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# Impacts of dairy wastewater and pre-aeration on the performance of SBR treating municipal sewage

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**ABSTRACT**

The influence of pre-aeration in the equalization basin and the percentage (0, 5; 10; 15; 20; 30; 50 and 100%) of dairy sewage in the municipal waste stream on organic contaminants removal efficiency in SBR was tested. The organic compound fractions contribution in raw and purified sewage was also determined. The optimal non-pre-aerated dairy sewage contribution in municipal wastewater, providing high efficiency of treatment, was 30%. The $S_S$ was not stated in treated wastewater. The increase in the quantity of dairy sewage caused an increase in COD remaining fractions concentration. Depending on the amount of dairy sewage, proportions between different fractions underwent a change. The resulting mathematical models allow for explanation of about 85.0% of changes in ($BOD_5$), 91.3% (COD), 85.1% ($X_S$), and 85.4% ($X_I$).

*Keywords:* COD fractions; Dairy sewage percentage; Empirical equations; Municipal wastewater; SBR

## 1. Introduction

Dairy wastewaters are characterized by a high content of COD and $BOD_5$ [1,2]. Exploitation problems of dairy wastewater treatment plants result not only from high concentrations of organic substances but also from flow fluctuations. Flowrates of dairy wastewater are characterized by a high seasonal variability, including ca. 20% increase in the spring and summer months. Additional fluctuations are observed in daily and hourly variability that are determined by the production rate and profile as well as multi-shift work in milk processing plants. Dairy wastewaters are also characterized by a high content of phosphorus and nitrogen which come from milk and cleaning agents like $HNO_3$, and $H_3PO_4$ [3].

While dairy wastewaters are treated under aerobic conditions, a large load of organic compounds and suspensions cause the increase of oxygen demand, difficulty of oxygen transfer, a large amount of an excess sludge as well as difficulties associated with sedimentation of activated sludge and its thickening. Meanwhile, in the case of municipal sewage treatment plants, the technology of activated sludge operating under aerobic-anaerobic conditions is the most commonly used [4]. Municipal wastewater treatment plants are often also target sites of pre-treated dairy sewage. Because of operational reasons, it is important to determine the influence of dairy sewage on the effectiveness of treatment process and to predict the effluent quality at a specified quality and quantity of dairy sewage. In this regard, the knowledge about organic substance fractions (based on COD) may be helpful. It allows the determination of principles for designing and operating of biological processes. Knowledge of individual COD fraction levels enables accurate assessment of the biodegradability of municipal wastewater containing dairy sewage and are also important for biological nutrient removal [5,6] but readily biodegradable to slowly biodegradable COD ratio (rbCOD/sbCOD).

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Data on COD fractions in municipal wastewater are relatively well-documented but at the same time there are serious gaps in relation to the effluent (Table 1). Multiple research describe the treatment of dairy, household, or municipal sewage but without going into detail regarding the specific share of dairy wastewater [7–10].

The aim of the study was to determine the influence of dairy sewage on the removal of organic pollutants efficiency in the SBR and the percentage of each COD fraction in raw and treated wastewater depending on amount of dairy wastewater. The influence of pre-aeration process on wastewater treatment performance was also determined. Empirical equations estimating the concentration of organic compounds in treated sewage were proposed.

Table 1
Percentage of COD fraction in raw municipal wastewater based on literature data

| Source | COD [mg·L$^{-1}$] | COD fraction [%] | | | |
|---|---|---|---|---|---|
| | | $S_S$ | $S_I$ | $X_S$ | $X_I$ |
| [9] | – | 9.0 | 14.0 | 68.0 | 9.0 |
| [10] | 183 | 27.0 | 15.0 | 41.0 | 17.0 |
| [11] | 313 | 15.0 | 6.0 | 71.0 | 8.0 |
| [12] | 260 | 19.2 | 11.5 | 59.7 | 11.5 |
| [5] | 516 | 41.5 | 4.6 | 16.7 | 37.2 |
| [13] | 334 | 31.7 | 6.7 | 42.4 | 19.2 |
| [14] | 392 | 10.0 | 6.0 | 59.0–69.0 | 15.0–25.0 |
| [15] | 180–300 | 22.0–26.0 | 7.0–9.0 | 53.0–54.0 | 12.0–15.0 |
| | | 16.0–33.0 | 3.0–15.0 | 40.0–60.0 | 4.0–17.0 |
| [16] | 380 | 10.0 | 4.0 | 66.0 | 20.0 |
| [17] | 663 | 5.1 | 46.8* | 48.1 | – |
| [6] | – | 9.0–42.0 | 3.0–10.0 | 10.0–48.0 | 23.0–50.0 |
| [18] | – | 18,3 | 6.4 | 64.0 | 11.3 |
| [19] | – | 20.3 | 7.6 | 58.7 | 13.0 |
| [20] | 848 | 29.2 | 2.4 | 51.3 | 17.1 |
| | 1056 | 22.6 | 2.7 | 56.0 | 18.7 |
| [21] | – | 27.4 | 5.4 | 48.0 | 19.2 |
| [22] | <360 | 32.0 | 4.0 | 46.0 | 18.0 |
| | 360-575 | 31.0 | 3.0 | 48.0 | 18.0 |
| | >575 | 30.0 | 2.0 | 50.0 | 18.0 |
| | – | 12.2–50.3 | 1.2–14.0 | 27.6–66.9 | 8.8–33.1 |
| [7] | 455–477 | 33.2–46.9 | 6.5–8.0 | 37.1–40.9 | 4.0–12.0 |
| [23] | 1362 | 21.9 | 4.6 | 49.9 | 23.7 |
| [24] | 624 | 24.6 | 5.5 | 52.4 | 17.5 |
| [25] | - | 6.0–45.0 | 4.0–9.0 | 20.0–70,0 | 4.0–69.0 |
| | - | 13.6–29.8 | 4.8–7.0 | 39.1–68.2 | 6.8–42.1 |
| | - | 22.0 | 5.5 | 56.0 | 16.5 |
| [26] | 249 | 23.4 | 20.1 | 53.0 | 3.5 |
| [27] | 754–1482 | 28.7–42.3 | 1.7–2.6 | 42.0–51.7 | –17.2 |

