Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.26158

206 (2020) 22–26
December

Characteristics of organic pollutants in wastewater from individual treatment systems

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Received 10 December 2019; Accepted 22 May 2020

ABSTRACT

This paper presents analyses of the percentage shares of organic pollutants fractions expressed as chemical oxygen demand in domestic wastewater, treated in individual systems. Wastewater from nine facilities, consisting of a primary settling tank and a biological reactor with activated sludge, or from a primary settling tank and a reed bed with a purification pond were examined within this study. The dissolved and suspended readily biodegradable fraction was found to be dominant (about 80%) in the effluent leaving the primary settling tank at a relatively high portion of the suspended biodegradable fraction in biologically treated wastewater (about 25%–51%). The tested wastewater was assessed as biodegradable. It was found that the differences in the composition of sewage from individual and municipal sewage treatment plants result from the diversity of sewage sources and the specific operation of the equipment.

Keywords: COD fractionation; Domestic wastewater; Individual wastewater treatment plant

1. Introduction

Pollutants contained in wastewater are found in the form of suspensions, colloids or dissolved substances. The content of organic pollutants in wastewater is most often determined by two indicators: biochemical oxygen demand (usually BOD_5) and chemical oxygen demand (COD). The former is a measure of the content of readily biodegradable compounds, while the latter also includes slowly biodegradable compounds. However, information on the values of these indicators is not sufficient to model and design unit processes in wastewater treatment and proper operation of bioreactors. The character of wastewater and biodegradability of organic compounds influence the course of nitrogen and phosphorus removal processes and determines biomass growth [1]. Readily biodegradable compounds are used in 50% by bacterial biomass, slowly biodegradable compounds are used by higher organisms, while the non-degradable substrate is eliminated by sorption or precipitation. Pharmaceutical residues are also examples of slowly biodegradable pollutants in wastewater. After intake, pharmaceuticals undergo metabolic processes in the organism. Significant fractions of the parent compound are excreted in an unmetabolized form or as active metabolites to domestic raw sewage and wastewater treatment systems [2].

The proportion of organic substrate fractions in wastewater depends on their source. Sewage from urban sewerage systems, small sewerage systems in rural areas, relieved sewerage or individual households can vary considerably [3]. Many authors present the percentage of shares of pollutants in wastewater within a wide range of wastewater fractions [4–7]. Different fractions of organic pollutants may be determined by physical–chemical or respirometric methods [8–12].

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The reaction rate constant is a parameter characterizing biochemical degradation. The kinetics of the first phase of decomposition may be described by the equation of the first order according to Street and Phelps [Eq. (1)]:

$$\text{BOD}_t = \text{BOD}_{\text{tot}} \cdot \left(1 - \text{e}^{-k \cdot t}\right) \tag{1}$$

where BOD_t – biochemical oxygen demand after time t, $\text{gO}_2\ \text{m}^{-3}$; BOD_{tot} – total biochemical oxygen demand for phase 1, $\text{gO}_2\ \text{m}^{-3}$; k – reaction rate constant, d^{-1}; t – time, d.

The experimentally determined constant k may range from 0.07 to 0.80 d^{-1}, which shows that the 5 d BOD_5 commonly used in practice is not sufficient to assess the contents of the readily biodegradable substrate in wastewater.

The purpose of the study is to analyze the composition of wastewater from individual households, before and after treatment in individual biological treatment systems of various designs.

2. Experimental procedures

For the purpose of designing and modeling biochemical processes, organic substrates are divided into dissolved and undissolved, and degradable and nondegradable [3,11], according to Eq. (2).

The organic substrate expressed as COD may be written as:

$$\text{COD} = S_S + X_S + S_I + X_I \tag{2}$$

where S_S – dissolved organic compounds, readily biodegradable, $\text{gO}_2\ \text{m}^{-3}$; S_I – inert dissolved organic compounds, $\text{gO}_2\ \text{m}^{-3}$; X_S – organic suspension, slowly biodegradable, $\text{gO}_2\ \text{m}^{-3}$; X_I – inert organic suspension, $\text{gO}_2\ \text{m}^{-3}$.

