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Original Research Article

THE EFFICIENCY OF NITROGEN COMPOUNDS REMOVAL IN WASTEWATER TREATMENT PLANT

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Abstract

In sewage treatment plants for removing nitrogen compounds are used biological processes of nitrification and denitrification. The parameters determining the efficiency of biological processes of nitrogen removal are organic carbon ratio (BOD_5) to total Kjeldahl nitrogen (TKN), temperature and pH. The impact of these parameters on the operation of the sewage treatment plant with an RLM of 45,000 based on operational data from the period 2011-2013 has been assessed. The efficiency of removing nitrogen compounds from sewage in the analysed treatment plant depended on the temperature of sewage and the quotient BOD_5/TKN. Even at the optimal ranges of BOD_5/TKN ratio temperature at 10°C nitrogen concentration in the treated wastewater was about 3 times higher than the limit value, and the removal efficiency of nitrogen varied between about 30 to 60%.

Keywords: nitrogen removal, BOD_5/TKN ratio, wastewater temperature

1. INTRODUCTION

Achieving stable conditions for effective biological removal of nitrogen and phosphorus from municipal wastewater is an important and difficult task of operating. While the efficiency of removal of phosphorus from wastewater

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successfully may be assisted chemical precipitation, in the case of removal of nitrogen compounds to obtain normalized concentrations in treating wastewater requires continuous control and an intensification of biological processes. In wastewater treatment, nitrification occurs in technical systems, low load and denitrification systems at high load. These processes, therefore, require different environmental conditions: aerobic for nitrification and anaerobic - for denitrification introduced into the technological system of treatment - for denitrification or anaerobic-aerobic conditions for biological phosphorus removal [2, 7].

In a mixed population of nitrification bacteria and heterotrophic growth rate of nitrifying bacteria besides concentration of ammonia nitrogen and dissolved oxygen also influenced other factors.

The most important include the ratio of organic carbon (BOD_5) to Total Kjeldahl Nitrogen (TKN) and the temperature and pH of the environment. The dependence between the number of nitrifying bacteria in the biomass sludge, and the ratio of BOD_5/TKN is shown in Table 1 [7].

Table 1. The relationship between the share of nitrification bacteria in the biomass sludge, and the ratio of BOD_5/TKN

BOD_5/TKN	The share of nitrifying bacteria	BOD_5/TKN	The share of nitrifying bacteria
0.5	0.35	5	0.054
1	0.21	6	0.043
2	0.12	7	0.037
3	0.083	8	0.033
4	0.064	9	0.029

The value of the ratio of BOD_5/TKN is larger the share of nitrifying bacteria in a mixed population of activated sludge are smaller. The ratio of BOD_5/TKN located in the range of 0.5 to 3 is a typical value for nitrification by the nitrifying bacteria share of the total biomass in the range of 0.35-0.083 (Table 1). When the wastewater treatment system occurs oxidation of organic carbon and ammonium nitrogen then the ratio of BOD_5/TKN is usually greater than 5 and the proportion of nitryfikatorów is less than 5.4%.

Temperature has a significant effect on the rate of nitrification [2, 3, 8]. Along with its decline, the rate of nitrification also decreases. From temperature change depends on both the value of the maximum growth rate of nitrification bacteria K_N max and the value of the constant Michaelis-Menten for ammonia nitrogen K_N.

Significant effect on the nitrification has also a pH value optimal for which nitrification process is in the range 7.2-9.0.

The efficiency of nitrogen removal from wastewater is often limited by the unsatisfactory efficiency of the denitrification process, which in turn is associated with a low content of readily assimilable organic substrates in the influent wastewater. The process of denitrification takes place without disruptions when the ratio of $BOD_5/N\text{-}NO_3$ is greater than 3.5 and BOD_5/TKN in the range of 3.5-5 [2,7,8]. At lower values of this ratio, it is necessary to add to the wastewater, organic compounds, and then denitrification are carried out with an external carbon source. As an external carbon source can be used as methanol, ethanol, acetic acid, organic acids, sewage, brewer sugar wastewater, etc.; In which the ratio of BOD_5 of total nitrogen is relatively large. Easily to obtain the carbon source in the wastewater treatment are volatile fatty acids (VFA), which can be produced in acid fermentation of initial or excessive sludge. The unfavourable share of organic carbon to nitrogen is currently frequently appearing problem in wastewater treatment plants.

