The Impact of Selected Parameters on the Condition of Activated Sludge in a Biologic Reactor in the Treatment Plant in Nowy Targ, Poland

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Abstract: The aim of this study was to determine the condition of activated sludge in the biologic reactor located in the collective wastewater treatment plant in Nowy Targ (Poland) based on OUR tests in the aspect of the impact of sludge’s concentration in the biologic reactor and dependence of BOD$_5$/TN and BOD$_5$/TP in wastewater flowing into the biologic reactor. The analysis was conducted based on test results from 61 samples of activated sludge taken from the biologic reactor and 61 samples of wastewater flowing into the biologic reactor. The analysis included the concentration of sludge in the biologic reactor. The following indicators were analyzed in wastewater flowing into the reactor: biochemical oxygen demand (BOD$_5$), total nitrogen (TN) and total phosphorus (TP). The statistical analysis concerning the impact of the analyzed factors on oxygen uptake rate (OUR) tests was developed based on the Pearson’s correlation coefficient and partial correlation of many variables. Based on the results of the partial correlation analysis, nomograms were developed to determine the condition of activated sludge microorganisms (OUR) based on the BOD$_5$/TN and BOD$_5$/TP connection and knowledge of the sludge concentration in the bioreactor of the treatment plant. The presented nomograms can be formulated for each bioreactor based on activated sludge technology related the load of organic and biogenic pollutants in the wastewater flowing into the bioreactor and the concentration of the sludge in the bioreactor.

Keywords: activated sludge; oxygen uptake rate; sludge concentration; organic and biogenic indicators

1. Introduction

Operation of a wastewater treatment plant over a long period of time is often a comprehensive problem for the operator because changes in the amount and quality of inflowing wastewater may cause disruption of mechanical and biologic processes over time [1–5]. Therefore, it is important to monitor the quantity and quality of wastewater at each stage of its treatment and intervene (if necessary) in order to prevent the access of excessive contaminants in to the tank. In typical collective wastewater treatment plants, the biologic part of the wastewater treatment plant (i.e., the biologic reactor) is a much larger operational problem than the mechanical part (screen, sand separator, basic settling tank). The problem results from the fact that microorganisms in a biologic reactor are sensitive to many factors—i.e., variability and quality of organic and biogenic substances in wastewater, wastewater temperature, pH the inflow of rainwater and heavy metal compounds in the wastewater [6–10]. Some of the problems listed are universal, i.e., they can affect many treatment plants in the world regardless of location (country), while some of the problems locally occur and may only apply to a specific treatment plant or the group of treatment plants.
An example of a problem that many treatment plant operators in the world have is the excessive inflow of potential rainwater [11–13]. One of the specific local problems in Nowy Targ in Poland is the sewage system, which is analyzed in this publication [14]. This is the sewage system in which the wastewater flowing into the treatment plant contains significant amounts of chromium compounds found in wastewater from furrier’s shops [10,14]. Bearing in mind general and/or local problems, it is important that exploiters and scientists exchange their experience in diagnosing the problems and try to solve them [15]. In the case of bioreactors with activated sludge technology, the most important factor affecting the proper metabolism of microorganisms is the maintenance of appropriate aerobic, anoxic and anaerobic conditions in the individual stages of wastewater treatment [7,15].

One of the methods that determine the correct course of biologic processes in a biologic reactor is the OUR test, i.e., measurement of the rate of oxygen taken by activated sludge microorganisms. As it has been demonstrated by many authors, the OUR value characterizes the activity of activated sludge microorganisms and it is a valuable indicator that can be successfully used to evaluate the adequate operation of a biologic reactor [16–19]. Preparation of algorithms for the dependence of basic parameters in the wastewater and biologic reactor, which are analyzed on an ongoing basis, will enable to forecast the conditions of activated sludge and (possibly) prevent its deterioration.