* including $X_I$

## 2. Methods

Studies were conducted in laboratory reactors of SBR-type with municipal and dairy sewage originated directly from dairy plant (series 1) and dairy wastewater pre-treated in an aerated equalization basin (24 hours retention time) (series 2).

### *2.1. SBR reactors*

Eight SBR-type reactors working in parallel were used. The total capacity of individual reactor was 17 L, while active volume 13 L. Oxygen concentration was 3.0 ± 0.5 $mgO_2·L^{-1}$ for aerobic stage and below 0.5 $mgO_2·L^{-1}$ for anoxic and anaerobic stages. Concentration of activated sludge biomass was kept at the level of about 3.7 $kg_{DM}·m^{-3}$. The volumetric exchange coefficient (decantation) for SBR was 0.3. Activated sludge organic loading varied from 0.14 to 0.61 $kg·kg_{DM}^{-1}·d^{-1}$ and increased with dairy wastewater share. The hydraulic load was 1.2 $m^3·m^{-3}·d^{-1}$.

The volume of municipal and dairy sewage entering the SBR was 5 L, whereas the activated sludge volume was 8 L. For 72 h (nine 8-h cycles), the content of reactors was subjected to technological regime in which the sequence and duration of the purification process phases was the same as in the sewage treatment plant, from where sludge and municipal wastewater was collected (prior to its merging with dairy sewage stream). The SBR phases included: filling and mixing - 20 min., aeration and stirring - 300 min., sedimentation - 100 min., decanting - 60 min. Then relevant studies were conducted, which lasted another 3 days (9 cycles). Samples for analysis of physicochemical properties were collected in cycle 3, 6, and 9. Municipal wastewater (MW) without dairy sewage, dairy wastewater (DW), mixture of municipal and dairy wastewater as well as treated sewage were examined. Percentage of wastewater in SBR reactors was: R1 – 100% MW, 0% DW; R2 – 95% MW, 5% DW; R3 – 90% MW, 10% DW; R4 – 85% MW, 15% DW; R5 – 80% MW, 20% DW; R6 – 70% MW, 30% DW; R7 – 50% MW, 50% DW; R8 – 0% MW, 100% DW.

### *2.2. Activated sludge and municipal wastewater*

Activated sludge from the reactor of SBR-type treating the municipal wastewater containing wastewater from the dairy plant located in Hajnowka (Poland) was used. The technological parameters of the sewage treatment plant are shown in Table 2.

The activated sludge was collected at the end of the aeration phase, the municipal wastewater after mechanical treatment and before delivery to SBR (Table 3).

### *2.3. Dairy wastewater*

Dairy wastewater was collected directly from dairy processing plant (series 1, Table 3), average milk processing in the plant was 160 $m^3·d^{-1}$. The plant generates sewage associated with milk processing including production of ripened cheese, full-fat Swiss type cheese, butter, cottage cheese, milk powder and cream. Between the sewage treatment plant and the dairy, there is an aerated tank averaging dairy wastewater. This enabled sampling of wastewater (series 2) with uniform composition.

Table 2
Average flows and pollution loads in the mixture of municipal and dairy wastewater delivered to the sewage treatment plant in Hajnówka, from which the activated sludge and municipal wastewater was collected during the study

| Index | Hajnówka |
|---|---|
| $Qd_{max}$, $m^3 \cdot d^{-1}$ | 6600 |
| $Qd_{mean}$, $m^3 \cdot d^{-1}$ | 5000 |
| $Qd_{meanliquid\ waste}$, $m^3 \cdot d^{-1}$ | 28 |
| RLM | 35000 |
| $Qd_{meandairy}$, $m^3 \cdot d^{-1}$ | 500 |
| The volume share of dairy sewage in municipal wastewater, % | 10 |
| $BOD_5$ load,$kg \cdot d^{-1}$ | 2100 |
| $BOD_{5\ dairy}$ load, $kg \cdot d^{-1}$ | 672 |
| Share of $BOD_5$load of dairy sewagein municipal sewage, % | 32 |
| COD load, $kg \cdot d^{-1}$ | 5605 |
| $COD_{dairy}$ load, $kg \cdot d^{-1}$ | 1183 |
| Share of CODload of dairy sewagein municipal sewage, % | 21 |

### 2.4. Physicochemical analyses

DO concentration, pH and temperature were measured directly in the reactors (using probe of Hach HQd Meter and IntelliCAL Smartprobes type, Germany). Analyses of COD; $BOD_5$; TN; ammonia nitrogen; nitrates; TP, orthophosphates, TSS were carried out in accordance with APHA [30]. To filter the sewage, membrane filters made of glass fiber with 0.45 µm pore size were used (Milipore or Whatman). The COD fractions were calculated ($S_S$ – COD for dissolved readily bio-degradable compounds; $S_I$ – COD for dissolved compounds that are not biologically decomposed (inert); $X_S$ – COD for insoluble hardly bio-degradable compounds; $X_I$ – COD for insoluble biologically non-degradable compounds (inert)) according to Struk-Sokolowska's methods [6].

