Changes of wastewater characteristic during transport in sewers

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Abstract: The main function of sewage system is disposal of wastewater. The intercepting sewer is a part of the municipal system: water supply system, sewage network and sewage treatment plant. The fact that a sewer is a biological reactor, in which biochemical processes occur, is often disregarded. They can significantly influence the physical-chemical composition of sewage, operation of the treatment plant and the receiver. Therefore, it is necessary to change the conventional thinking which perceives that sewage treatment begins at the treatment plant, because in specific conditions, these processes begin already in the sewage system.

This article presents results of research concerning changes in the physical-chemical composition of wastewater, especially COD and nitrogen compounds divided into fractions. The data relate to the main sewage collector in town of 20000 habitants in Poland. The town has a good working combined sewage system: about 30 km of gravitational collectors and about 4 km of pressure pipes. The total length of the inspected collectors was 12,13 km. On the basis of COD and BOD values in raw and treated sewage, the "f" coefficient which determine the organic nitrogen fractions, were appointed. The largest part in TKN in raw wastewater was accounted ammonia nitrogen and biodegradable, soluble (easily amonifiable) nitrogen. Part of non-biodegradable fraction of organic nitrogen in the sewage changed slightly with their inflow to the treatment plant. On the basis of the obtained results, it was also found that regardless of the value of Kjeldahl total nitrogen concentration in sewage collected at subsequent points of the collector, values of the suspension organic fraction of nitrogen – limited biodegradation was very similar in all research series.

Key-Words: wastewater characteristic, sewers, COD and nitrogen fraction

1 Introduction

The main function of a sewerage system is reception and channelling of sewage to a treatment plant, or a receiver. Currently, more and more frequently, a sewerage systems is analysed in the context of biochemical processes which take place therein. A sewer which carries sewage to a treatment plant can be treated as a flow sewage receiver, and it can be assumed that this is where transformations the basis of which are self-purification processes, occurring in rivers, take place. Changes in the composition of sewage in sewage system can significantly influence operation of treatment plants and receivers of treated sewage [1,2,16, 26].

Transformations in sewage system, which directly influence quality of the sewage incoming into the treatment plant are, among others, hydrolysis, increase in micro-organism biomass, changes in organic substance fractions, and sedimentation.

Hydrolysis of organic compounds, increase in biomass of micro-organisms, alterations in fractions of organic substance, as well as sedimentation of suspended matters are processes which take place during transport of sewage through a sewage system, and which directly influence quality of the sewage incoming to the treatment plant. These processes occur in water environment, in deposits, bacterial jelly which form on the inside walls of a sewer, and their intensity depends, among other factors, on the type and length of the sewage system [4, 8, 17].

Due to the increasing requirements concerning quality of treated sewage, it is necessary to optimize the processes of biological removal of biogenic compounds, which require very precise characteristics of the sewage composition. Intercepting sewer is a part of the sewage collection and treatment system. Unlike other elements of this system, it is rarely considered a biochemical reactor, and is treated only as a mean of transport. Issues related to the hydraulics of sewage flow are generally known, and the knowledge of physical, chemical ad biochemical processes occurring in intercepting sewers is indeed recognised in the theoretical aspect, but empirical studies of this subject are still insufficient [10, 13, 18, 22].

Cognition and description of processes which occur in sewage system is important for both sewage system management, and for designing of the sewage treatment technology. Due to high concentration of contaminations, biochemical changes proceed slowly, and the result of purification of sewage during its transport will be determined by intensifying interference of human. Decomposition of organic compounds occurs the most intensively in oxygen environment, between the layer of bottoms and the flowing sewage. These processes cause significant decrease in sewage contamination. Both at the cellular level, and at the eco-system level, the processes of transforming organic substrates require hydrolysis of insoluble organic polymers into soluble forms, available for micro-organisms. Part of the pollutants undergo direct, biochemical oxidation into carbon dioxide and water, while the remaining fraction is assimilated in the form of increase in the living mass of the micro-organisms [6, 7, 12, 33].

Sewage transported via the sewage system contain various groups of microorganisms, the development of which depends on specific environmental conditions. Living organisms which dwell in the bottoms often manifest high metabolic activity, participating in the process of biodegradation of various organic contaminations contained not only in the deposits, but also in the sewage which flows through the system [15, 19, 32].