The aim of the study is to determine the impact of selected factors, i.e., concentration of sludge in the biologic reactor and the dependence of \( \text{BOD}_5/\text{TN} \) and \( \text{BOD}_5/\text{TP} \) in wastewater flowing into the biologic reactor on the condition of activated sludge microorganisms based on oxygen uptake rate (OUR). Based on the analysis of the \( \text{BOD}_5/\text{TN} \) and \( \text{BOD}_5/\text{TP} \) connection, i.e., the ratio of organic carbon to nitrogen compounds and phosphorus compounds in wastewater flowing into the biologic reactor, determined the susceptibility of activated sludge microorganisms to the automatic distribution of biogenic pollutants in the wastewater in the biologic reactor.

The analysis covered the concentration of sludge in the biologic reactor and in the inflowing wastewater based on the following indicators: biochemical oxygen demand (\( \text{BOD}_5 \)), total nitrogen (TN) and total phosphorus (TP).

The novelty of this work is the development of nomograms, on the basis of which the treatment plant operator can determine the condition of activated sludge microorganisms in the biologic reactor based on the \( \text{BOD}_5 \), TN and TP parameters as well as the sludge index and, if necessary, take quick corrective actions. These types of nomograms can be developed for each treatment plant, where the biologic treatment process is based on the activated sludge method. In the analytical part, the research hypothesis is verified: the metabolism of activated sludge microorganisms depends on the amount of available organic carbon in the wastewater flowing into the bioreactors.

2. Materials and Methods

2.1. Characteristics of the Sewage System and Wastewater Treatment Plant

The sewage system in Nowy Targ has a length of 86.9 km. The sewage network works in the gravitational system and only 1.7 km of the sewage lines are in the pressure system. The sewage network is made of PVC pipes and stoneware with DN diameters from 200 to 400 mm. The sewage network is a sanitary network and it is intended to collect the domestic sewage. Currently, approximately 4800 residential buildings, public buildings and service facilities are connected to the sewage system. In addition, 60 legally operating furrier’s shops are connected to the sewage system, from which industrial wastewater is discharged. In addition, wastewater from the tannery, which is difficult to estimate, is discharged into the sewage network. Domestic sewage and wastewater flows into the collective mechanical–biologic wastewater treatment plant with the designed capacity 21,000 m\(^3\).d\(^{-1}\) and assumed in the project PE = 116,000 inhabitants.

The wastewater treatment plant in Nowy Targ was established in 1995 and is located at 49°29’ N, 20°3’ E. The sewage from the municipal sewerage network is conveyed via a collector with a diameter DN = 1.2 m to a pumping station. The main pumping station operates two pumps...
with a capacity of 1400 m$^3$·h$^{-1}$. The pumps lift sewage to a height of 7.5 m for easy gravity flow through the entire process line. The sewage flows from the pumping station to a screen room, where screenings are caught on two step-screens with a slot width of 3 mm and a rated power of 1.5 kW. Then, the wastewater flows into two sand traps, where mineral substances such as sand or gravel are sedimented. The sand separated by sedimentation is discharged into a sand scrubber separator, and after cleaning and dewatering, is forced into a container. The wastewater leaving the sand traps is conveyed by an 800 mm DN pipeline to two basic settling tanks. The horizontal-flow settling tanks are 42.0 m long, 6.0 m wide and 3.6 m high. The basic sludge is collected in sludge hoppers and steadily removed to a gravity thickener. Biologic treatment is performed using the sequencing batch reactor method (SBR). In the biologic treatment section, three bioreactors are installed, which work in 8-h cycles. Each is 70 m long, 23 m wide and 4.5 m deep. After decanting, treated wastewater is discharged through a 1000 mm DN collector pipe to the receiver, the Dunajec river. The scheme of the technological layout of the wastewater treatment plant is presented in Figure 1.

Figure 1. Scheme of the technological layout of the wastewater treatment plant in Nowy Targ.