### 2.5. Statistical processing

To process the test results the Statistica 10 software (StatSoft) was applied. Calculations included analysis of variance in order to assess the impact and significance of dairy sewage type (wastewater directly from the production plant/wastewater from the aeration equalization basin) on the quality of treated municipal wastewater. No effect was confirmed by the least significant difference test (Fisher LSD), which was chosen because of its high potency and quality. The evaluation of dairy sewage type impact was carried out for all test parameters in raw and treated sewage. The Pearson correlation coefficients (R) and Spearman analysis was performed to determine the degree of linear relationship between the share of dairy sewage in municipal wastewater and value of each COD fraction in raw and treated wastewater.

The last stage of statistical analysis was to develop mathematical models estimating the amount of organic compounds in the SBR outflow. Multi-parameter regression was applied using stepwise method aimed at selecting only the relevant elements in the equation and allowing the fullest commitment of changes in the estimated parameter in the model system. The idea of this method is to add another variable to the model. In the first step variable with the highest correlation coefficient with respect to explanatory variable was added. In the second step variable that is most strongly correlated with the rest remaining after the first step was added. Algorithm of adding variables was continued until all the variables that statistically influence the explanatory variable were used up or until the addition of another variable caused the deterioration of the equation, i.e. decrease in determination coefficient or decrease in the equation significance. The equations will enable the estimation of values of $BOD_5$, COD and fractions $S_S$, $S_I$, $X_S$ and $X_I$ in treated wastewater based on the same parameters in raw sewage as well as share of dairy wastewater in municipal sewage.

Table 3
Physicochemical indicators of wastewater used in the study

| Parameter | Municipal wastewater | | Dairy wastewater | |
|---|---|---|---|---|
| | Series 1 | Series 2 | Series 1 | Series 2 |
| $BOD_5$ [$mg \cdot L^{-1}$] | 720.0 | 440.0 | 1300.0 | 1950.0 |
| COD [$mg \cdot L^{-1}$] | 1360.0 | 754.0 | 1740.0 | 2254.0 |
| TN [$mgN \cdot L^{-1}$] | 109.8 | 100.0 | 60.9 | 69.0 |
| Ammonia nitrogen [$mgN \cdot L^{-1}$] | 78.4 | 45.9 | 23.5 | 22.4 |
| Nitrates [$mgN \cdot L^{-1}$] | 10.3 | 0.5 | 18.1 | 1.2 |
| TP [$mgP \cdot L^{-1}$] | 17.4 | 20.3 | 36.2 | 63.1 |
| Orthophosphates [$mgP \cdot L^{-1}$] | 12.4 | 16.7 | 23.1 | 59.1 |
| TSS [$mg \cdot L^{-1}$] | 380.0 | 620.0 | 480.0 | 910.0 |
| pH | 7.0 | 7.0 | 6.6 | 6.5 |
| EC [$mS \cdot cm^{-1}$] | 1.7 | 1.9 | 2.3 | 2.1 |

## 3. Results and discussion

The impact of wastewater type (wastewater directly from the plant, wastewater from the aerated equalization basin) on the concentration of selected pollutants and the COD fraction was determined by means of statistical analysis through the use of LSD Fisher test. The test results are shown in the form of a probability value - a difference between values of concentration of various parameters obtained from cycles of dairy wastewater types (Supp. 1). The results allow to conclude that in the case of raw municipal wastewater supplied into the SBR tank, the type of dairy sewage significantly affected the concentration of ammonia nitrogen, orthophosphate, TP, TSS, COD, and $S_S$ fraction. For other studied parameters of raw municipal sewage the type of sewage had no statistically significant impact. Nevertheless, for treated wastewater, no statistically significant effect on any analyzed parameter was recorded: ammonia nitrogen, TN, orthophosphates, TP, TSS, as well as values of $BOD_5$, COD and $S_S$, $S_I$, $X_S$ and $X_I$ fractions. In the case of $S_I$

fraction no differences were found between raw and treated wastewater (Supp. 1).

Efficiency of organic compounds removal depended on participation of dairy sewage, however, for individual fractions, the impact was different. Based on the correlation a conclusion was drawn that the increase in the amount of dairy wastewater resulted in an increase of all fractions in raw sewage. These correlations were average to very high. In the treated wastewater fraction, $S_S$ fraction was not determined (below the limit of quantification or absent), while in the case of other fractions, the increase in the amount of dairy wastewater was the same as for raw sewage: an increase in the fractions $S_I$, $X_S$ and $X_I$. These were positive correlations between average to very high (Table 4) [31].

### 3.1. Wastewater before treatment

In addition to the amount of organic compounds belonging to COD fraction the proportions between fractions are relevant to the wastewater treatment technologies. Organic compounds determined by the biodegradable fractions ($S_S$; $X_S$), will be used with the highest efficiency during the SBR cycle, while organic compounds concentration expressed by hardly or non-biodegradable fractions is subject to the smallest variation. As a result the percentage of fractions in total COD is changed.