Chemical and biological processes in the intercepting sewers can significantly influence the composition of the sewage, particularly during rainless stretches.

In an oxygen-free environment, next to an increase in concentration of sulphur compounds, transformations of organic matter into easily-biodegradable substrates, which are a notable base of effective denitrification and biological dephosphatation, gain crucial importance. Whereas in oxygen environment, concentration of biodegradable fraction of organic biomass decreases, and heterotrophic biomass which can be effectively removed in the mechanical section of a treatment plant, increases [28, 29, 30, 31].

Municipal wastewater is mainly comprised of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Table 1 shows the levels of the major constituents of strong, medium and weak domestic wastewaters [14, 20, 21, 23, 24].

Table 1 The levels of the major constituents of strong, medium and weak domestic wastewater

Parameter	Concentration, mg/dm^3		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

As nitrogen compounds are one of the more important indexes of municipal sewage contamination, it is necessary to assess to what extent do they undergo transformations, both in the sewage system and after subsequent faculties of a treatment plant. Knowledge of the form in which sewage occur in the sewers is very important for selection of the sewage treatment technology. Thanks to such analyses, it is possible to choose appropriate methods of treatment, and increase efficiency of, e.g., nitrification and denitrification. Biological processes of removing nitrogen from sewage require presence of organic carbon in the form of biodegradable substrates and easily-hydrolysing organic substance. Share of individual forms of organic matter in sewage is usually described by means of COD fractionation. It also allows to assess the amount of non-biodegradable pollution, which decreases effectiveness of biological sewage treatment. Therefore, in designing and modelling of systems for removal of biogenic compounds, partition of general COD in raw sewage into fractions is applied. This partition also allows to calculate the part of individual forms of organic nitrogen which occur in municipal sewage. COD of sewage, divided into fractions, can be calculated in accordance with the following dependence [3, 4, 5, 9]:

$$COD = S_S + S_I + X_S + X_I \quad (1)$$

S_S – COD of dissolved organically compounds, easily biodegradable,
S_I – COD of dissolved organically compounds, non-biodegradable,
X_S– COD of biodegradable organic suspensions,
X_I – COD of organic suspensions, non-biodegradable.

Determination of the phase distribution of pollutants in the substances dissolved and suspended can be done by filtration. Depending on the type of wastewater COD the contribution of individual fractions can be very different, and the percentage of organic components in the total COD is shown in Fig. 1 [11, 14, 24, 25, 27].

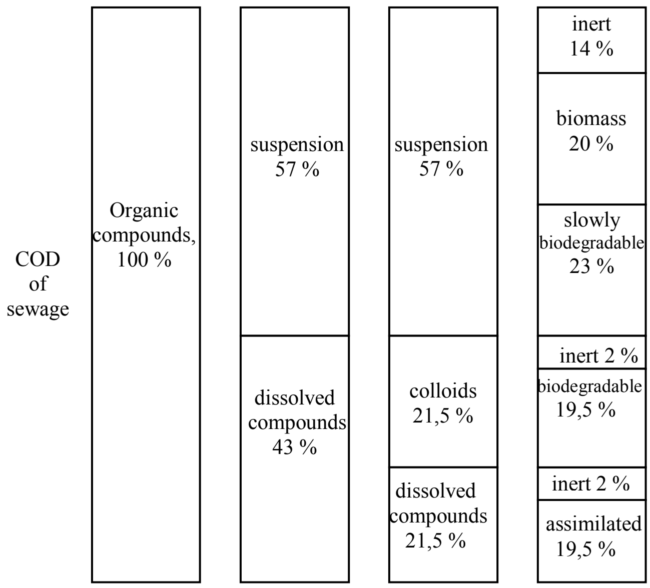

Fig.1. Percentage contribution of organic components in total COD of domestic sewage a) classical model, b) postclassical model, c) model considering the state of aggregation of organic compounds, d) model considering bio-degradability of organic compounds

The problem with determine fraction of COD, due to lack of definition, based on which one could clearly determine the distribution of pollutants in the dissolved and suspended. By some authors [14, 20, 23, 25, 27] fraction colloidal is classified like suspensions, and by others to solutes. In the case of the first division, the authors report that the percentage of suspension fractions, present in the total COD of waste water, at an average is from 65 to 79% and from 21 to 35% on dissolved.