### 2.2. Analytical and Statistical Methods

The research was carried out over a period of two years (2017 and 2018). During these tests, 61 samples of activated sludge from the biologic reactor and 61 samples of wastewater flowing into the biologic reactor were collected and analyzed. Samples of activated sludge and wastewater were subjected to the physical–chemical analysis in accordance with the reference methods set out in the applicable legal acts [20].

- BOD$_5$—oxygen measurement after 5-day incubation at 20 °C in OXI TOP—197 WTW
- TN—by PN-EN 25663:200 (European Standard accepted into the collection of Polish Standards)
- TP—spectrophotometer Hach DR 2800 using cuvette tests LCK 349 and LCK 350
- Concentration of sludge’s dry mass–weight method—by PN-EN 12880:2004

Samples of activated sludge from the biologic reactor and wastewater were collected twice per month in the studied period of two years, on average at 2-week intervals. The test stand was located in the laboratory at the sewage treatment plant. The air temperature in the laboratory ranged from 18 to 20 °C. Figure 2 presents the stand for measuring the rate of oxygen uptake PPT (rate of oxygen uptake by activated sludge) by microorganisms in the activated sludge.

Tests of activated sludge with the use of the OUR were made according to the recommendations by Kristensen et al. [21]. The tests included:

- Collection of a sample of activated sludge from the biologic reactor;
- Filling of a measuring cylinder (volume: 3 dm$^3$) followed by aeration (3 h);
- After 3 h of aeration, addition of wastewater (constituting medium for microorganisms) to the measuring cylinder, after this time, the oxygenation level was 8 (±0.3) mgO$_2$·dm$^{-3}$;
- Determination of a dry matter content of sediments in the wastewater mixture;
- Filling of a vessel (equipped with an oxygen probe) with wastewater containing biomass;
- Recording of the initial value of dissolved oxygen (TR);
- Measurement of oxygen concentration within 10 min—at 1 min interval;
- Based on the test of a sample with activated sludge (biomass), the rate of PPT oxygen uptake was determined with the use of Formula (1). It was presented in the test stand in Figure 2.


\[
PPT = \frac{TR_p - TR_k}{t} \tag{1}
\]

where:
- \(PPT\) — rate of oxygen uptake by activated sludge (\(\text{mgO}_2 \cdot \text{dm}^{-3} \cdot \text{min}^{-1}\));
- \(TR_p\) — initial reading of dissolved oxygen (\(\text{mg} \cdot \text{dm}^{-3}\));
- \(TR_k\) — final reading of dissolved oxygen (\(\text{mg} \cdot \text{dm}^{-3}\));
- \(t\) — time between initial and final reading (min);

The unit oxygen uptake rate (OUR) was determined based on the following Formula (2):

\[
OUR = \frac{PPT \times 60 \times 1000}{X_{sfr}} \tag{2}
\]

where:
- \(OUR\) — Unit oxygen uptake rate (\(\text{mgO}_2 \cdot \text{g}^{-1} \cdot \text{s.m.} \cdot \text{h}^{-1}\));
- \(PPT\) — Rate of oxygen uptake by activated sludge (\(\text{mgO}_2 \cdot \text{dm}^{-3} \cdot \text{min}^{-1}\));
- 60 — converter (min\(^{-1}\));
- 1000 — converter (mg\(^{-1}\));
- \(X_{sfr}\) — concentration of sludge’s dry mass in the chamber (mg s.m.\(^{-1}\)).

**Figure 2.** Test stand for measuring the rate of PPT (rate of oxygen uptake by activated sludge) oxygen uptake by activated sludge with the use of OUR test. 1—measuring cylinder (\(V = 3 \text{ dm}^3\)) with aeration diffuser; 2—magnetic stirrer with a vessel equipped with an oxygen probe; 3—oxygen meter; 4—compressor.

In the analytical part, it was assumed that microorganisms of activated sludge function effectively when the unit oxygen uptake rate ranges from 8 to 20 \(\text{mgO}_2 \cdot \text{g}^{-1} \cdot \text{s.m.} \cdot \text{h}^{-1}\) [16,22,23].

