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Original Research Article

COD FRACTIONS IN MECHANICAL-BIOLOGICAL WASTEWATER TREATMENT PLANT

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Abstract

The paper presents results of studies concerning the designation of COD fraction in the raw, mechanically treated and biologically treated wastewater. The test object was a wastewater treatment plant with the output of over 20,000 PE. The results were compared with data received in the ASM models. During investigation following fractions of COD were determined: dissolved non-biodegradable S_I, dissolved easily biodegradable S_S, in organic suspension slowly degradable X_S and in organic suspension non-biodegradable X_I. Methodology for determining the COD fraction was based on the guidelines ATV-A 131. The real percentage of each fraction in total COD in raw wastewater are different from data received in ASM models.

Keywords: wastewater, COD fractions, ASM models, organic substances biodegradable and non-biodegradable

1. INTRODUCTION

In the design and optimisation of biological wastewater treatment processes, it is very important to determine the biodegradability of contaminants with taking into account the ratios of contained by them compounds responsive and resistant to

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decomposition, and the influence of wastewater constituents on the course of unit processes. Detailed characterisation of organic contaminants is of increasing significance also in sludge stabilisation processes and problems related to sludge liquors forming in wastewater treatment plants [5,11,12,13,18,20]. The index BOD_5, so commonly used in designing technology sewage treatment systems, only provides information about easily biodegradable contaminant content. The index COD, with division into fractions, is currently presented as the most appropriate for the characterisation of organic substrates present in wastewater, because it makes it possible to obtain information on biodegradability of organic contaminants, both in dissolved and suspension form [1,3,16,25,26].
The basic division of total COD [4,17,19] in raw wastewater into fractions used in designing and modelling of wastewater treatment systems is presented in Fig. 1. The percentage ratio of the suspension fraction in total COD of raw household wastewater is 65÷79% and dissolved – 21÷35% [4,17,19].

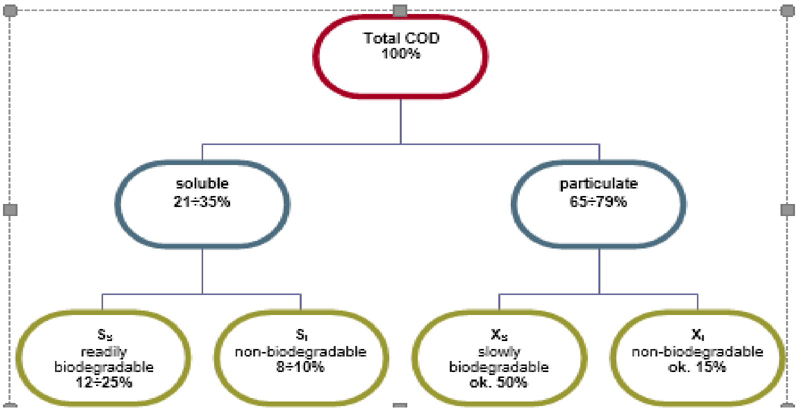

Fig. 1. Basic division of total COD in raw wastewater into fractions [4, 17, 19]

2. COD FRACTION IN BIOKINETIC ASM MODELS

The International Association on Water Pollution Research and Control (IAWPRC) work group published in 1987 first version of the model named Activated Sludge Model No.1 [10, 15, 21]. ASM1 model enables the simulation of the processes of removal of organic compounds and nitrogen compounds from wastewater, with taking into account unit processes which occur both in wastewater, as well as active sludge [7, 10, 14, 27]. The next version of the Model was ASM2. A novelty in the ASM2 model is the isolation from the group of active sludge microorganisms ones with the ability of phosphorus accumulation by polyphosphate storage [6, 8, 10].
The ASM1 model includes eight unit processes which are divided into 3 groups: hydrolysis processes, organic substance decomposition processes occurring in the

presence of heterotrophic bacteria and processes conducted by autotrophic bacteria (nitrificants). The division of organic substances in the ASM2 model is much more complex than in the ASM1 version, because it takes into account 19 constituents used in wastewater and active sludge characterisation. Ten of them relate to insoluble constituents, nine to soluble ones [2, 6, 9, 10].