If denitrification is not going well, despite the appropriate values of the ratio C/N, the limiting factor in this process may be a degree of internal recirculation (recycling the $N\text{-}NO_3$) and wastewater temperature. The optimum temperature for denitrification is 20°C, and with its reduction, the efficiency of denitrification decreases. At temperatures below 5°C, the rate of denitrification is approx. 20% of the rate achieved at 20°C. Apart from temperature, factor influencing the degree of denitrification, is pH, which optimal value should be within the range 6.5-7.5.

The process is rapidly inhibited if the pH falls to a value below pH 6.0 or pH value exceeds 8.0.

The presence of oxygen inhibits the denitrification process. If the wastewater is dissolved oxygen, it becomes an electron acceptor instead of nitrates, as the rate of nitrate reduction by microorganisms is less than the rate of aerobic respiration of the cells. Therefore, the oxygen concentration in the biological reactor should not exceed 0.5 gO_2/m^3. Factors that influence favourably the process of denitrification is [1, 8, 9, 10]:

- The ratio of nitrogen to BOD_5 in the supply of less than 0.2,
- No pre-settler (if permitted by the treatment system) or the short duration of the pre-sedimentation (e.g. 20 minutes in dry weather),
- High ratio of BOD_5 after filtration to total BOD_5,
- Pre-acidification wastewater,
- Alignment of the concentrations and amounts of supply. Factors influencing negatively on the process of denitrification (because, for example, they reduce the necessary BOD_5 value) are [1,8]:
- A large share of random water supply and sewage general-navigable,

- Reduction of the concentration of rapidly decaying fraction BOD_5 in the sewage system,
- Long retention time in the initial settlers, without pre-acidification
- Pre-precipitation,
- The ratio of nitrogen to BOD_5 at the inlet greater than 0.3,
- Low quotient BOD_5 after filtration to BOD_5 total,
- Bringing oxygen into the denitrification
- Different timelines of the content of organic compounds (BOD_5) and nitrogen in inflow.

The paper presents the assessment of the mechanical and biological efficiency of sewage treatment plants with the capacity of Q=6,000 m^3/d and the equivalent number of inhabitants of PE = 45,000 based on operational data from the period 2011-2013 The analysis included both the removal of organic compounds and nutrients from wastewater, with particular emphasis on the impact of temperature and the ratio of BOD_5/TKN.

2. CHARACTERISTICS OF WASTEWATER TREATMENT PLANT

The analysed sewage treatment plant was built in the 70s as a mechanical treatment, whose main feature was the settler Imhoff. In 2001-2003, the treatment plant was thoroughly modernized and now she works in technology, mechanical-biological treatment of waste water with the chemical precipitation of phosphorus. Continued treatment technology consists of the following features:

- Grille dense stepped,
- Expansion chamber,
- Grit has blown PISTA,
- Primary settling tank — settler Imhoff,
- Chamber phosphorus removal,
- Aeration activated sludge with simultaneous nitrification and denitrification and chemical precipitation of phosphorus,
- Secondary sedimentation tank, radial,
- Installation of dewatering sludge press sieve-belt.

The wastewater flowing into wastewater treatment come from households, public facilities, industrial waste from the food industry, wood and metal and from the vacuum trucks [5]. The wastewater treatment plant has been designed to yield: Q = 6,000 m^3/d and Q_{max} = 720 m^3/d.
According to the Regulation of the Minister of the Environment of November 18, 2014 treated wastewater should be to the following levels [6]:

- BOD_5 15.0 mg O_2/dm^3
- COD 125.0 mg O_2/dm^3
- TKN 15.0 mg N/dm^3
- Phosphorus 2.0 mg P/dm^3
- TSS 35.0 mg/dm^3

The share of wastewater from the vacuum trucks in the whole volume wastewater flowing into the sewage treatment plant in 2011-2013 ranged from 0.8 to 4.0%, and industrial waste water from 4.4 to 11.0% [5]. The average amount of wastewater fed to the treatment plant during the analysed period was 3720 m^3 /d, which represents 62.5% of the designed capacity of the Wastewater treatment plant.