The connection BOD\(_5\)/TN and BOD\(_5\)/TP was determined as the quotient of these indicators in the wastewater flowing into the bioreactor on the days on which the OUR analysis was performed. In the Analytical Part the effect of the BOD\(_5\)/TN ratio in the inflow to the OUR and the effect of the BOD\(_5\)/TP...
ratio on the OUR were developed. In addition, the effect of sludge dry matter concentration (Sc) in the biologic reactor on OUR was developed.

Statistical analysis regarding Pearson’s linear correlation, partial correlation and developed nomograms was performed using the “STATISTICA 8” (StatSoft, TIBCO Software Inc., Palo Alto, CA, USA). The significance of the studied connection was checked with the Student’s t-test at the significance level \(\alpha = 0.05\).

3. Results and Discussion

3.1. Characteristics of Wastewater Flowing into the Biologic Reactor

The analyzed wastewater treatment plant was designed for a capacity of 21,000 m\(^3\)·d\(^{-1}\), while during the two-year study, the actual average daily wastewater inflow amounted to 14,381.9 m\(^3\)·d\(^{-1}\). This indicated that the facility was hydraulically underloaded by 31.5%. As demonstrated in previous publications concerning the functioning of the wastewater treatment plant in Nowy Targ, this phenomenon may have negative effects on the course of wastewater treatment processes both in mechanical and biologic part of the wastewater treatment plant [10,24,25] as shown in Table 1. Contaminants in wastewater after mechanical treatment (flowing into the biologic reactor) expressed by indicators (i.e., BOD\(_5\), TN, TP) were characterized by typical sizes in domestic wastewater that underwent a process of mechanical treatment [14,24,26,27]. In wastewater after mechanical treatment (flowing into the biologic reactor), the median of BOD\(_5\) value was 409.4 mg·dm\(^{-3}\) (average: 400.5 mg·dm\(^{-3}\)). The coefficient of variation of BOD\(_5\) was \(C_v = 25\%\). This indicated the average differentiation of BOD\(_5\) value according to the scale presented by Wawrzynek [28]. The median for TN concentration was 80.5 mg·dm\(^{-3}\) (average: 80.6 mg·dm\(^{-3}\)), and the value of the coefficient of variation (\(C_v\)) was 28%. This showed the average differentiation of concentrations for this parameter in inflowing wastewater. Another biogenic indicator that was analyzed, i.e., TP, was characterized by a concentration median in the value of 12.0 mg·dm\(^{-3}\), and average concentration in the value of 12.5 mg·dm\(^{-3}\). Irregularity of concentration for this parameter (expressed by \(C_v\) coefficient) amounted to 30% and as in the previous two cases, it was at the level of average diversity.

| Parameters | Statistics |
|------------|------------|
|            | Average mg·dm\(^{-3}\) | Median mg·dm\(^{-3}\) | Min. mg·dm\(^{-3}\) | Max. mg·dm\(^{-3}\) | Deviation Stand. mg·dm\(^{-3}\) | Coefficient of Variation % |
| BOD\(_5\)  | 400.5      | 409.4      | 222.5      | 634.6      | 101.1                | 25 (average)               |
| TN         | 80.6       | 80.5       | 44.1       | 162.5      | 22.4                 | 28 (average)               |
| TP         | 12.5       | 12.0       | 7.1        | 22.8       | 3.8                  | 30 (average)               |
| Sludge concentration MLSS (Sc) | 4446.2 | 4460.0 | 2930.0 | 6900.0 | 760.1 | 17 (low) |

The concentration of sludge’s dry matter in the biologic reactor was characterized by a median in the value of 4460.0 mg·dm\(^{-3}\) (4.46 g·dm\(^{-3}\)). In the case of this parameter, its low variability in the study group was noted. It was expressed by the coefficient of variation (\(C_v\)) in the value of 17%. This variation was at a low level—as indicated in the scale provided by Wawrzynek [28]. The characteristic values of the analyzed indications of impurities in wastewater after mechanical treatment are presented in Table 1.