The constituents of total COD according to the ASM1 and ASM2 models are presented respectively by the equations (2.1) and (2.2):

$$COD_{tot.} = S_S + S_I + X_S + X_I + X_H + X_A + X_P, \quad gO_2/m^3 \tag{2.1}$$

$$COD_{tot.} = S_A + S_F + S_I + X_S + X_I + X_H + X_A + X_{PAO} + X_{PHA} \quad gO_2/m^3 \tag{2.2}$$

where:

- S_s - soluble readily biodegradable substrates, gO_2/m^3,
- S_A - fermentation products (acetate) gO_2/m^3,
- S_F - fermentable, readily biodegradable organic substrates gO_2/m^3,
- S_I - inert soluble organic material, gO_2/m^3,
- X_I - inert particulate organic material, gO_2/m^3,
- X_S - particulate slowly biodegradable substrates, gO_2/m^3,
- X_H - heterotrophic organisms, gO_2/m^3,
- X_A - autotrophic nitrifying organisms, gO_2/m^3,
- X_P - decay products, gO_2/m^3,
- X_{PAO} - phosphorus accumulating organisms, gO_2/m^3,
- X_{PHA} - cell internal storage product of PAO's, gO_2/m^3.

When the biomass fraction is not included, both equations are simplified to the form $COD_{tot} = S_S+S_I+X_SX_I$, g/m^3.

The both models ASM1 and ASM2 assume that in raw wastewater fractions X_S and S_S are dominant, whereas in lower concentrations two other fractions, S_I and X_I, occur. The percentage ratios of the individual fractions in raw wastewater assumed by the ASM1 and ASM2 models are presented in Table 1.

The ASM1 model assumes constant values of the percentage ratio of the individual fractions, whereas the ASM2 model gives ranges of percentage ratios of the individual fractions in total COD of raw sewage.

Table1. The percentage ratios of COD fractions in biokinetic models [4, 9, 10]

COD fractions,%	The percentage ratios of the COD fractions in biokinetic models	
	ASM1	ASM 2
X_S	70	35÷75
S_S	15	12÷30
X_I	10	10÷15
S_I	5	5÷10

3. MATERIAL AND METHODS

The goal of the research was to determine the actual concentrations of COD fractions in raw, mechanically treated and treated wastewater in wastewater treatment plant with the output of over 20 000 PE. The results and calculations obtained have made it possible to determine percentage ratios of the individual fractions in total COD and compare the results obtained with the assumptions of the biokinetic ASM models.

3.1. The characteristics of the research objects

The research were conducted in mechanical-biological wastewater treatment plant with the output of 6000 m^3/d (20 000 PE). Wastewater samples were taken in designated measurement points: on the inlet (P1), after primary settling tank (P2) and on the outlet (P3). The technology diagram of the WWTP is presented in Fig. 2.