Proponents to connect the fraction of colloids to solutes reported that the percentage of suspended solids in municipal wastewater are at an average of about 57% COD, and colloids and dissolved substances, including about 43%. Biodegradable organic compounds are represented on average 39% of all organic substances in wastewater, and not susceptible to biological degradation - about 61% [26, 27, 29].

Hypothetically assumed that the dissolved easily biodegradable fraction consists of substances that can be directly absorbed and metabolized by the organisms (eg bacteria, heterotrophic) for the synthesis and energy production. However, in order to be utilized by microorganisms, have been subject to hydrolysis.

It is assumed that the slowly biodegradable fraction, is formed of particulate material (colloidal) and complex organic molecules, which require the use of before the break, the extracellular enzymes. Like the dissolved fraction, the biodegradable suspended fraction has a strong influence on the dynamics of the activated sludge process.

It is believed that the non-biodegradable matter, dissolved and suspended, there is no change in aerobic biological wastewater treatment. Fraction X_I associated with activated sludge can be removed from the excessive sludge. However, the flocs have a limited opportunity to adsorption and not able to selectively involve only non-biodegradable substances, which reduces the elimination of such pollutants [11, 23, 25, 35]. In the activated sludge process, non-biodegradable dissolved fraction S_I leaves the system in the effluent from secondary settling tank, in a concentration equal to the inflow concentration [2].

Characteristic of nitrogen compounds in raw sewage coming into a treatment plant usually takes into account the Kiejdahl total nitrogen concentration (TKN). In some cases, significant concentration of nitrites and/or nitrates, is also recorded in municipal sewage, caused, e.g., by recirculation of sewage and returning of sedimentary liquids to the beginning of the technological system. This significantly influences designing and operation of a treatment plant. In such cases, the inflow of sewage to a treatment plant should take into account, apart from TKN, also concentrations of nitrites/nitrates.

The basic partition of TKN_{INF} in sewage includes two forms: free ammonia and ammonia salts, as well as part of nitrogen in the form of organic compounds. The organic part of TKN is initially divided into two parts: biodegradable and non-biodegradable, and further each of them is divided into dissolved fraction (N_{SS} and N_{IS} respectively), and suspension fraction (N_{SX} and N_{IX} respectively). Partition of nitrogen compounds into forms and fractions in municipal sewage is as follows [5, 14, 24]:

$$\begin{aligned} TKN_{INF} &= N_o + NH_4^+ = N_S + N_I + NH_4^+ \\ &= N_{SS} + N_{SX} + N_{IS} + N_{IX} + NH_4^+ \end{aligned} \quad (2)$$

N_o - organic nitrogen
NH_4^+ - ammonia nitrogen
N_S – biodegradable organic nitrogen
N_I – non-biodegradable organic nitrogen
N_{SS} – dissolved biodegradable organic nitrogen
N_{SX} - biodegradable organic nitrogen of suspensions
N_{IS} - dissolved non-biodegradable organic nitrogen
N_{IX} - non-biodegradable organic nitrogen of suspensions

In order to simplify calculations, all forms of nitrogen are given in gN/m^3.

2 Methods of calculation

Partition of organic nitrogen into fractions is not as easy as defining individual components of COD. The reason are difficulties in analytic designation of biodegradable and non-biodegradable nitrogen in the sewage, as well as numerous inconsistencies of adopting the dependency between COD, total suspension and organic nitrogen. As about 50 – 67% of the Kjeldahl total nitrogen is usually ammonia nitrogen, division of the remaining nitrogen into four fractions in practical dissertations is usually disregarded.

It is important to make a detailed division of nitrogen into fractions at the designing stage, because the amount of biodegradable nitrogen available for the microorganisms influences the final, total nitrogen concentration in treated sewage. Analytic indication of the dissolved fraction of nitrogen compounds is made by means of a direct measurement of ammonia nitrogen and TKN in a sample strained through 0.45 μm filter. In a non-filtered sample, TKN_{INF} is indicated (concentration of ammonia nitrogen in a strained and non-strained sample will be identical).