3.2. Impact of BOD\(_5\)/TN and BOD\(_5\)/TP for OUR

In the next stage of analysis concerning wastewater after mechanical treatment, the dependencies of BOD\(_5\)/TN (Figure 3A) and BOD\(_5\)/TP (Figure 3B) that have a direct impact on the susceptibility of biogenic pollution removal in biologic reactors with activated sludge technology as indicated by Łomotowski and Szpindor [29], Dymaczewski [23], Sadecka [30], Ganigué [31], were determined. The average
value of BOD$_5$/TN value was 5.1 and it ranged from 2.7 to 10.2. On the other hand, the average value of BOD$_5$/TP was 33.5 and it ranged from 14.9 to 52.0. The diversity of both analyzed dependencies determined by the coefficient of variation ($C_v$) was at the level of average differentiation [26] and it amounted to 23% and 24% (respectively). The dependence of BOD$_5$/TN in 16.4% of cases, and the dependence of BOD$_5$/TP in 14.8% of cases (Figure 3A,B) indicated that wastewater flowing into the biologic reactor was not very susceptible to the removal of nitrogen and phosphorus compounds. The reason for this was that in the wastewater inflowing (after mechanical treatment) to the analyzed bioreactor was too low of a level of organic matter (BOD$_5$) in relation to nitrogen compounds (TN) and phosphorus compounds (TP) was excessive BOD$_5$ removal in the primary pre-sedimentation tank and negligible nitrogen removal and phosphorus [25]. The initial pre-sedimentation tank in the plant with SBR technology was designed to retain an excessive amount of mineral suspension, but somehow a “side effect” was the retention of an excessive amount of organic suspension, which results in a low quotient of BOD$_5$/TN and BOD$_5$/TP [25].

![Figure 3. Frequency distribution (A) biochemical oxygen demand (BOD$_5$)/total nitrogen (TN) and (B) BOD$_5$/total phosphorus (TP) in wastewater after mechanical treatment (n = 61).](image)

During the analysis of the unit oxygen uptake rate (OUR), it was found that in 61 samples of activated sludge, OUR ranged from 5.61 to 14.61 mgO$_2$·g$^{-1}$·s.m.$^{-1}$·h$^{-1}$. The median of OUR tests was 8.57 mgO$_2$·g$^{-1}$·s.m.$^{-1}$·h$^{-1}$, and the average was 9.02 mgO$_2$·g$^{-1}$·s.m.$^{-1}$·h$^{-1}$. Taking into account the proper value of activated sludge (OUR) in the range of 8–20 mgO$_2$·g$^{-1}$·s.m.$^{-1}$·h$^{-1}$ (presented by Kośnierska [16] and Henze et al. [32]), it was found that in the analyzed 61 samples, 32.8% of cases the value of OUR was below the lower limit, i.e., below 8 mgO$_2$·g$^{-1}$·s.m.$^{-1}$·h$^{-1}$. OUR usually ranged from 8 to
10 mgO₂·g−1·s.m·h−1, where 41.0% of cases were recorded. In ranges above 10 mgO₂·g−1·s.m·h−1, it was found that the OUR value occurred in 26.2% of cases (in total). Characteristics frequencies of OUR in individual class intervals are presented in Figure 4.

Figure 4. Frequency distribution oxygen uptake rate (OUR) in wastewater after mechanical treatment (n = 61).