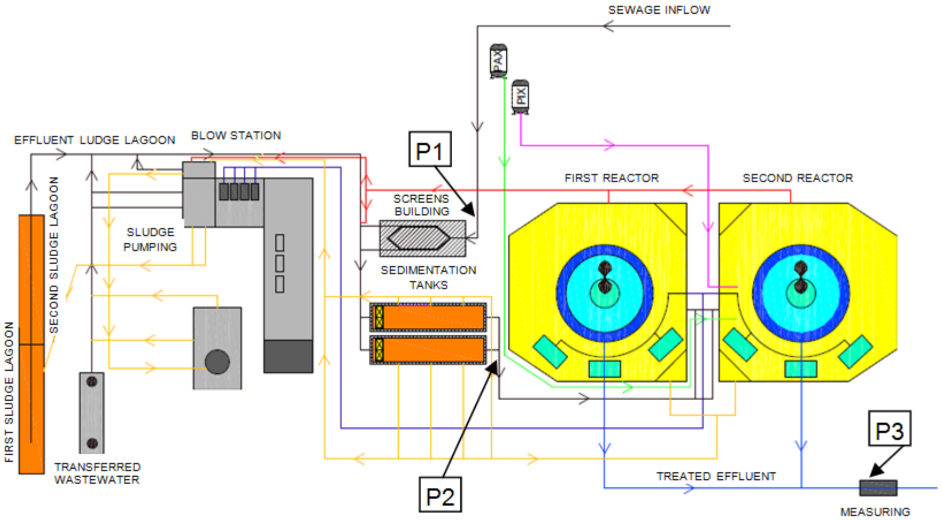

Fig. 2. The technology diagram of the WWTP

3.2. Methodology of research

Wastewater samples were taken in accordance with PN-ISO 5667-10:1997.
The wastewater samples included the characterisation of:

- Chemical oxygen demand, COD – with the potassium dichromate method, as per PN-74/C-04578.03, PN-ISO 6060:2006,
- Biochemical oxygen demand, BOD - with the manometric method, using the OxiTop Control OC110 measurement system made by WTW,

The characterisations were conducted in three repetitions, in non-filtred samples and samples filtered through a 0.45μm filter.
Based on the results of COD and BOD_5 measurements obtained, COD fractions were calculated.
The methodology of COD fraction determination has been developed on the basis of the ATV-A131 guidelines [22, 23, 24, 28].

- Total COD of raw wastewater as the sum of the fractions is determined with the equation:

$$COD_{tot.}= S_I + S_S + X_S + X_I,\ gO_2/m^3, \qquad (3.1)$$

where:

S_S - soluble readily biodegradable substrates, gO_2/m^3,
S_I - inert soluble organic material, gO_2/m^3,
X_S - particulate slowly biodegradable substrates, gO_2/m^3,
X_I - inert particulate organic material, gO_2/m^3.

- The dissolved, non-biodegradable fraction S_I is termed as COD in filtered (through a 0.45μm filter) treated wastewater.
- The dissolved, easily biodegradable fraction S_S is calculated from the difference of the concentration of dissolved organic contaminants S_{COD} determined in filtered raw wastewater and the concentration of the dissolved non-biodegradable fraction (S_I):

$$S_S = S_{COD} - S_I,\ gO_2/m^3. \qquad (3.2)$$

- The slowly biodegradable organic suspension fraction X_S is defined as the difference of total BOD (BOD_T), calculated based on the BOD_5 of non-filtered raw wastewater and biochemical decomposition coefficient (k1) and the dissolved easily biodegradable fraction:

$$X_S = (BZT_5/k_1) - S_S,\ gO_2/m^3, \qquad (3.3)$$

for household wastewater, it is assumed that k_1=0.6, 1/d.

- Non-biodegradable organic suspension X_I is calculated from the dependence:

$$X_I = X_{COD} – X_S,\ \ gO_2/m^3, \qquad (3.4)$$

where:

X_{COD} - total concentration of dissolved organic substances in suspension.

4. RESULTS AND DISCUSSION

The test results of raw, mechanically treated and treated wastewater composition as mean values are presented in Table 2. The organic contaminant values in raw wastewater were: COD = 627÷739 gO_2/m^3, BOD_5 = 307÷390 gO_2/m^3. Mechanically treated processes resulted in a decrease concentration of organic pollutants: COD = 484÷600 gO_2/m^3 and BOD_5 = 264÷273 gO_2/m^3. The treated wastewater were as follows: COD = 53÷67 gO_2/m^3 and BOD_5 = 1.7÷4.2 gO_2/m^3. The efficiency of the mechanicall treatment for COD was between 16.6 and 25.8% and for BOD_5 from 11.5 to 32.3%, while the totally efficiency for the WWTP was at the level 90.6÷91.5% for COD and 98.9÷99.5% for BOD_5.