Fractions of organic compounds were determined using the DWA-ATV standard methods. They were calculated as follows:

$$S_I = 0.9 \cdot S_{e\text{COD}} \tag{3}$$

$$S_S = S_{\text{COD}} - S_I \tag{4}$$

$$X_S = \frac{\text{BOD}_{\text{tot}}}{1 - f_{\text{BOD}}} - S_S \tag{5}$$

$$S_I = \frac{S_S}{1 - A} - X_S \tag{6}$$

where $S_{e\text{COD}}$ – COD of treated wastewater, $\text{gO}_2\ \text{m}^{-3}$; S_{COD} – COD for raw filtered wastewater, $\text{gO}_2\ \text{m}^{-3}$; f_{BOD} – correction factor due to the transformation of the biodegradable compounds into the inert fraction (0.15), A – constant for domestic wastewater (according to ATV – 0.25).

The reaction rate constant k (Eq. (1)) was determined at a temperature of 20°C. The level of BOD_5 for unfiltered wastewater with an addition of the nitrification inhibitor was measured over the course of 15 d in three replications. The constant k was calculated using the Polymath program as an average of three recorded values.

For the purpose of this study individual wastewater treatment systems differing in design were selected. All the systems consisted of a pre-treatment plant and a biological treatment plant. In the mechanical part, a septic tank or fresh-water settling tank was used as the primary settling tank. The biological part consisted of a flow reactor or a sequential reactor with activated sludge, a biological trickling filter or a plant filter with a purification pond (Fig. 1).

The capacity of the tanks, the volume of wastewater flowing into the treatment plants and the number of people using individual installations were similar (Table 1). Differences in the values of indicators of organic pollutants in the effluent from the settling tanks may have resulted from the different lifestyles of the residents, cleaning products used and differing effectiveness of pretreatment.

Wastewater samples were collected from effluents after mechanical treatment and following treatment in biological reactors or purification ponds. The samples were collected three times (objects 3–9) or eight times (objects 1 and 2). The BOD_5 was determined in wastewater samples – not filtered and filtered through a medium filter, while the COD was recorded in wastewater filtered through a medium filter. Susceptibility of the sewage from the settling tank to biological treatment was also assessed based on calculated COD/BOD_5 values [13].

3. Results and discussion

Fig. 2 shows fractions of organic pollutants, expressed as COD, calculated for sewage after preliminary treatment in settling tanks. In most of the investigated systems, the dominant fraction in the effluent discharged from the settling tank was the readily degradable S_S fraction (maximum 64%). In three cases (objects 1, 2 and 4) the suspended fraction of slowly decomposable X_S (maximum 57%) was predominant.

The S_S fraction was almost completely decomposed at the biological treatment stage, while the X_S fraction remained at the level of 25%–51% of organic compounds (Fig. 3). The most effective removal of degradable fractions was found in the treatment plants with a plant filter and a purifying pond (objects 4 and 5), in the treatment plant with a trickling filter (object 6) and with activated sludge in the flow system (object 9).

Similar proportions of organic pollutant components were found previously in mechanically treated wastewater and biologically treated wastewater in medium-sized objects with a capacity of 12 and 22 $\text{m}^3\ \text{d}^{-1}$. In large objects with a capacity of tens $\text{m}^3\ \text{d}^{-1}$, fractions X_S and X_I accounted for approx. 80% of organic compounds expressed as COD in wastewater after the first treatment stage; similarly, in biologically treated wastewater fractions X_S and X_I were dominant [3,6,14,15].

The content of degradable dissolved and suspended organic compounds affects the efficiency of wastewater treatment (Fig. 4). Non-linear regression analysis produced a curve in the form of a square polynomial ($y = -0.1164x^2 + 19.38x - 720.83$), with a high regression coefficient (Fig. 4). As can be seen from the graph, the relationship between treatment efficiency and the percentage content of the $S_S + X_S$ fraction is statistically significant.