In the detailed analysis concerning the condition of activated sludge microorganisms expressed as OUR, the impact of BOD₅/TN and BOD₅/TP on OUR was characterized. Taking into account data presenting the ratio of BOD₅/TN and BOD₅/TP, as well as OUR values, a statistical analysis of the Pearson’s correlation coefficient was conducted. The aim of this analysis was to determine the strength of the dependence for two variables, where the independent variable is the ratio of BOD₅/TN and BOD₅/TP, and the dependent variable is OUR value in individual wastewater samples. It was stated that the correlation between BOD₅/TN and the value of OUR is rₓᵧ = 0.63. In the scale proposed by Stanisz [33], it means that the level of correlation was high. In the case of dependence between BOD₅/TP and OUR, it was found that the correlation level was rₓᵧ = 0.51. This also indicates high correlation. In the analyzed cases, the correlation was statistically significant at the confidence level α = 0.05. There was no significance of the free expression in the regression line equation describing the effect of independent variables BOD₅/TN and BOD₅/TP on OUR.

The equation describing the regression line presented in Figure 5A indicated that an increase in the BOD₅/TN dependence by one caused an increase in OUR by 1.0325 mgO₂·g⁻¹·s.m·h⁻¹. In the case of the second dependence (BOD₅/TP to OUR) from the equation of the regression line shown in Figure 5B, it was stated that an increase in the BOD₅/TP dependence by one caused an increase in OUR by 0.1244 mgO₂·g⁻¹·s.m·h⁻¹.

Figure 5. Connection (A) BOD₅/TN and (B) BOD₅/TP with OUR and results of linear regression analysis.
3.3. Impact of Sludge Concentration (Sc) in the Biologic Reactor on OUR

By using the linear correlation (similarly to the previous part of the analysis), the dependence between OUR (dependent variable) and concentration of (Sc) sludge (independent variable) in the biologic reactor was developed. It was found that the correlation between the concentration of sludge (Sc) and OUR is \( r_{xy} = -0.70 \). In the proposed Stanisć’s scale [33], it meant that the level of correlation was very high. The analyzed correlation was statistically significant at the confidence level \( \alpha = 0.05 \). There was no significance of the free word in the regression line equation describing the effect of the independent variable sludge concentration (Sc) on OUR.

The equation describing the regression line is presented in Figure 6. It indicates that an increase in sludge concentration (Sc) in the biologic reactor by 1000 mg·dm\(^{-3}\) (1.0 g·dm\(^{-3}\)) causes a decrease of OUR by 1.8 mgO\(_2\)·g\(^{-1}\) s.m.·h\(^{-1}\).

![Figure 6.](image)

Based on the results from the above analysis, it can be stated that in the case of the analyzed bioreactor, the condition of activated sludge microorganisms depended on the availability of an appropriate ratio of organic compounds to biogenic compounds in the wastewater inflowing into the reactor, as indicated by reports by Krzanowski and Wałeća [17], Sui et al. [34] and Moretti et al. [35]. In addition, according to the above analysis, the impact on of the activated sludge condition was a concentration of activated sludge in the bioreactor.

3.4. Partial Correlation for OUR—Sludge Concentration and BOD\(_5\)/TN and BOD\(_5\)/TP Ratio

As a result of the conducted analysis of linear correlation, it was shown that the variation of OUR, i.e., the condition of activated sludge microorganisms in the biologic reactor, was affected by two factors (independent of each other). In order to determine the strength of the interaction for two factors, a statistical analysis of partial correlation for three variables was carried out. The aim of this analysis was to determine the magnitude of the impact of two independent variables (the ratio of BOD\(_5\)/TN and BOD\(_5\)/TP, as well as the concentration of sludge in the biologic reactor) on the dependent variable (OUR).

In the case, where partial correlation analysis for the dependence between OUR and BOD\(_5\)/TN and the sludge concentration were performed, it was found that the concentration of sludge in the biologic reactor has a greater impact on OUR \( R_c = -0.60 \) than the ratio of BOD\(_5\)/TN in wastewater flowing into the biologic reactor \( R_c = 0.50 \). The significance of the calculated correlation coefficients was tested with the use of the Student’s \( t \)-test at the significance level \( \alpha = 0.05 \). In both cases, the significance of the examined dependencies at the significance level of \( \alpha = 0.05 \) was found. Detailed results of the regression analysis for multiples of analyzed dependencies are presented in Table 2.
Table 2. Results of the regression analysis of the multiple of the influence depending on BOD\textsubscript{5}/TN and sludge concentration on OUR.