Table 2. The organic contaminants in analyzed wastewater samples

Wastewater samples	COD, gO_2/m^3		BOD_5, gO_2/m^3		COD/BOD_5
	Non-filtred samples	Filtred samples	Non-filtred samples	Filtred samples	Non-filtred samples
P1	695.1±59.4	413.2±80.4	352.7±42.1	248.7±4.0	1.97±0.07
P2	543.8±58.3	348.7±48.0	269.0±4.6	213.0±28.2	2.02±0.23
P3	61.1±7.1	28.8±14.8	2.8±1.3	2.2±1.5	25.29±12.81

P1 – raw wastewater, P2 – wastewater after primary settling tank, P3 – treated wastewater

In accordance with the procedure for determining the COD fraction given in point 3, the concentrations of the individual fractions in the analyzed wastewater samples have been calculated. The results showing the concentrations of the individual fractions are presented in Table 3.

Table 3. COD fraction concentrations in wastewater samples

Wastewater samples	COD fractions, gO_2/m^3			
	S_I	**S_S**	X_S	**X_I**
P1	28.8±14.8	384.4±65.7	203.4±48.2	78.4±21.6
P2	28.8±14.8	319.9±34.6	128.4±34.3	66.6±47.1
P3	28.8±14.8	0.0±0.0	4.7±2.1	27.6±7.2

P1 –raw wastewater, P2 – wastewater after primary settling tank, P3 – treated wastewater

The test results shows that in raw wastewater, the most concentrated are fractions S_S and X_S. Definitely lower are the concentrations of fractions X_I and $S_{I.}$ The highest concentrations among the calculated fractions characterised the dissolved, easily biodegradable fraction S_S. In raw wastewater, its concentration was between 314 and 443 gO_2/m^3, while the X_s fraction was in range 158÷254 gO_2/m^3 and the X_I fraction was from 59 to 102 gO_2/m^3. In the mechanically treated wastewater the concentration of each fractions was at the level S_s: 298÷360 gO_2/m^3, X_s: 90÷157gO_2/m^3, X_I: 15÷107 gO_2/m^3. In the treated wastewater samples the most concentrated are fractions X_I and S_I. During the tests the lowest were the concentrations of fraction S_I from 14 to 43 gO_2/m^3. The value of this fraction did not change in subsequent purification steps of mechanical - biological treatment.

The determined percentage ratio of the individual fractions in wastewater samples are presented in Fig. 3.

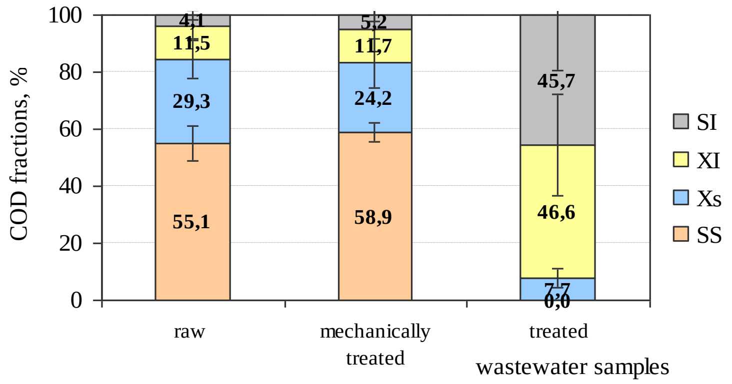

Fig. 3. The average percentage ratio of the individual fractions in total COD of analyzed wastewater samples

Among biodegradable fractions in raw wastewater, fraction S_S which characterises dissolved, easily biodegradable substances constitutes between 50.0 and 61.7 % of total COD is predominant. The ratio of fraction X_S (insoluble, slowly biodegradable fraction) in total COD of the wastewater was between 22.0 and 34.4%. The percentage content of fraction X_I was at 8.0÷16.2%. The lowest ratio, at 2.2÷6.0% in total COD of the tested raw wastewater, was that of fraction S_I. In mechanically treated wastewater samples the share of individual fractions was as follows: S_S: 55.0÷61.7%, X_S: 15.0÷32.4 %, X_I: 3.0÷17.8% and S_I 2.8÷7.2%, while in the treated wastewater was respectively: X_I=31.4÷66.3%, S_I = 25.9÷64.4% and X_S=4.2÷11.2%.