3. RESULTS AND DISCUSSION

3.1. Evaluation of wastewater treatment plants

The amount of raw sewage flowing into the treatment plant in 2011-2013 (Fig. 1) Were variations over time. The sharp increase was recorded during periods of intense rainfall (July) and snowmelt (March). The biggest irregularity of the amount of wastewater flowing into the treatment plant was observed in 2013.

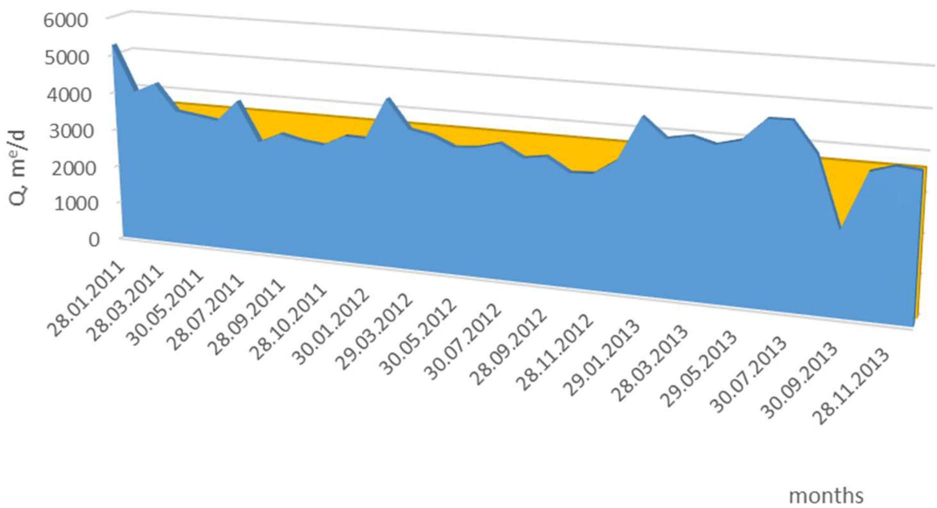

Fig. 1. Changes in the amount of wastewater flowing into the treatment plant in the period 2011-2013

Water infiltration into drains caused a dilution of wastewater and reduction of concentrations of pollutants flowing into the treatment plant. Changes in concentration of organic compounds (BOD_5, COD), and suspension and biogens depending on the amount of wastewater are shown in turn in fig. 2-4.

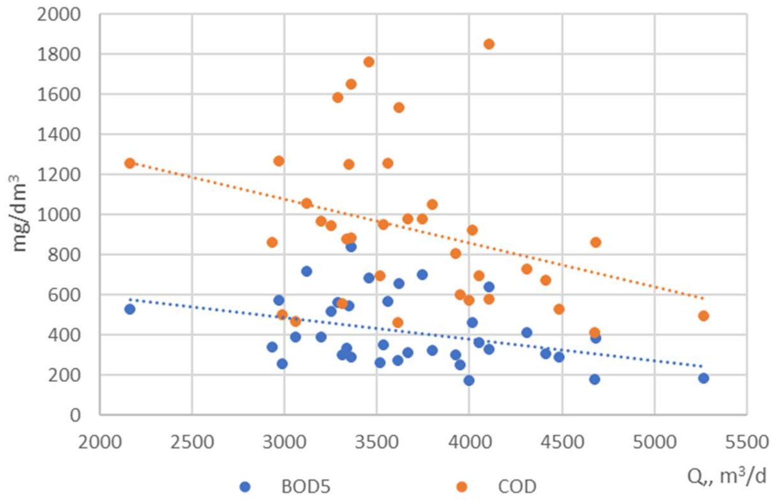

Fig. 2. The relationship between the concentration of organic compounds, and the amount of inflowing sewage in the years 2011-2013