Hypothetically non-biodegradable fraction of organic nitrogen does not partake in biochemical transformations. Large amount of indecomposable fraction N_{IS} makes biological methods of sewage treatment ineffective [3]. In the active deposit method, fraction of organic nitrogen N_{IS} leaves the secondary settling tank with treated sewage in a concentration equal to the one of the inflow to the treatment plant. Non-biodegradable suspension fraction N_{IX} is a material connected with indecomposable part of COD (fraction X_I) in the sewage, and it leaves the system with the removed excessive sludge [24]:

$$f_{NIX} = \frac{N_{IX}}{X_I} \frac{\left(TKN_{INF} - TKN_{INF}^{0,45\mu,}\right)}{\left(COD_{INF} - COD_{INF}^{0,45\mu}\right)} \qquad (3)$$

(coefficients "f" indicate the part of individual fractions in TKN_{INF}).

The amount of organic nitrogen related in indecomposable suspension fraction is approximately lower than 1% of the Kjeldahl total nitrogen in raw sewage. Definition of dissolved, non-biodegradable fraction of organic nitrogen N_{SI} can be estimated in the basis of concentrations of ammonia nitrogen and TKN in sewage treated in the system, with complete nitrification. In a strained sample (filter 0.45 μm) of treated sewage, TKN consists of: the remaining and non-nitrifiable ammonia nitrogen, dissolved biodegradable organic nitrogen (N_{SS}), and small amounts of dissolved non-biodegradable organic nitrogen (N_{SI}) [24].

$$TKN_{EFL}^{0,45\mu,} = NH_4^+ + N_{SS} + N_{SI} \qquad (4)$$

The difference between the TKN_{EFL} $^{0,45\mu m}$ concentration and concentration of ammonia nitrogen NH_4^+ will be the sum of dissolved biodegradable and non-biodegradable organic nitrogen (N_{SS} and N_{IS}). In a sewage treatment system with full nitrification, concentration of $TKN_{EFL}^{0,45\mu m}$ should come to about 0.5 mg N/dm^3, and concentration of ammonia nitrogen should be lower than 0,1 mgN/dm^3, thus the difference which indicates dissolved organic nitrogen is 0.4 mg N/dm^3 (N_{SS} + N_{IS}). In many cases, concentration $TKN_{EFL}^{0,45\mu m}$ is higher and ranges from 3 to 5 mgN/dm^3.

Determining low concentration of ammonia acid, and assuming that the amount of dissolved biodegradable organic nitrogen is presumable still 0.4 mgN/dm^3, it should be assumed that a specific part of dissolved, indecomposable TKN is in the sewage. The described method of assessing the part of the N_{SS} + N_{IS} fraction is not particularly satisfying. Nonetheless, there is no analytical possibility of dividing nitrogen dissolved in municipal sewage into biodegradable and non-biodegradable. Concentration of these TKN fractions is usually a small part of the total TKN_{INF} (< 3%), so errors in value assessment are not very important.

Biodegradable organic nitrogen (N_S) is calculated as difference between TKN in the sewage and sum of components NH_4^+, N_{IS}, N_{IX} [6]:

$$N_S = N_{SX} + N_{SS} = TKN_{INF} - \left(NH_4^+ + N_{IS} + N_{IX}\right) \qquad (5)$$

It is hypothetically assumed that the dissolved decomposable N_{SS} fraction consists of substances which can be directly assimilated and metabolised by organisms (e.g. heterotrophic bacteria) for the purposes of photosynthesis and acquisition of energy. Yet, if they are to be adsorbed by micro-organisms, they must first undergo a hydrolysis [24]. It is assumed that the N_{SX} fraction (similarly to X_S fraction of COD), is created of molecular (colloidal) material and complex organic particles, which, prior to adsorption and utilization, must be broken by extracellular enzymes. Just like the dissolved N_{SS} fraction N_{SX} also significantly influences the sewage treatment process [23, 27]. Division of biodegradable organic nitrogen into dissolved and suspension part can be expressed using as follow [24]:

$$N_{SS} = \left(1 - f_{NSX}\right) \cdot N_S \qquad (6)$$

$$N_{SX} = f_{NSX} \cdot N_{SS} \qquad (7)$$

If the typical value of the f_{NIX} coefficient is lower than ≈ 0.1 mgN/mgChZT, calculation of f_{NSX} requires the following coefficients to be known: f_{NH}, f_{NSI}, f_{NIX}, [24]:

$$f_{NSX} = \frac{TKN_{INF} - TKN_{INF}^{0,45\mu,} - f_{NIX} \cdot f_{XI} \cdot COD_{INF}}{(1 - f_{NH_4^+} - f_{NIS}) \cdot TKN_{INF} - f_{NIX} \cdot f_{XI} \cdot COD_{INF}} \qquad (8)$$

Due to the fact that the value of f_{NIS} is usually several times lower than the value of f_{NH4}, replacing f_{NIS} = 0 in the above equation will not cause the estimate of f_{NSX} to be burdened with any significant error. If the content of total suspensions in the sewage is considerably different from the typical values, this method can incorrectly assess the value of f_{NIX}.

3 Characteristics of sewers

On the basis of field research, an attempt was made to characterize changes in the sewage composition occurring in the main receiver of sewage system which collectors of sewage from the town of 20000 habitants in Poland.

The town has a good combined sewage system: about 30 km of gravitational collectors and about 4km of pressure collectors (6 pumping stations). The distances between individual sampling points (inspection chambers) were as follows:

$$P0 \xrightarrow{4{,}6km} P1 \xrightarrow{1{,}22km} P2 \xrightarrow{1{,}61km}$$
$$P3 \xrightarrow{1{,}03km} P4 \xrightarrow{0{,}20km} P5 \xrightarrow{0{,}79km}$$
$$P6 \xrightarrow{2{,}68km} P7 = \text{sewage treatment plant}$$

The total length of the inspected interceptor was 12.13km.

Mechanical-biological wastewater treatment plant, with capacity of 6450 m^3/day, are currently taking waste in quantities about 2822 m^3/day. In the aeration bioreactor simultaneously occurring processes of nitrification, denitrification and chemical dephosphatation.

The research was performed on rainless days. In the taken sewage samples, the following indexes were determined: BOD, COD, TOC, TKN, ammonia nitrogen, nitrate nitrogen, total phosphorus, total suspension, pH, alkalinity, concentrations of heavy metals.

4 Results

In accordance with the aforementioned methodology of determining organic nitrogen fractions and calculating the "f" coefficients which specify the share of the given fraction in TKN_{INF}, division of COD of sewage into fractions is required. On the basis of the COD and BOD values marked in the sewage collected from the collector and in treated sewage, COD fractions were calculated, in accordance with methodology developed on the basis of ATV-131 guidelines [9]. An important component of COD is X_I, related to the share of organic nitrogen of non-biodegradable suspension N_{IX}. The value of X_I in COD was from 45 to 230 mgO_2/dm^3 (on average 114 mgO_2/dm^3), with total COD of the sewage ranging from 416 mgO_2/dm^3 to 1320 mgO_2/dm^3. COD of dissolved substances was from 120 mgO_2/dm^3 to 362 mgO_2/dm^3. Table 2 presents a value of fractions in the total COD of sewage during transport in sewer, determined in own studies compared with data from literature. The obtained results are comparable to data presented buy other authors.

Table 2 Fractions of total COD in wastewater during transport in sewer

Fraction	Own data (for points 1-7 series I-IV)		Kappeler and Gujer [6]	Kalinowska and Oleszkiewicz [5]	Ekama et al. [2]	Henze et al. [3]	Orhon et al. [8]
	value	aver.					
	% of total COD						
S_S	17 -44	31	10 - 20	12 - 25	20 - 25	24 - 32	9
S_I	3 – 9	4	7 - 11	8 - 10	8 - 10	8 - 11	4
X_S	32 - 59	49	53 - 60	50	60 - 65	43 - 49	77
X_I	11 - 19	17	7 - 15	15	5 - 7	11 - 20	10

Changes in concentrations of nitrogen forms in wastewater at subsequent points of the collector are presented in table 3.