Availability of hydrolyzed organic compounds easily absorbed by microorganisms is one of the factors which determine the efficiency of biological nutrients removal. In dairy sewage supplied from dairy plants (series 1) fraction $X_S$ dominated (64.5%), whereas fraction $S_S$ amounted to 13.2%. In wastewater after averaging and pre-aeration (series 2) fraction $S_S$ predominated (48.8%), while $X_S$ fraction ranked the second place (37.1%). Pre-aeration dairy wastewater in series 2 probably caused the slowly-biodegradable non-soluble organic matters ($X_S$) to be hydrolyzed which increased $S_S$ fraction contribution [32]. Composition of the dairy sewage affected the quality of municipal wastewater entering the SBR. In municipal wastewater of series 1, $S_S$ fraction accounted for between 17.2 to 31.9%. The smallest percentage of $S_S$ fraction was in the municipal wastewater with 30% share of dairy sewage, while the largest in wastewater with 5% share. In series 2, fraction $S_S$ made up from 41.8 to 53.5%. The smallest percentage of this fraction was observed in municipal wastewater with 50% share, while the largest in municipal wastewater with 20 and 30% share of dairy sewage (Table 5). Achieved results for $S_S$ fraction were similar to those reported earlier [7–9,23,16,33].

The results indicate that the insoluble organic slowly biodegradable substances ($X_S$) underwent hydrolysis in aerated equalization basin. In municipal wastewater with the participation of dairy sewage obtained directly from the treatment plant, fraction $X_S$ accounted for between 49.3 to 60.9%. The lowest percentage was reported in municipal wastewater with 5% share of dairy sewage, while the largest in municipal wastewater with 30% share. In municipal wastewater containing dairy sewage collected from the aerated equalization basin, fraction $X_S$ amounted to 33.5–42.6%. The smallest percentage of this fraction was observed in municipal wastewater with 20% share, while the largest in municipal wastewater with 50% share of dairy sewage (Table 5). Percentages of $X_S$ fraction in wastewater were similar to those reported by other scientists [8,23,33,34,22,14,11].

Percentage of non-biodegradable dissolved organic substances ($S_I$) in raw sewage was insignificant regardless of the quantity of dairy sewage. In wastewater from dairy plant, this fraction accounted for 0.9%, while in the wastewater from the aerated equalization basin 1.8%. In municipal sewage and the mixture of municipal and dairy wastewater of series 1, fraction $S_I$ accounted for between 1.5 to 2.6%. The smallest percentage of $S_I$ was in municipal wastewater with 50% share of dairy wastewater, whereas the largest in municipal sewage. In series 2, $S_I$ fraction constituted to 1.4–1.9%. The lowest percentage was reported in municipal wastewater with 50% share, while the largest in municipal wastewater with 15 and 20% share of dairy sewage (Table 5). Shares of fraction $S_I$ were similar to those published in: [8,23,17].

Insoluble non-biodegradable organic substances ($X_I$) in dairy wastewater made up 21.4% (sewage from the dairy plant) in total COD, while in wastewater from the aerated tank, their participation was approximately half of the amount, i.e. 12.3% (Table 5). In municipal wastewater with varying share of dairy sewage supplied directly from the plant, $X_I$ fraction accounted for 16.4 to 20.3%. The lowest percentage was reported in municipal wastewater with 5% share of dairy wastewater, while the largest in municipal wastewater with 30% share. In a mixture of municipal and dairy sewage in series 2, fraction $X_I$ accounted for between 11.1 to 14.2%. The lowest value was recorded in the municipal wastewater with 20% share, and the highest in the municipal wastewater with 50% share of dairy wastewater (Table 5). Achieved percentages of insoluble non-biodegradable organic substances $X_I$ in wastewater were similar to those reported by other scientists [23,16,33,15,35]. In the municipal wastewater without dairy sewage, share of insoluble and non-biodegradable substances ($X_I$) averaged to 15.3% (Table 5). Also percentages of Ss, $X_S$, $S_I$ and $X_I$ fractions were at similar levels to those presented in literature references (Table 1).

Comparing the characteristics of municipal wastewater without dairy sewage addition, dairy sewage, and municipal containing dairy wastewater, extended by COD fraction, it was observed that they differ in their composition from other wastewater from food industry. Research

Table 4
The R Pearson and Spearman correlations between the percentage of dairy wastewater and COD fraction concentration in raw and treated sewage

| Parameter | Share of dairy wastewater | | | |
|---|---|---|---|---|
| | R Pearson correlations | | Spearman correlations | |
| | Raw sewage | Treated sewage | Raw sewage | Treated sewage |
| $S_S$ | 0.36 | – | 0.35 | |
| $S_I$ | 0.86 | 0.86 | 0.81 | 0.81 |
| $X_S$ | 0.78 | 0.44 | 0.91 | 0.20 |
| $X_I$ | 0.78 | 0.45 | 0.91 | 0.20 |

conducted by Chiavola et al. [30] upon wastewater from olive mill purified in SBR revealed that the shares of biodegradable organic substances averaged 66.6%, including $S_S$ = 29.2%, and $X_S$ = 37.4%, while on-biodegradable 33.4%, including $S_I$ = 9.9%, and $X_I$ = 23.5%. Municipal wastewater with the participation of dairy sewage have a greater share of insoluble organic hardly biodegradable substances and a smaller fraction of non-biodegradable (inert) which classifies them as more susceptible to biological treatment processes. Rodriguez et al. [31], when analyzing the composition of wastewater from food industry, found that the share of non-biodegradable fractions $S_I$ and $X_I$ in the wastewater from tomatoes, sugar beet, potato and wine processing were respectively 18.4, 18.9, 28.8, and 20.9%.

### 3.2. Treated wastewater

Efficiency of organic compounds removal expressed as $BOD_5$ and COD indicators varied in a narrow range from 98.2 to 99.5% and from 98.3 to 99.6%, respectively (Table 6) depending on dairy sewage share.