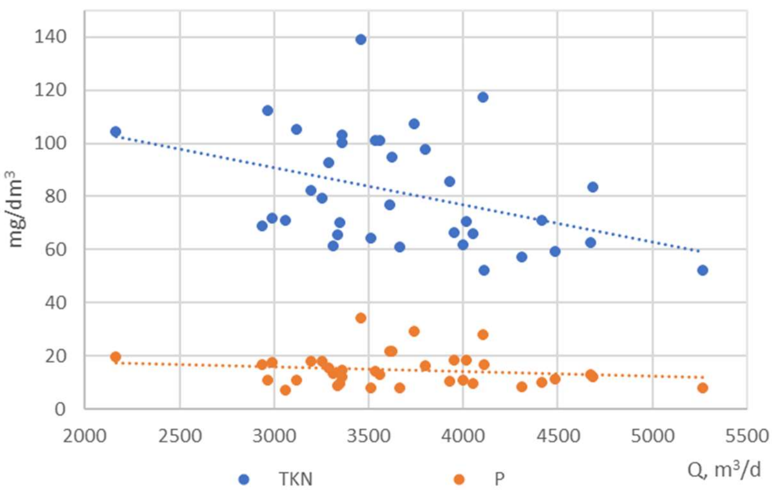

Fig. 3. The relationship between the concentration of nitrogen and phosphorus, and the amount of inflowing sewage in the years 2011-2013

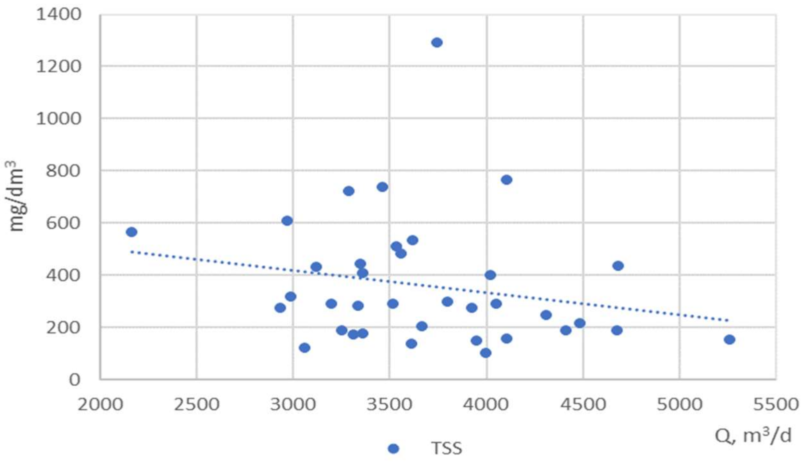

Fig. 4. The relationship between the concentration of the suspension and the amount of inflowing sewage in the years 2011-2013

The processes of biological wastewater treatment do not provide stable concentrations of total nitrogen in treating wastewater. Concentrations of nitrogen compounds oscillated in the range of 5.7 to 47.3 mg /dm^3. Exceeding the limit value of 15 mg/dm^3 occurred primarily during periods of low temperatures (Table 2).

3.2. Assessment of nitrification and denitrification process

In the wastewater treatment plant processes of nitrification and denitrification take place simultaneously in the ditch biological. The parameters for assessing the wastewater biological processes are summarized in Table 2.

The concentrations of total nitrogen in the raw wastewater ranged from 51.9 to 139.0 mg/dm^3, the removal efficiency of 33.4 to 94.7%. The values of the ratio COD/BOD$_5$ in raw sewage oscillated between 1.2 and 3.4.

In the 50% of cases the ratio of COD/BOD$_5$ was below 2.2 what qualifies sewage to easily degradable.

The values of the ratio of BOD$_5$/TKN changed in the range of 2.7 to 8.1. High values of this ratio (>3) lead to a reduction in the efficiency of the nitrification process associated with the decrease of the nitrifying bacteria in the microbial population (Table 1). The values of the ratio beyond the scope of 3.5-5 [2] indicate that the wastewater conditions are not fulfilled for classical denitrification. The pH values of the raw wastewater varied in the range 7.2-9 for nitrification, and exceed the scope 6.5–7.5 for denitrification. Temperature of raw sewage depending on the time of year ranged from 8.4 to 22.2 °C.