| Statistics          | Number of Measurements | Partial Correlation Coefficient | Coefficient of Determination | Variable Standard Deviation | Arithmetic Mean of the Variable | Value of t-Statistic | Value of Test \( \alpha = 0.05 \) |
|---------------------|------------------------|---------------------------------|-----------------------------|------------------------------|-------------------------------|----------------------|-----------------------------|
| Designation correlation |                        |                                 |                             |                              |                               |                      |                             |
| BOD\textsubscript{5}/TN | 61                     | 0.50                            | 0.21                        | 1.2                          | 5.1                           | 4.22                 | 0.000087                   |
| OUR                 |                        |                                 |                             |                              |                               |                      |                             |
| Sludge concentration  | 61                     | −0.60                           | 0.21                        | 760.1                        | 4446.2                        | −5.66                | 0.000000                   |
| OUR                 |                        |                                 |                             |                              |                               |                      |                             |

In the second case, in which the partial correlation analysis was conducted for the dependence between OUR and BOD\textsubscript{5}/TP and concentration of sludge, it was found that the concentration of sludge in the biologic reactor (\( R_c = −0.61 \)) had a greater impact on OUR than the ratio of BOD\textsubscript{5}/TP in wastewater flowing into the biologic reactor (\( R_c = 0.31 \)). Based on the calculation, it was stated that the BOD\textsubscript{5}/TP dependence has a smaller impact on OUR than in the case of the BOD\textsubscript{5}/TN dependence. The significance of the calculated correlation coefficients was tested with the use of the Student’s \( t \)-test at the significance level \( \alpha = 0.05 \). In both cases, the significance of the examined dependencies was determined at the significance level \( \alpha = 0.05 \). The detailed results of the regression analysis for multiples of analyzed dependencies are presented in Table 3.

Table 3. Results of the regression analysis of the multiple of the influence depending on BOD\textsubscript{5}/TP and sludge concentration on OUR.

| Statistics          | Number of Measurements | Partial Correlation Coefficient | Coefficient of Determination | Variable Standard Deviation | Arithmetic Mean of the Variable | Value of t-Statistic | Value of Test \( \alpha = 0.05 \) |
|---------------------|------------------------|---------------------------------|-----------------------------|------------------------------|-------------------------------|----------------------|-----------------------------|
| Designation correlation |                        |                                 |                             |                              |                               |                      |                             |
| BOD\textsubscript{5}/TP | 61                     | 0.31                            | 0.20                        | 8.0                          | 33.5                          | 2.50                 | 0.015409                   |
| OUR                 |                        |                                 |                             |                              |                               |                      |                             |
| Sludge concentration  | 61                     | −0.61                           | 0.20                        | 760.1                        | 4446.2                        | −5.88                | 0.000000                   |
| OUR                 |                        |                                 |                             |                              |                               |                      |                             |

Based on the obtained results concerning the partial correlation, nomograms presented in Figures 7 and 8 were developed. These nomograms enabled to forecast (state) the condition of activated sludge expressed as OUR depending on the concentration of sludge in the biologic reactor and the simultaneous knowledge of the dependence (ratio) between BOD\textsubscript{5}/TN and BOD\textsubscript{5}/TP.

In the case of the BOD\textsubscript{5}/TN connection in the wastewater inflowing into the bioreactor, which in 83.6% of cases oscillated between four and six (axis abscissa on the nomogram—Figure 7), to obtain an OUR value above 10, the sludge concentration should be maintained at an average level of 3700 mg·dm\(^{-3}\) (ordinate axis on the nomogram—Figure 7). In the case of the BOD\textsubscript{5}/TP connection in the wastewater inflowing into the bioreactor, which in 85.2% of cases oscillated between 25 and 45 (axis abscissa on the nomogram—Figure 8), to obtain an OUR value above 10 it is necessary to keep the dry matter concentration of sludge at 4500 mg·dm\(^{-3}\) (ordinate axis on the nomogram—Figure 8).