Table 5
Percentage of COD fraction in raw and treated municipal wastewater from laboratory SBR tank

| COD fraction, % | wastewater | Municipal wastewater | The mixture of municipal and dairy wastewater | | | | | | Dairy wastewater |
|---|---|---|---|---|---|---|---|---|---|
| | | R1 | R2 (95+5%*) | R3 (90+10%*) | R4 (85+15%*) | R5 (80+20%*) | R6 (70+30%*) | R7 (50+50%*) | R8 |
| Wastewater directly from the plant (series 1) | | | | | | | | | |
| $S_S$ | raw | 31.3 | 31.9 | 27.8 | 21.7 | 20.1 | 17.2 | 19.4 | 13.2 |
| | treated | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $S_I$ | raw | 2.6 | 2.4 | 2.2 | 2.0 | 1.7 | 1.6 | 1.5 | 0.9 |
| | treated | 68.3 | 64.7 | 68.1 | 66.4 | 68.7 | 74.6 | 73.1 | 62.1 |
| $X_S$ | raw | 49.6 | 49.3 | 52.5 | 57.2 | 58.6 | 60.9 | 59.3 | 64.5 |
| | treated | 23.7 | 26.5 | 23.9 | 25.3 | 23.4 | 19.1 | 20.1 | 28.4 |
| $X_I$ | raw | 16.5 | 16.4 | 17.5 | 19.1 | 19.6 | 20.3 | 19.8 | 21.4 |
| | treated | 8.0 | 8.8 | 8.0 | 8.3 | 7.9 | 6.3 | 6.8 | 9.5 |
| Wastewater from the aeration averaging tank (series 2) | | | | | | | | | |
| $S_S$ | raw | 42.3 | 52.6 | 51.2 | 50.3 | 53.5 | 53.5 | 41.8 | 48.8 |
| | treated | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $S_I$ | raw | 1.7 | 1.6 | 1.7 | 1.9 | 1.9 | 1.6 | 1.4 | 1.8 |
| | treated | 53.5 | 52.9 | 44.8 | 49.4 | 54.1 | 52.9 | 60.4 | 46.8 |
| $X_S$ | raw | 42.0 | 34.3 | 35.3 | 35.8 | 33.5 | 33.7 | 42.6 | 37.1 |
| | treated | 34.9 | 35.3 | 41.4 | 38.0 | 34.5 | 35.3 | 29.7 | 39.9 |
| $X_I$ | raw | 14.0 | 11.5 | 11.8 | 12.0 | 11.1 | 11.2 | 14.2 | 12.3 |
| | treated | 11.6 | 11.8 | 13.8 | 12.6 | 11.4 | 11.8 | 9.9 | 13.3 |

*shares of dairy wastewater

Table 6
Efficiency of pollutants removal in SBR

| Efficiency [%] | Series | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| | Percentage of dairy wastewater | | | | | | | | | | | | | | | |
| | 0 | | 5 | | 10 | | 15 | | 20 | | 30 | | 50 | | 100 | |
| $BOD_5$ | 98.9 | 98.8 | 98.8 | 98.8 | 99.0 | 98.2 | 99.9 | 98.3 | 99.3 | 98.6 | 99.5 | 98.8 | 99.5 | 99.2 | 99.5 | 98.2 |
| COD | 96.6 | 97.9 | 96.6 | 97.8 | 97.2 | 97.8 | 96.7 | 97.9 | 97.4 | 97.9 | 97.7 | 98.1 | 97.9 | 97.9 | 98.3 | 97.4 |
| TN | 75.0 | 83.5 | 79.0 | 82.3 | 76.6 | 80.4 | 77.7 | 82.8 | 70.6 | 81.9 | 81.9 | 81.3 | 72.0 | 81.5 | 73.9 | 63.1 |
| Ammonia nitrogen | 91.3 | 87.0 | 91.3 | 87.9 | 91.2 | 84.3 | 92.4 | 86.1 | 86.4 | 88.9 | 92.4 | 87.2 | 84.4 | 80.3 | 77.7 | 58.5 |
| Nitrates | – | 36.4 | 21.8 | 33.6 | – | 53.1 | – | 47.8 | 12.5 | 42.8 | – | 55.6 | – | 60.5 | – | 58.0 |
| TP | 73.9 | 71.3 | 80.4 | 75.1 | 87.8 | 66.2 | 78.0 | 64.5 | 84.8 | 61.6 | 88.8 | 57.2 | 84.5 | 78.9 | 85.3 | 73.8 |
| Orthophosphates | 67.7 | 74.1 | 86.6 | 73.0 | 89.4 | 64.9 | 78.0 | 70.4 | 93.0 | 67.0 | 92.4 | 61.7 | 86.6 | 70.9 | 90.0 | 69.5 |
| TSS | 98.4 | 98.5 | 96.8 | 98.5 | 97.7 | 98.8 | 97.7 | 98.2 | 97.2 | 98.6 | 98.0 | 98.5 | 95.9 | 98.5 | 95.1 | 98.3 |

The efficiency of wastewater treatment plant for the removal of organic compounds can also be assessed on the basis of biodegradable fractions $S_S$ and $X_S$. On this basis operation of reactors can be controlled or a range of necessary modernization can be planned. In this study there was no presence of $S_S$ in treated wastewater. Lack or negligible quantity of $S_S$ fraction provides the use of biodegradable organic substances by microorganisms regardless of the wastewater treatment technology applied.