Table 2. Parameters of sewage and removal efficiency of nitrogen compounds

Date	TKN in raw wastewater, mg/dm^3	TKN in treated wastewater, mg/dm^3	Efficiency of nitrogen removal, %	COD/BOD_5	BOD_5/TKN	pH	Tem., °C
28.01.11	51.9	16.3	68.6	2.7	3.4	7.8	10.2
28.02.11	65.8	24.3	63.1	1.9	5.4	8.1	8.4
28.03.11	57.0	18.6	67.4	1.8	7.2	7.8	11.4
28.04.11	76.8	14.8	80.7	1.7	3.5	7.8	16.8
30.05.11	101.0	12.9	87.2	2.7	3.5	7.8	19.0
28.06.11	139.0	12.8	90.8	2.6	4.9	7.7	21.0
28.07.11	70.3	10.9	84.5	2.0	6.5	7.6	20.7
28.08.11	71.5	11.3	84.2	2.0	3.5	7.6	22.2
28.09.11	79.2	12.0	84.8	1.8	6.5	7.6	20.3
28.10.11	105.0	15.5	85.2	1.5	6.8	7.4	16.2
28.11.11	70.7	13.7	80.6	1.2	5.5	8.4	12.8
22.12.11	70.1	8.6	87.7	2.3	7.7	7.1	11.4
30.01.12	65.3	36.1	44.7	2.6	5.1	7.7	9.5
28.02.12	71.0	47.3	33.4	2.2	4.3	7.7	9.7
29.03.12	60.8	15.6	74.3	3.1	5.1	7.4	13.9
26.04.12	101.0	13.9	86.2	2.2	5.6	7.5	15.3
30.05.12	61.4	9.1	85.2	1.9	4.8	7.8	19.8
28.06.12	100.0	12.1	87.9	3.0	2.9	7.4	19.5
30.07.12	64.2	8.0	87.5	2.6	4.1	7.6	23.0
29.08.12	82.1	17.7	78.4	2.5	4.7	7.7	21.9
28.09.12	92.7	10.7	88.5	2.8	6.0	7.5	19.6
29.10.12	68.8	7.3	89.4	2.5	4.9	7.6	15.5
28.11.12	112.0	13.9	87.6	2.2	5.1	7.5	14.0
20.12.12	103.0	16.5	84.0	2.0	8.1	7.1	11.9
29.01.13	59.0	25.8	56.3	1.8	4.8	7.5	9.7
28.02.13	61.6	23.6	61.7	3.4	2.7	7.7	9.8
28.03.13	52.2	23.2	55.6	1.8	6.2	7.6	10.5
29.04.13	66.2	8.7	86.8	2.4	3.7	7.5	16.1
29.05.13	117.0	7.8	93.3	2.9	5.4	7.3	15.9
28.06.13	62.6	12.8	79.6	2.3	2.8	7.6	17.9
30.07.13	83.3	7.1	91.5	2.3	4.6	7.6	20.8
29.0813	85.5	11.8	86.2	2.7	3.5	7.1	20.2
30.09.13	104.0	17.0	83.7	2.4	5.0	7.6	18.5
30.10.13	94.4	13.0	86.2	2.3	6.9	7.8	18.0
28.11.13	97.3	14.2	85.4	3.3	3.3	9.0	14.8
20.12.13	107.0	5.7	94.7	1.4	6.5	6.5	13.1

When analysing the correlation between the concentrations of total nitrogen in treating wastewater and the ratio of BOD_5/TKN, and the temperature it was found that the effectiveness of nitrogen removal was primarily determined by the temperature of wastewater (Fig. 5-8).

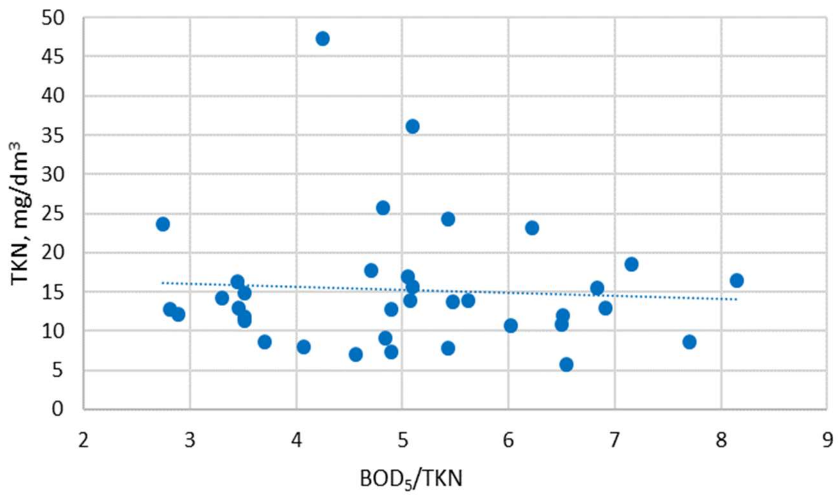

Fig. 5. The relationship between the nitrogen concentration of the treated wastewater and the ratio of BOD_5/TKN

