reduction scope of the concentration value of a given substance with the reduction scope of the load of a given substance, the cluster analysis was performed using the agglomeration method, in the form of a binary tree, as presented in the dendrogram in Figure 8.

The carried out analysis in the form of a hierarchical tree yielded the agglomeration in which the objects form clusters as a result of which four main groupings were distinguished. The first contains total suspended solids and biological oxygen demand (BOD_5), the second contains chemical oxygen demand (COD), the third contains total phosphorus, and the fourth contains nitrogen. The smallest distance between bonds occurs at the level of the first cluster and is (x = 4.86; y = 2.31), and for the second cluster the distance is (x = 4.11; y = 3.22) and it applies to COD. Within the third cluster, the bond distance is (x = 3.43; y = 4.83), while for the fourth cluster the bond has the parameters (x = 1.83; y = 15.48). Such a state of bond distance shows that the three main clusters (BOD_5, suspension, COD, phosphorus) are within the distance (y = 4.83), which bespeaks of intensive agglomeration of four objects and comparable efficiency parameters for the reduction of concentrations and load contained in wastewater. The outlier bond in the form of nitrogen (y = 15.48) results from the fact that the effectiveness for the reduction of this concentration oscillates around 90% and differs from the others.

Dissolved organic carbon in the municipal wastewater treatment process plays an important role in dividing these pollutants into dissolved and absorbed fractions, which affects the capacity of wastewater treatment plants, including the removal of toxic substances. The research carried out by Katsoyiannis & Samara (2007), showed that the average concentrations of dissolved organic carbon were at a similar level (~70 $mg \cdot dm^3$). Such a situation suggests that the pretreatment of wastewater has little effect on the concentration in the wastewater. It was not until the last stage of wastewater treatment (biological) that the calculated efficiency of this process was 69%. The conducted tests showed large differences in the removal efficiency of individual concentrations, e.g. with respect to organic pollutants, such as BOD_5 and COD. The authors demonstrated that the complete removal of dissolved organic carbon is independent of its concentration in untreated sewage [49]. The issues involving the impact of wastewater treatment process on the environment in five Chinese treatment plants were presented in the work Chen et al., (2021), where hybrid fuzzy analysis was applied for this purpose. They took into account GHG emissions, the potential to cause eutrophication of wastewater, ecological hazards posed by endocrine disrupting compounds in the treated wastewater, and hazards posed by heavy metals in excess sludge. The results of the analysis showed that the biological wastewater treatment process (68%) and electricity consumption (64%) are the main factors contributing to greenhouse gas emissions. One way to reduce greenhouse gas emissions and to improve the efficiency of wastewater treatment processes is to use renewable energy sources directly in the facility. This involves the application of the produced wastewater in the fermentation process for the production of biogas in order to generate energy in cogeneration systems [50,51]. The problem of defining the optimization process of wastewater treatment installations was presented in the work Kim et al., (2015), using the ASMN_G Model and the optimization algorithm. The aim of the study was to minimize greenhouse gas emissions, combined with the reduction of operating costs with a simultaneous rise of the reduction scope of pollution load in the treated wastewater. The obtained results allowed for the reduction of greenhouse gas emissions by 31%, the reduction of operating costs of the treatment plant by 11%, while improving the quality of the treated wastewater by 2%. The applied model can be used when defining the strategy for technological optimization processes and the diversification of energy sources for wastewater treatment plants [52]. A key aspect of generating energy from biogas in a sewage treatment plant involves energy use for own needs, as presented in the work (Rosa et al. 2018). In order for the energy production to run smoothly in the CHP unit, high-quality biogas is absolutely essential. A properly selected and properly operated biogas treatment installation allows for reliable and safe generation of electricity and heat necessary to power a sewage treatment plant [53]. The efficiency of wastewater treatment and the amount of atmospheric emissions are directly related to energy expenditure for a given process, which means that the municipal sector, including wastewater treatment plants, resort more and more frequently to the use of renewable energy sources such as biogas to minimize the carbon footprint for a facility such as municipal wastewater treatment plant.

5. CONCLUSION

The research was aimed at checking whether the sewagetreated parameters do not exceed the maximum permissible values of pollutants. The analysis of the effectiveness of wastewater treatment in a sewagetreatment plant, carried out in the work, using the activated sludge technology with biomass recirculation, demonstrated that all the legally required levels involving the reduction of pollution contained in untreated and treated sewage were achieved. This applies to the concentration of nitrogen or total phosphorus, total suspended solids, BOD_5 and COD_{Cr}. As to the reduction of the concentration in wastewater, the efficiency of this process was from 89.12% for total nitrogen to 99.82% for COD_{Cr}. And for the reduction of pollution load, the efficiency of this process was from 90.06% for total nitrogen to 98.73% for BOD_5. The achieved levels of concentration reduction and those of load contained in the wastewater bespeak of high efficiency of the wastewater treatment, which results from the technology applied in the treatment plant based on the UCT biological reactor. The parameters of the treated municipal wastewater discharged into surface waters have been defined in the relevant legal acts for a given type of sewage treatment plant. The operator of the sewage treatment plant is also bound by the provisions of the Water Law Permit, which impose additional obligations on the treatment plant in terms of ensuring the quality of treated sewage. The treated sewage discharged into the aquatic environment from the treatment plant in question meets all the parameters required by law. Continuous monitoring of the purification process of wastewater at every stage of its treatment ensures that the treated wastewater discharged into the receiver does not pose any threat to the natural environment and people.

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