Fraction $X_S$ in treated wastewater made up 19.1 to 28.4% (series 1). The lowest share of $X_S$ fraction was in sewage treated in R6 (with 30% share of dairy wastewater). The highest percentage of $X_S$ fraction in treated sewage was found in R3 (with 10% share). In series 2, fraction $X_S$ made up from 29.7 to 41.4%. The lowest percentage of $X_S$ fraction was observed in R7 (with 50% share), while the highest in reactor R3 (with 10% share).

In the case of dissolved non-biodegradable substances fraction ($S_I$) there were no statistically significant differences in values of COD fraction between raw and treated sewage. This is due to the inability to use this type of compounds in biochemical processes of microorganisms. As a result of using up the $S_S$ and $X_S$ fractions, percentage of $S_I$ in the total COD increased (Table 5), thus that faction dominated in the treated wastewater.Insoluble organic non-biodegradable substances ($X_I$) composed from 6.3 to 13.8% in treated wastewater.

Table 7
Summarized regression models - $BOD_5$, COD, $X_S$, $X_I$

| | b* | SE | b | SE | t(12) | p | Estimation error |
|---|---|---|---|---|---|---|---|
| $BOD_5$ | | | | | | | |
| Free term | | | –3.893 | 3.0748 | –1.266 | 0.2295 | ±2.229 |
| $S_{S\,WR}$ | 0.7485 | 0.1614 | 0.012 | 0.0025 | 4.637 | 0.0006 | |
| $S_{I\,WR}$ | 0.3746 | 0.1833 | 0.320 | 0.1564 | 2.044 | 0.0635 | |
| $COD_{WR}$ | –0.1835 | 0.1701 | -0.002 | 0.0021 | –1.078 | 0.3020 | |
| $BOD_{5\,WT} = –0{,}012 \cdot S_{S\,WR} + 0{,}32 \cdot S_{I\,WR} – 0{,}002 \cdot COD_{WR} – 3{,}893$ | | | | | | | |
| COD | | | | | | | |
| Free term | | | 9.951 | 3.896 | 2.55 | 0.027 | ±1.826 |
| $S_{I\,WR}$ | 0.645 | 0.187 | 0.568 | 0.165 | 3.44 | 0.005 | |
| $COD_{WR}$ | 0.651 | 0.273 | 0.008 | 0.004 | 2.38 | 0.036 | |
| $BOD_{WR}$ | -0.613 | 0.366 | –0.009 | 0.005 | -1.68 | 0.122 | |
| $W_D$ | 0.331 | 0.261 | 0.056 | 0.044 | 1.27 | 0.230 | |
| $COD_{WT} = 0{,}568 \cdot S_{I\,WR} + 0{,}008 \cdot COD_{WR} – 0{,}009 \cdot BOD_{5\,WR} + 0{,}056 \cdot W_D + 9{,}951$ | | | | | | | |
| $X_s$ | | | | | | | |
| Free term | | | -6.492 | 5.1130 | –1.270 | 0.2283 | ±3.707 |
| $SS_{WR}$ | 0.7491 | 0.1610 | 0.019 | 0.0042 | 4.652 | 0.0006 | |
| $SI_{WR}$ | 0.3728 | 0.1828 | 0.531 | 0.2601 | 2.039 | 0.0641 | |
| $COD_{WR}$ | -0.1812 | 0.1697 | -0.004 | 0.0035 | –1.068 | 0.3067 | |
| $X_{S\,WT} = 0{,}019 \cdot S_{S\,WR} + 0{,}531 \cdot S_{I\,WR} – 0{,}004 \cdot COD_{WR} – 6{,}492$ | | | | | | | |
| $X_I$ | | | | | | | |
| Free term | | | –2.188 | 1.6883 | –1.296 | 0.2193 | ±1.224 |
| $SS_{WR}$ | 0.7481 | 0.1596 | 0.006 | 0.0014 | 4.688 | 0.0005 | |
| $SI_{WR}$ | 0.3740 | 0.1811 | 0.177 | 0.0859 | 2.064 | 0.0613 | |
| $COD_{WR}$ | –0.1788 | 0.1682 | –0.001 | 0.0012 | –1.063 | 0.3086 | |
| $X_{I\,WT} = 0{,}006 \cdot S_{S\,WT} + 0{,}117 \cdot S_{I\,WT} – 0{,}001 \cdot COD_{WT} – 2{,}188$ | | | | | | | |

Explanations:
$BOD_{5\,WT}$ – $BOD_5$ value in treated wastewater,
$BOD_{5\,WR}$ – $BOD_5$ value in raw wastewater,
$COD_{WT}$ – COD value in treated wastewater,
$COD_{WR}$ – COD value in raw wastewater,
$S_{S\,WR}$ – $S_S$ fraction value in raw wastewater,
$S_{I\,WR}$ – $S_I$ fraction value in raw wastewater,
$X_{S\,WT}$ – $X_S$ fraction value in treated wastewater,
$X_{I\,WT}$ – $X_I$ fraction value in treated wastewater,
$W_D$ – share of dairy wastewater in municipal sewage expressed in per cents.
SE – Standard error