Table 3 Nitrogen forms in wastewater

measuring point	1	2	3	4	5	6	7
TKN	70,0	63,0	66,5	80,5	84,0	94,5	96,0
(non-filtered sample)	98,5	97,0	94,3	87,5	98,0	98,3	119,0
mg N/dm^3	70,0	67,4	70,0	80,5	69,6	73,5	91,0
	84,0	58,8	75,6	72,8	67,2	75,6	120,0
average value	**80,6**±13,6	**71,6**±17,3	**76,6**±12,4	**80,3**±6,0	**79,7**±14,3	**85,5**±12,7	**106,5**±15,2
TKN	64,4	44,8	58,8	61,6	58,8	70,0	95,0
(filtered sample)	58,8	47,6	56,0	61,6	70,0	67,2	70,0
mg N/dm^3	75,3	70,0	66,5	63,0	78,8	70,0	92,3
	60,2	56,0	61,6	70,0	58,4	63,0	70,0
average value	**64,7**±7,5	**54,6**±11,3	**60,7**±4,5	**64,1**±4,0	**66,5**±9,8	**67,6**±3,3	**81,8**±13,7
ammonia nitrogen	31,8	21,3	24,7	30,4	26,2	31,5	32,0
mg N/dm^3	41,6	36,6	38,1	51,9	52,2	51,3	52,0
	40,8	50,0	40,3	38,5	41,5	43,8	44,4
	41,1	40,8	45,9	52,3	41,1	46,4	46,6
average value	**38,8**±4,7	**37,1**±12,0	**37,3**±9,0	**43,3**±10,7	**40,2**±10,7	**43,2**±8,4	**43,8**±8,5

Average concentration of Kjeldahl total nitrogen for samples taken at measuring points form 1 to 7 was from 75 mgN/dm^3 (series IV) to 98 mgN/dm^3 (series III) (Fig. 2-5). Average concentration of ammonia nitrogen was below 44 mg $N\text{-}NH_4/dm^3$. Concentration of nitrate nitrogen in the tested sewage was between 0.13 and 0.89 mg $N\text{-}NO_3/dm^3$, and it was omitted in the total nitrogen balance. In sewage collected at subsequent points of the collector, the ammonia nitrogen constituted from 27 to 66% of the Kjeldahl total nitrogen. Regardless of the series and point of sampling, the greatest dynamics was displayed by transformation of ammonia nitrogen and the N_{SS} fraction.

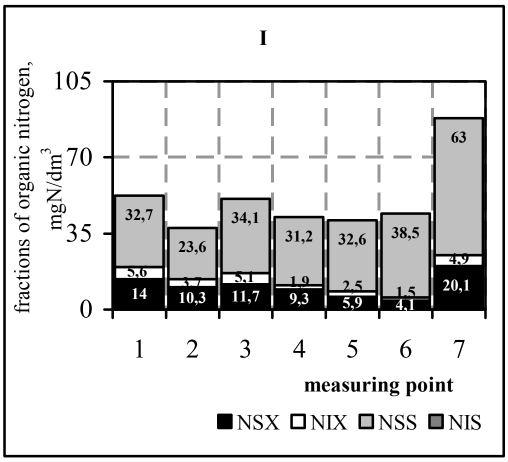

Fig. 2 Fractions of organic nitrogen (N_{SX}, N_{IX}, N_{SS}, N_{IS}) in sewage in series I

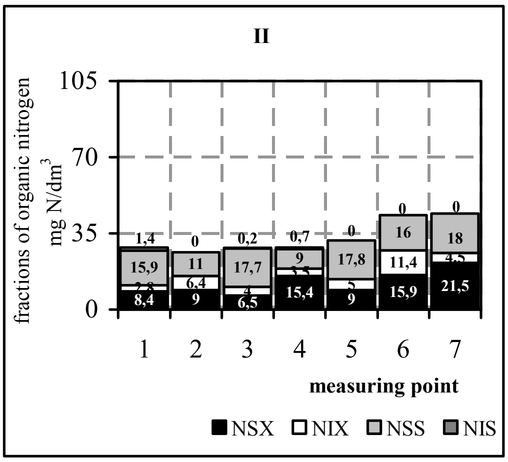

Fig. 3 Fractions of organic nitrogen (N_{SX}, N_{IX}, N_{SS}, N_{IS}) in sewage in series II