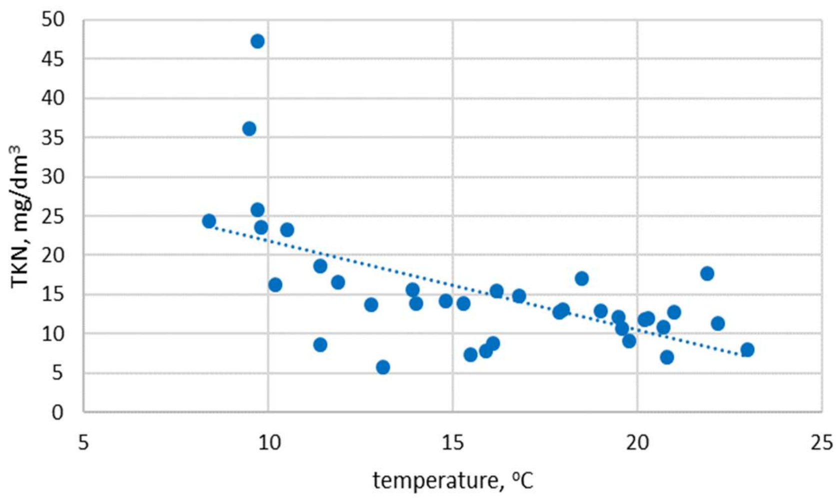

Fig. 6. The relationship between the nitrogen concentration and the temperature of the treated wastewater

The data shown in Fig. 6 confirm that with increasing temperature have reduced the concentration of nitrogen in the treated wastewater. At temperatures below

10°C is not achieved effective process of denitrification, which confirms the increase in the concentration of nitrogen in treated wastewater (Fig. 6) and a decrease the efficiency of nitrogen removal (Fig. 7).

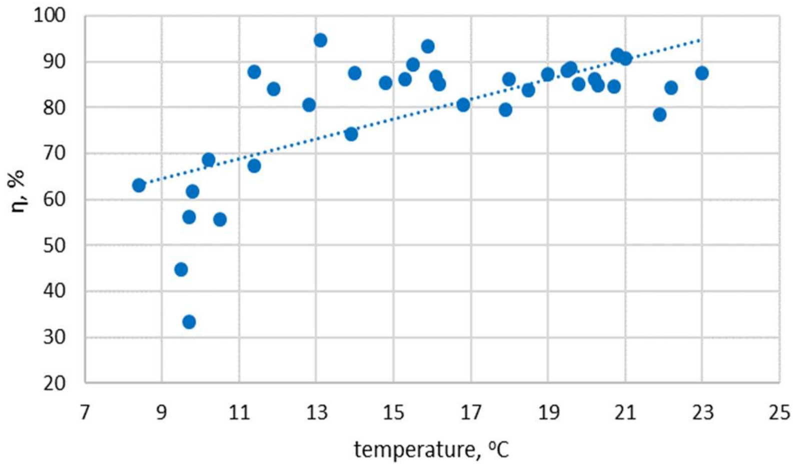

Fig. 7. The relationship between the efficiency of nitrogen removal and the temperature