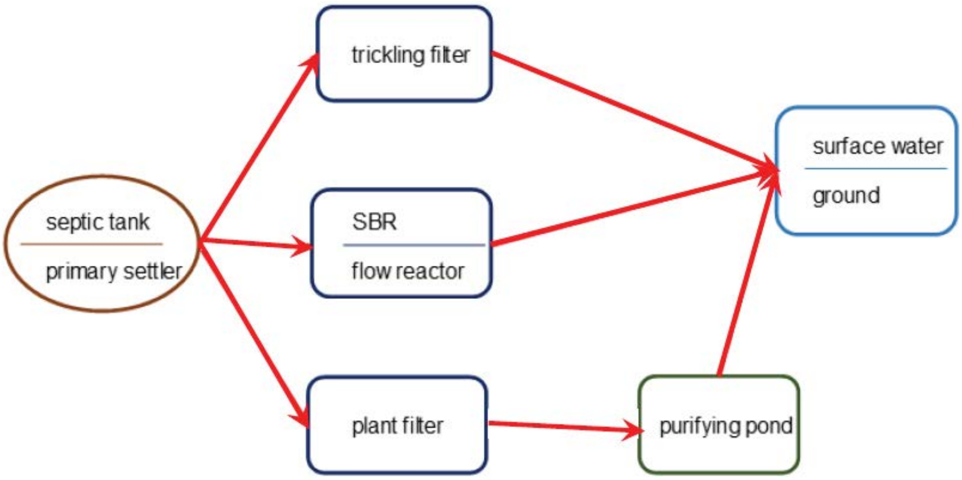

Fig. 1. A block diagram of the tested treatment systems.

Table 1
Technological characteristics of the investigated treatment plants

No.	Object	Technological steps	PE	Mean daily flow, $m^3\ d^{-1}$	BOD_5/COD after pre-treatment $gO_2\ m^{-3}$	Volume/area, m^3/m^2		
						Primary settler	Reactor/ filter	Secondary settler/ pond
1.	Individual wastewater treatment plant Dakowy Mokre	Septic tank + activated sludge	5	0.66	220/550	1.50	3.00	
2.	Individual wastewater treatment plant Rakoniewice	reactor	6	0.80	280/416	1.50	3.00	
3.	Individual wastewater treatment plant Kobylniki		7	0.73	360/780	2.60	3.00	
4.	Individual wastewater treatment plant Troszczyn	Septic tank + plant	2	0.30	224/140	2.30	12	1.30
5.	Individual wastewater treatment plant Troszczyn	filter + purifying pond	7	0.80	313/240	2.30	12	1.30
6.	Individual wastewater treatment plant Zielniczki (1)	Septic tank + trickling	5	0.75	370/532	2.00	2.00	
7.	Individual wastewater treatment plant Zielniczki (2)	filter	6	0.90	258/494	2.00	2.00	
8.	Individual wastewater treatment plant Trzebisławki (2)	Primary settler + activated sludge	5	0.66	663/812	1.50	3.00	
9.	Individual wastewater treatment plant Trzebisławki (7)	reactor	6	0.80	668/613	1.50	3.00	

The efficiency of biological treatment is related to the reaction rate constants, which may vary even for wastewater with a similar BOD_5. Fig. 5 compares the values of this factor with the efficiency of organic pollutant removal. No significant functional dependence was found; however, for most of the investigated objects with a higher reaction rate value, higher efficiency of biological processes was obtained.

Biodegradability of wastewater expressed as COD/BOD_5 was also analyzed (Fig. 6). It was found that wastewater subjected to biological treatment in the investigated objects was mostly readily biodegradable (COD/$BOD_5 < 1.8$) and partially contained slowly biodegradable compounds ($2.5 <$ COD/$BOD_5 > 1.8$). An analogy was observed with the content of the dissolved readily biodegradable fraction (except for objects 2 and 4, where the suspended slowly biodegradable fraction was predominant).