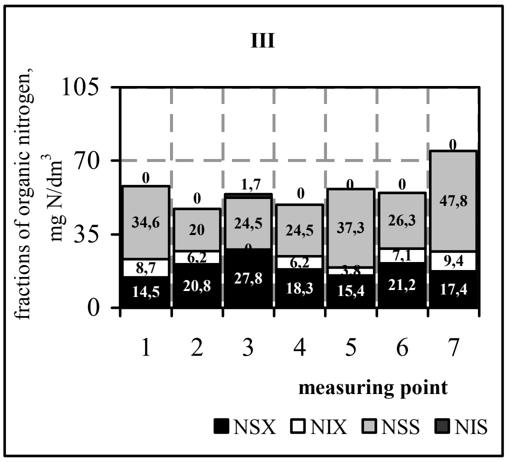

Fig. 4 Fractions of organic nitrogen (N_{SX}, N_{IX}, N_{SS}, N_{IS}) in sewage in series III

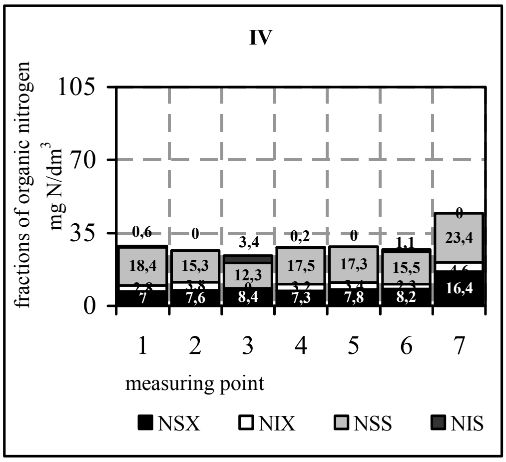

Fig. 5 Fractions of organic nitrogen (N_{SX}, N_{IX}, N_{SS}, N_{IS}) in sewage in series IV

The sum of ammonia nitrogen and biodegradable dissolved fraction of organic nitrogen ($\sum NH_4^+$ and N_{SS}) predominated in the sewage and ranged from 69 to 93% (on average 80%).

Whereas the share of non-biodegradable fraction of organic nitrogen was low, and, for N_{IX}, it came to 5% on average. On the basis of chemical analyses and calculations, it was found that in most sewage samples there is no N_{IS} fraction. The average value of this fraction's share in TKN was 0,4% (up to 5%, for sample 3, series IV). Analysing changes in concentration and share of individual fractions in the sewage during its flow through the sewage system, a share of biologically decomposable organic nitrogen bounded in the N_{SX} suspension – almost constant for every series – was found (on average 15%).

5 Summary

The research of changes in the composition if sewage in the main interceptor of sewage network demonstrated that:

1. Ammonia nitrogen and biodegradable, soluble (easily amonifiable) nitrogen (NH_4^+ and N_{SS}) have the largest share in TKN_{INF}. These forms determine effectiveness of removing nitrogen compounds from sewage using the biological method.
2. Part of non-biodegradable fraction of organic nitrogen in the sewage changed slightly with their inflow to the treatment plant. The conducted computational simulations demonstrate that in the studied sewage, the fraction related in the suspension is dominating.
3. On the basis of the obtained results, it was also found that regardless of the value of Kjeldahl total nitrogen concentration (and various concentrations of the total suspension) in sewage collected at subsequent points of the collector, the part of organic nitrogen fraction related in biodegradable suspension was very similar in all series of the research.
4. In each of the four research series, the share of dissolved organic nitrogen in relation to the suspension fraction was different at subsequent sampling points (1-6), whereas at point 7 (inlet to the treatment plant) was comparable (about 23%).

Assessment of changes in the composition of sewage collected directly from the interceptor depends on numerous external factors connected with: time of sampling, time of the day, day of the week (unevenness of water consumption) and it requires ling-term research. The presented results and interpretation thereof should be treated as preliminary and demonstrative. A detailed description of changes in the sewage composition during transportation via sewage system requires extending the scope (e.g. by studies of the bottoms) and continuation of field studies.

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