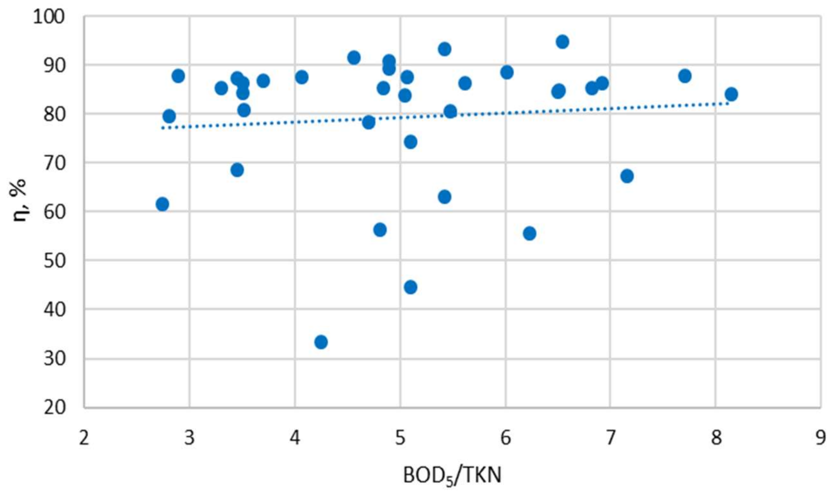

Fig. 8. The relationship between the efficiency of nitrogen removal
and the quotient of BOD_5/TKN

Statistical evaluation of the relationship between the efficiency of removal of nitrogen and the ratio of BOD_5/TKN (Fig. 8) Indicates a high fluctuation of the

efficiency of total nitrogen removal from wastewater in the range from 30 to > 90% for various values of the ratio of BOD_5/TKN.
Even at the optimal ranges of BOD_5/TKN at temperature under 10°C nitrogen concentration in the treated wastewater was even about 3 times higher than the limit value (Table 2) and nitrogen removal efficiency was in the range of 30 to about 60% (Fig. 8).

4. CONCLUSION

Analysis of effluent treatment work has shown that:

- Wastewater treatment plant varying load of pollution caused by the inflow of water infiltration, especially in periods of rainfall and snowmelt spring,
- A technological, mechanical-biological treatment provides high-efficient removal from wastewater organic compounds and throughout the analysed period, the value of BOD_5 and COD in treating wastewater does not exceed the limit values for this type of treatment,
- High efficiency removal of phosphorus from wastewater is achieved through the use of the chemical precipitation process,
- Efficiency of removal of nitrogen compounds was variable in time and depends on the temperature of sewage and the ratio of BOD_5/TKN.

Even at the optimal ranges of BOD_5/TKN at temperature under the 10°C nitrogen concentration in the treated wastewater was even about 3 times higher than the limit value and nitrogen removal efficiency were in the range of 30 to about 60%. The variable ratio BOD_5/TKN in the range of 2.7 to 8.1 affected the efficiency of both the nitrification and denitrification.

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OCENA EFEKTYWNOŚCI PRACY OCZYSZCZALNI ŚCIEKÓW O RLM 45 000

Streszczenie

W oczyszczalniach mechaniczno-biologicznych do usuwania związków azotu wykorzystuje się biologiczne procesy nitryfikacji i denitryfikacji. Usuwanie fosforu odbywa się przy wykorzystaniu metod biologicznych lub chemicznych. Sprawność procesów biologicznych wymaga odmiennych warunków środowiskowych tzn. tlenowych dla nitryfikacji, a beztlenowych dla denitryfikacji, czy tez warunków beztlenowo-tlenowych dla defosfatacji biologicznej. Parametrami decydującymi o sprawności procesów biologicznych usuwania azotu są: stosunek węgla organicznego (BZT_5) do ogólnego azotu Kjeldahla (TKN), temperatura i odczyn środowiska. Wpływ tych parametrów na pracę oczyszczalni o RLM 45 000 oceniono na podstawie danych eksploatacyjnych z okresu 2011-2013. Efektywność usuwania związków azotu ze ścieków w analizowanej oczyszczalni zależała od temperatury ścieków oraz ilorazu BZT_5/TKN Zmienne wartości ilorazu BZT_5/TKN w zakresie od 2,7 do 8,1, wpływały na uzyskiwaną efektywność zarówno procesu nitryfikacji, jak i denitryfikacji. Nawet przy optymalnych zakresach BZT_5/TKN w temperaturze poniżej 10°C stężenia azotu w ściekach oczyszczonych były nawet o około 3-krotnie wyższe od wartości dopuszczalnej, ze sprawnością usuwania azotu w zakresie od 30 do 60%.

Słowa kluczowe: usuwanie związków azotu, BZT_5/TKN, temperatura ścieków

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