The concentration of biodegradable fractions COD(S) = S_S+X_S, constituted over 80% of total COD in raw and mechanically treated wastewater (Fig. 4).

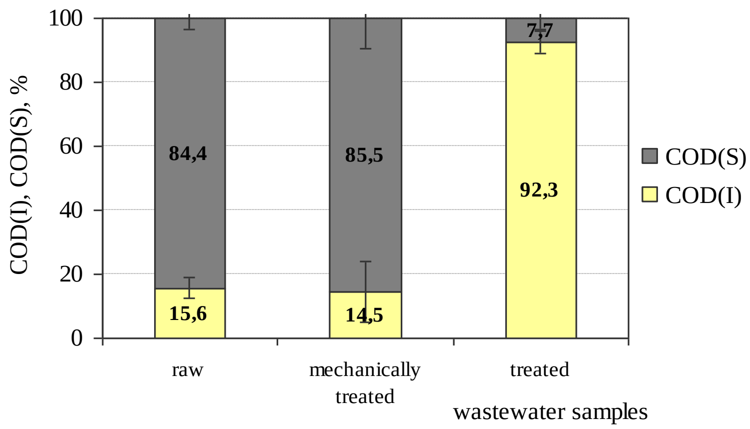

Fig. 4. The average percentage ratio of biodegradable COD(S) and non-biodegradable fractions COD (I) of analyzed wastewater samples

In treated wastewater are dominated non biodegradable fractions COD(I) at the level 88.8÷95.85%. Changes in the share of biodegradable and non-biodegradable fractions in wastewater samples, as well as COD/BOD_5 values changes (raw wastewater: about 2.0, treated wastewater over 15.0) confirm the good work of the wastewater treatment plant in terms of the removal of organic pollutants.

5. CONCLUSIONS

The presented test results are a basis for the formulation of final conclusions:

- The concentrations and percentage ratios of the individual COD fractions in raw wastewater determined in real conditions differ from the values assumed by the ASM models.
- The difference between the assumptions of the ASM1 and ASM2 models and the research results is the percentage of the X_S and S_S fractions in total COD. According to the models in raw wastewater the X_S fraction dominates (35÷75%), but the results of the research showed that in analyzed raw wastewater in the highest concentrations occur S_s fraction (50÷61.7%), then X_S (20÷34.4%), X_I and S_I fractions.
- The results of the research confirmed the assumptions in the models for the advantage of biodegradable fractions in raw wastewater, $COD(S)=S_S+X_S$, constituted over 80% of total COD.
- The share of biodegradable and non-biodegradable fractions and COD/BOD_5 values in raw and treated wastewater indicate the good work of the analyzed wastewater treatment plant.

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FRAKCJE ChZT W MECHANICZNO-BIOLOGICZNEJ OCZYSZCZALNI ŚCIEKÓW

Streszczenie

W artykule przedstawiono wyniki badań dotyczące wyznaczania frakcji ChZT w ściekach surowych, mechanicznie oczyszczonych oraz oczyszczonych. Obiektem badań była mechaniczno-biologiczna oczyszczalnia ścieków o wielkości powyżej 20 000 RLM. Uzyskane wyniki porównano z założeniami modeli biokinetycznych ASM. W badaniach wyznaczono następujące frakcje: rozpuszczone substancje organiczne, biologicznie nierozkładalne S_I, rozpuszczone substancje organiczne, biologicznie łatwo rozkładalne S_S, substancje organiczne w zawiesinie, biologicznie wolno rozkładalne X_S oraz substancje organiczne w zawiesinie, biologicznie trudno rozkładalne X_I. Metodyka wyznaczania frakcji ChZT została opracowana w oparciu o wytyczne ATV-131. Wyznaczone w badaniach wartości procentowego udziału frakcji w badanych ściekach surowych różnią się od założeń modeli ASM.

Słowa kluczowe: ścieki, frakcje ChZT, modele ASM, substancje organiczne biodegradowalne i niebiodegradowalne

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