Besides organic compounds, the effectiveness of other pollutants removal was monitored. Total nitrogen removal efficiency varied from 63.1 to 83.5%. For ammonia nitrogen, the efficiency varied in the range of 80.31 to 92.43%. Lower removal efficiency of ammonia nitrogen was observed for treatment of dairy wastewater only. Concentrations of total nitrogen in purified wastewater were affected by the concentration of nitrates and ammonia nitrogen. It was from 3.5 to 8.3 mgN-$NO_3$·$L^{-1}$ and from 2.9 to 11.0 mgN-$NH_4$·$L^{-1}$, respectively. The reason for the high concentration of ammonia nitrogen in treated wastewater can be some nitrification inhibitors such as dissolved oxygen, pH, or temperature [36]. The dissolved oxygen concentration was above minimum levels (1.0–1.5 m$gO_2$·$L^{-1}$) recommended for appropriate development of nitrification microorganisms. Temperature and pH of wastewater were within the optimum ranges. Removal of nitrogen during the processes of biological treatment is the result of ammonification processes, synthesis of biomass, nitrification, denitrification. However, only the synthesis of biomass and denitrification make the reduction of nitrogen concentration possible. The presence of ammonia nitrogen could also be due to the duration of nitrification during the cycle being too short which was consistent with the length of this phase in the real object, from which the activated sludge originated. Regardless of dairy sewage type the lowest concentration of total nitrogen was in reactors where the share of dairy sewage amounted to 30%.

Efficiency of total phosphorus removal varied from 57.2 to 88.8%. The total phosphorus concentration in treated wastewater amounting up to 11.0 mgP·$L^{-1}$ could be affected by short anaerobic filling and stirring phases (20 min). However, such duration was accepted in accordance with data for the real object that treats municipal sewage with 10% share of dairy wastewater. Regardless of dairy sewage type there was no re-release of phosphates.

### 3.3. Estimation of study results

Based on the study results, empirical equations were determined estimating the quantity of organic matter expressed as $BOD_5$ and COD in treated wastewater depending on the share of dairy sewage in municipal wastewater (Table 7; Fig. 1).

Mathematical model also allowed for calculating the predicted values of insoluble slowly biodegradable organic substances $X_S$ and non-biodegradable organic substances $X_I$ fractions in treated wastewater (Table 7; Fig. 1). No equation for $S_S$ fraction in treated wastewater was developed because it made up below 0.1 mg·$L^{-1}$ in the effluent, thus variance for this variable was zero. In the case of $S_I$, the equation was not defined due to lack of significant differences between this fraction concentration in raw and treated wastewater. Table 7 presents the summary of the regression models.

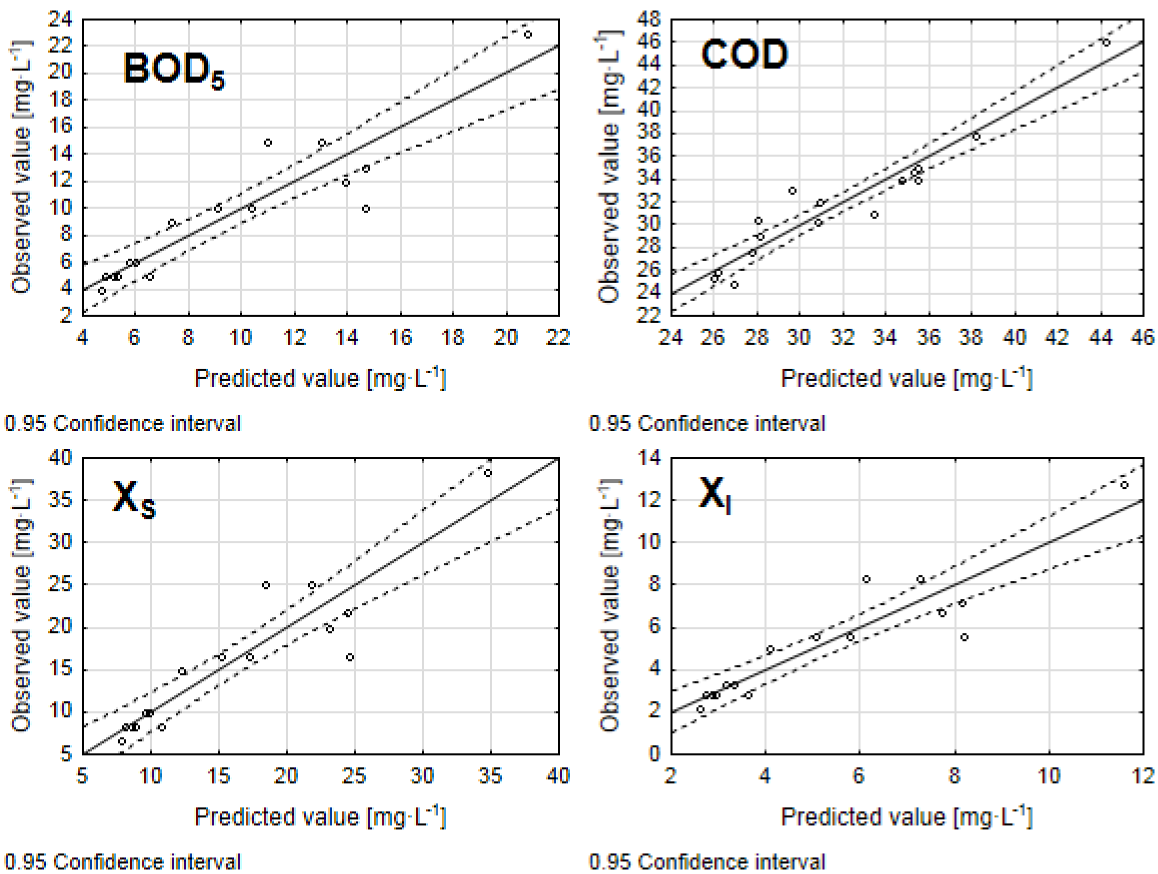


Fig. 1. Estimation of $BOD_5$, COD, fraction $X_S$, and fraction $X_I$ in treated wastewater.