The calculated values are mostly below 1.8, in contrast to those in medium-sized treatment plants [16]. Wastewater treated in the small wastewater treatment plants contains readily degradable organic compounds, which was also

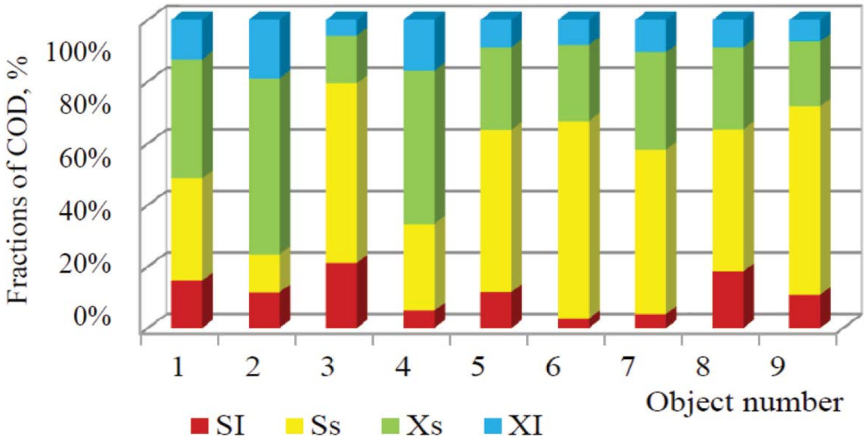

Fig. 2. COD fractions in wastewater after the primary settler treatment.

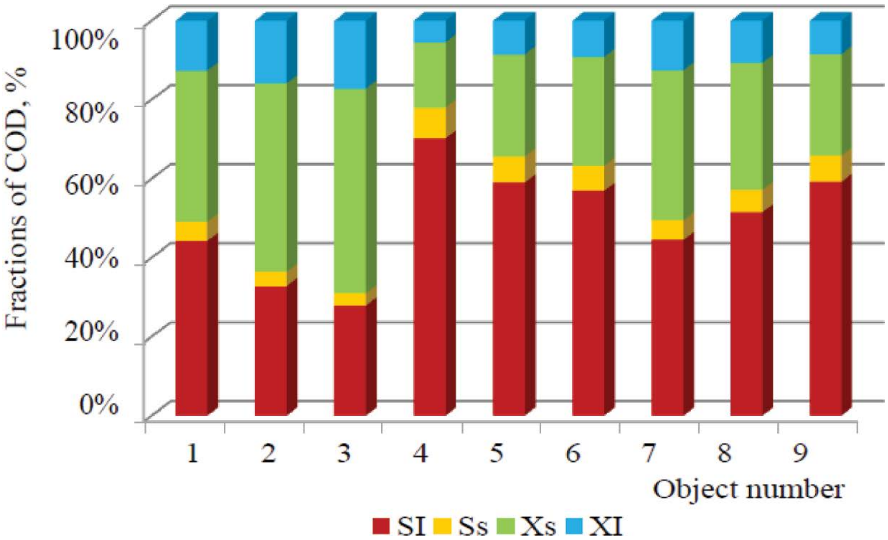

Fig. 3. COD fractions in wastewater following the biological reactor treatment.

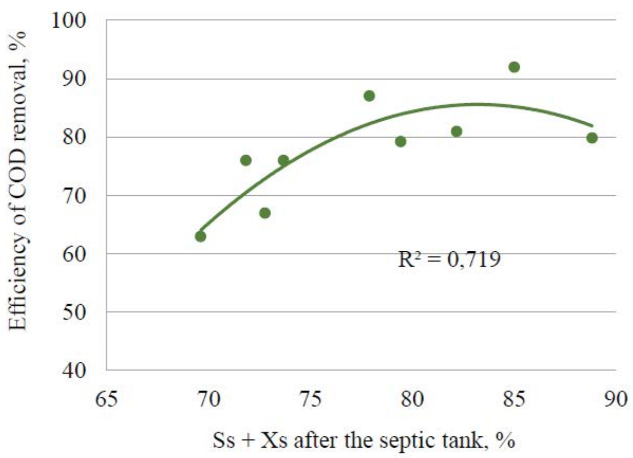

Fig. 4. Relationship between treatment efficiency in the biological reactor and degradable organic fractions.

indicated by recorded contents of individual fractions. This composition of wastewater is advantageous for nitrogen and phosphorus removal processes. The difference in the composition of the organic substrate at specific treatment stages between individual systems and municipal sewage treatment plants [17–19] results from the type of sewage source and the manner, in which these facilities are operated.