The created models presented graphically in Figures 7 and 8 can be described by the equations:

1. \( \text{OUR} = 11.6685 + 0.6391 \times \text{BOD}\textsubscript{5}/TN - 0.0013 \times \text{Sludge concentration (Sc)} \) (Figure 7)
2. \( \text{OUR} = 13.6554 + 0.0601 \times \text{BOD}\textsubscript{5}/TP - 0.0015 \times \text{Sludge concentration (Sc)} \) (Figure 8)
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**Figure 7.** Nomogram for predicting OUR depending on BOD5/TN and sludge concentration (Sc) in biologic reactor.

**Figure 8.** Nomogram for predicting OUR depending on BOD5/TP and sludge concentration (Sc) in biologic reactor.

4. Conclusions

Based on the conducted analysis, it was found that the condition of activated sludge microorganisms in the analyzed biologic reactor, determined by the unit oxygen uptake rate (OUR), is weak in nearly 33% of the cases. This result is evidenced by the calculated respiration rate below the value of 8 mgO$_2$·g$^{-1}$ s.m.$^{-1}$·h$^{-1}$. In 41% of the cases, the respiration rate of activated sludge microorganisms (OUR) ranged from 8 to 10 mgO$_2$·g$^{-1}$ s.m.$^{-1}$·h$^{-1}$. This indicates their low condition. It has been shown that two factors have an impact on the condition of activated sludge in the analyzed biologic reactor—i.e., too little organic matter expressed in the BOD5 parameter in the wastewater inflowing into the bioreactor compared to the use of the nitrogen and phosphorus function and too high sediment concentrations in the bioreactor. Then apply the effect of increasing the condition of the activated sludge. One method is supplied to the wastewater inflowing into the wastewater bioreactor with a high BOD5 concentration in the form of easy organic decomposition. It is recommended that the BOD5/TN ratio inflowing to the biologic reactor be at least six. We can use the function of removing excess sludge in the operation of the sludge from the biologic reactor after the decanting process to achieve its concentration in the range of 3700 mg·dm$^{-3}$.

**Author Contributions:**

Conceptualization, E.N.-M.; methodology, E.N.-M. and P.B.; formal analysis, E.N.-M.; investigation, E.N.-M.; resources, E.N.-M.; data curation, E.N.-M.; writing—original draft preparation, E.N.-M. and P.B.; writing—review and editing, E.N.-M. and P.B.; visualization, E.N.-M.; All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:**

The authors declare no conflicts of interest.
4. Conclusions

Based on the conducted analysis, it was found that the condition of activated sludge microorganisms in the analyzed biologic reactor, determined by the unit oxygen uptake rate (OUR), is weak in nearly 33% of the cases. This result is evidenced by the calculated respiration rate below the value of 8 mg O₂·g⁻¹·s.m.⁻¹·h⁻¹. In 41% of the cases, the respiration rate of activated sludge microorganisms (OUR) ranged from 8 to 10 mg O₂·g⁻¹·s.m.⁻¹·h⁻¹. This indicates their low condition. It has been shown that two factors have an impact on the condition of activated sludge in the analyzed biologic reactor—i.e., too little organic matter expressed in the BOD₅ parameter in the wastewater inflowing into the bioreactor compared to the use of the nitrogen and phosphorus function and too high sediment concentrations in the bioreactor. Then apply the effect of increasing the condition of the activated sludge. One method is supplied to the wastewater inflowing into the wastewater bioreactor with a high BOD₅ concentration in the form of easy organic decomposition. It is recommended that the BOD₅/TN ratio inflowing to the biologic reactor be at least six. We can use the function of removing excess sludge in the operation of the sludge from the biologic reactor after the decanting process to achieve its concentration in the range of 3700 mg·dm⁻³.

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