Variables skipped in the regression model were insufficiently related with the model. Based on variables adopted for the analysis mathematical models were accepted which explains about 85.0% value changes ($BOD_5$), 91.3% (COD), 85.1% ($X_S$), and 85.4% ($X_I$). Determination coefficients ($R^2$) amounted to 0.8501 ($BOD_5$), 0.9133 (COD), 0.8509 ($X_S$), 0.8536 ($X_I$).

The developed equations were subject to estimation test, the results of which are presented in Fig. 1. Correlation coefficients between predicted and observed values in treated wastewater were 0.92 ($BOD_5$), 0.96 (COD), 0.92 ($X_S$), and 0.92 ($X_I$).

## 4. Conclusions.

The following conclusions can be drawn:

- There was no effect of averaging the dairy sewage in an aerated tank on the quality of treated wastewater in the SBR reactor but there was a significant effect on the quality of raw wastewater.
- 30% is the optimal share of non-pre-aerated dairy sewage in municipal wastewater ensuring greatest efficiency of organic compounds, nitrogen, and phosphorus removal.
- Regardless of the percentage of dairy sewage there were no dissolved readily biodegradable organic substances ($S_S$) in treated wastewater.
- In the case of dissolved hardly biodegradable substances (inert, $S_I$) their concentration did not reveal any statistically significant differences between wastewater before and after treatment.
- Detailed analysis of organic compounds fractions allows through the use of empirical equations the estimation of organic compound concentration in treated wastewater, including insoluble fractions ($X_S$ and $X_I$).

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**Supplement**

Results from NIR Fisher test between concentrations of selected pollutants and type of dairy wastewater (1 - directly from the treatment plant / 2 - from aerated averaging tank)

| | Parameter | Wastewater | Series | {1} | {2} | {3} | {4} |
|---|---|---|---|---|---|---|---|
| 1 | Ammonianitrogen | Raw | 1 | | 0.006702 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.006702 | | 0.000017 | 0.000002 |
| 3 | | Treated | 1 | 0.000000 | 0.000017 | | 0.465035 |
| 4 | | Treated | 2 | 0.000000 | 0.000002 | 0.465035 | |
| 1 | TN | Raw | 1 | | 0.660839 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.660839 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.000000 | 0.000000 | | 0.386711 |
| 4 | | Treated | 2 | 0.000000 | 0.000000 | 0.386711 | |
| 1 | Orthophosphates | Raw | 1 | | 0.000067 | 0,007246 | 0.004727 |
| 2 | | Raw | 2 | 0.000067 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.007246 | 0.000000 | | 0.863903 |
| 4 | | Treated | 2 | 0.004727 | 0.000000 | 0.863903 | |
| 1 | TP | Raw | 1 | | 0.003217 | 0.000627 | 0.000262 |
| 2 | | Raw | 2 | 0.003217 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.000627 | 0.000000 | | 0.747548 |
| 4 | | Treated | 2 | 0.000262 | 0.000000 | 0.747548 | |
| 1 | TSS | Raw | 1 | | 0.000000 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.000000 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.000000 | 0.000000 | | 0.595762 |
| 4 | | Treated | 2 | 0.000000 | 0.000000 | 0.595762 | |
| 1 | $BOD_5$ | Raw | 1 | | 0.222447 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.222447 | | 0.000002 | 0,000002 |
| 3 | | Treated | 1 | 0.000000 | 0.000002 | | 0.954427 |
| 4 | | Treated | 2 | 0.000000 | 0.000002 | 0.954427 | |
| 1 | COD | Raw | 1 | | 0.010708 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.010708 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.000000 | 0.000000 | | 0.972484 |
| 4 | | Treated | 2 | 0.000000 | 0.000000 | 0.972484 | |
| 1 | $S_S$fraction | Raw | 1 | | 0.000000 | 0.000000 | 0.000000 |
| 2 | | Raw | 2 | 0.000000 | | 0.000000 | 0.000000 |
| 3 | | Treated | 1 | 0.000000 | 0.000000 | | 1.000000 |
| 4 | | Treated | 2 | 0.000000 | 0.000000 | 1.000000 | |
| 1 | $S_I$ fraction | Raw | 1 | | 0.142013 | 1.000000 | 0.142013 |
| 2 | | Raw | 2 | 0.142013 | | 0.142013 | 1.000000 |
| 3 | | Treated | 1 | 1.000000 | 0.142013 | | 0.142013 |
| 4 | | Treated | 2 | 0.142013 | 1.000000 | 0.142013 | |
| 1 | $X_S$fraction | Raw | 1 | | 0.115126 | 0.001351 | 0.001132 |
| 2 | | Raw | 2 | 0.115126 | | 0.000017 | 0.000014 |
| 3 | | Treated | 1 | 0.001351 | 0.000017 | | 0.946543 |
| 4 | | Treated | 2 | 0.001132 | 0.000014 | 0.946543 | |
| 1 | $X_I$fraction | Raw | 1 | | 0.115174 | 0.001351 | 0.001132 |
| 2 | | Raw | 2 | 0.115174 | | 0.000017 | 0.000014 |
| 3 | | Treated | 1 | 0.001351 | 0.000017 | | 0.946594 |
| 4 | | Treated | 2 | 0.001132 | 0.000014 | 0.946594 | |