4. Conclusions

This study allowed us to determine the shares of four basic fractions of organic pollutants in sewage treated in household wastewater treatment plants. It was found that the soluble fraction dominant after mechanical pretreatment in the settling tank is usually readily biodegradable. This is due to the character of the wastewater discharged from households and hydrolysis of the organic suspension in the settling tank, which is usually characterized by

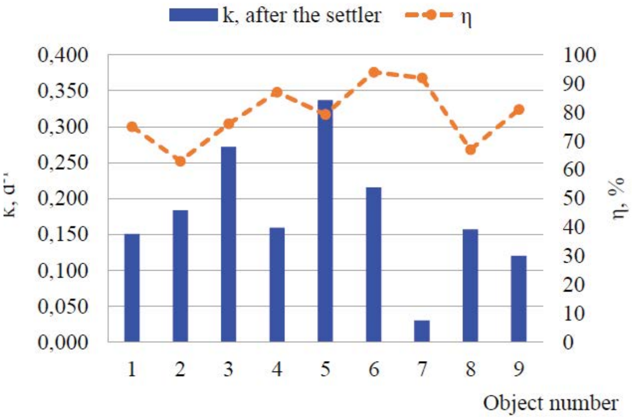

Fig. 5. The average reaction rate constant k compared to the efficiency of the biological reactor in investigated systems.

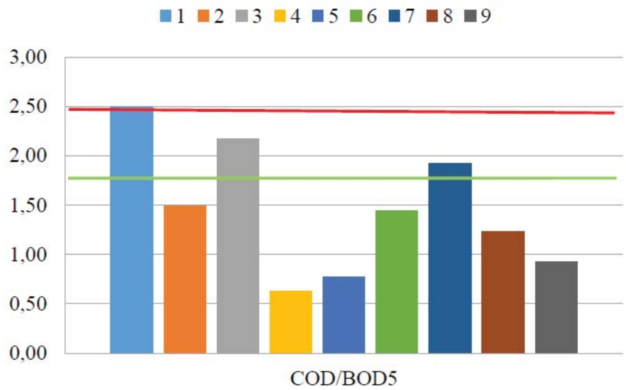

Fig. 6. Average COD/BOD$_5$ as a measure of the biodegradability of wastewater after mechanical treatment; green line – high biodegradability limit (1,8), red line – low.

long retention time (even up to several days). The greater share of the suspended fraction X_S recorded in objects in Rakoniewice (Table 1) and in Troszczyn (Table 1) may be caused by the accumulation of excess sludge in relation to the total capacity of the tank. In total, the biodegradable fractions in the analyzed wastewater (as opposed to large municipal wastewater treatment plants) represented about 80% of organic compounds expressed as COD. Organic pollutants in treated wastewater were characterized by a relatively high content of the X_S fraction, which may have been caused by the insufficient frequency of secondary sludge removal from the chamber of the biological reactor (some individual systems are not equipped with automatic sludge recirculation). The biodegradability of wastewater treated in the small systems expressed in terms of the COD/BOD$_5$ ratio is good. Wastewater treated in small wastewater treatment plants contain readily decomposable organic compounds, which is advantageous in the case of nitrogen and phosphorus removal processes. The difference in the composition of the organic substrate is due to the type of sewage source and the manner wastewater treatment facilities are operated. Municipal sewage treatment plants frequently treat domestic wastewater together with industrial wastewater, but the processes are continuously monitored by the operator. In contrast, individual systems, while treating biodegradable wastewater, are often incorrectly operated and irregularly inspected, which may result in a large percentage content of suspended fractions in treated wastewater.

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