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The Influence of an External Waste Carbon Source on the Rate of Changes in Pollutant Concentrations During Wastewater Treatment

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1. Indroduction

Carbon sources may come from wastewater flowing into the treatment plant or may be supplied as additional external carbon sources added to the treatment system. These sources are divided into internal (present in wastewater), endogenous (produced in activated sludge chambers as a result of biomass decomposition) and external (absent in wastewater) (Mąkinia et al. 2008, Smyk & Ignatowicz 2017, Cherchi et al. 2009). Internal carbon sources refer to organic carbon substrates obtained both in the sewage system (as an organic load of introduced sewage) or produced and stored in cells, also called endogenous carbon sources (Min et al. 2002, Elefsiciotis & Li 2006, Fernandeaz-Nava et al. 2010).

One of the initial stages of the activities related to the possibility of using alternative carbon sources in the denitrification process is the screening of available waste products due to the high COD/N ratio and high content of easily decomposable organic compounds. The main consideration is given to post-production wastewater, waste and semi-finished products such as starch syrup, glucose, molasses, beet pulp, raw spirit or Fusel alcohol (Mąkinia et al. 2008, Kalinowska 2006, Yang et al. 2012, Tora et al. 2011, Silva et al. 2009, Bernat et al. 2016 Dąbrowski & Puchlik 2010).

Molasses is produced as a by-product of the sugar industry and used in the distillery industry. Molasses is a malleable brown liquid. The substance has a characteristic smell and a bittersweet taste. Molasses contains about 48-50% sucrose (Arshad et al. 2008, Silva et al. 2009, Smyk & Ignatowicz 2017). The main component of molasses, i.e. polysaccharides, contains long chains that prevent rapid use of this substrate by denitrifying bacteria, therefore it is recommended that molasses be hydrolysed to convert it into simpler compounds such as glucose, sucrose and fructose (Ignatowicz et al. 2011, Janczukowicz & Rodziewicz 2013, Janczukowicz et al. 2011).

The aim of the research was to confirm the effectiveness of the use of waste products, in the example of molasses, in the denitrification process, as well as to determine their influence on the rate of changes in pollutant concentrations during wastewater treatment.

2. Testing methodology

The research was carried out in two SBR reactors with activated sludge supplied by mechanically treated municipal wastewater. (Smyk & Ignatowicz 2017, Smyk et al. 2019) The active capacity was 13 dm^3, of which 8 dm^3 was activated sludge. A single reactor cycle lasted 6 hours and included the following phases: wastewater supply (2 min), mixing (anaerobic) (60 min), aeration (210 min), sedimentation (60 min) and decantation (30 min). During the aeration phase, compressed air was fed through a diffuser placed at the bottom of the rector. Depending on the phase of work, from 0.1 to 2.0 mg O_2 /dm^3, active sludge concentration 3.5 kg/m^3, sludge index ranged from 120-180 cm^3/g, hydraulic load of the chamber was 1.5 m^3/m^3d and load of organic pollutants 0.2-0.3 kg COD/m^3d.

An external source of carbon was added to one of the chambers twenty minutes after filling the sewage. The dose was calculated with the amount and composition of raw sewage taken into account, assuming the COD/N ratio was equal to 6. The sewage samples were subjected to filtration immediately after collection. During filtration, the samples were measured in accordance with the current methodology (Smyk et al. 2019, Puchlik et al. 2015, Ignatowicz & Puchlik 2011):

- COD – dichromate method as per PN-74/C-04578.03 standard,
- BOD – manometric method of OxiTop Standard system,
- $N\text{-}NH_4$ – spectrophotometric method according to PN-ISO 7150-1:2002,
- $N\text{-}NO_3$ – spectrophotometric method according to PN-82/C-04576/08,
- N tot. – Spectrophotometric method according to PN-EN ISO 6878:2006,
- P tot. – Spectrophotometric method according to PN-C-04576-00:1973P.

On the basis of the results obtained, the rate of removal of individual pollutants from waste water during the process phases of SBR reactors (anaerobic denitrification phase and aerobic nitrification phase) was determined using the formula:

$$r_v = \frac{A-B}{T}\left[\frac{mg}{dm^3 \cdot h}\right]$$

where:
A – value/concentration at the beginning of the process phase [mg/dm^3],
B – value/concentration at the end of the process phase [mg/dm^3],
T – process phase lengh [h].

The nitrate utilization rate NUR was also determined from the formula:

$$NUR = \frac{S_{N-NO3,t1} - S_{N-NO3,t2}}{\Delta t}\left[\frac{mg\ N - NO_3}{dm^3 \cdot h}\right]$$

where:
S_(N-NO3,t) – nitrate nitrogen concentration at t [mg N/dm^3],
Δt – measurement time [h].

The phosphorus release rate PRR was determined based on the formula:

$$PRR = \frac{S_{P,t2} - S_{P,t1}}{\Delta t}\left[\frac{mg\ P}{dm^3 \cdot h}\right]$$

The phosphorus uptake rate PUR based on the formula:

$$PUR = \frac{S_{P,t1} - S_{P,t2}}{\Delta t}\left[\frac{mg\ P}{dm^3 \cdot h}\right]$$

where:
S_(P,t) – concentration of phosphorus at time t [mg P/dm^3],
Δt – measurement time [h].

3. Results and Interpretation of tests

The COD/Nog ratio in municipal sewage was 7.2 on average (Fig. 1). Filling the reactors with sewage and a twenty-minute process of wastewater mixing resulted in a lower COD/Nog ratio - the value ranged from 4.2 to 4.4. According to the literature data, denitrification has been conducted when the COD/Nog ratio is from 5 to 10. A lower value indicates the necessity of introducing an external carbon source into the sewage (Elefsioris & Li 2006, Smyk et al. 2019, Janczukowicz & Rodziewicz 2013). The addition of external carbon sources to the SBR reactors increased the COD/Nog ratio – during the denitrification phase. The ratio gradually increased to its highest value of 6.3 in the reactor with the addition of molasses at the end of the anaerobic phase. This ensured the correct course of denitrification. During the anaerobic phase, the COD/Nog relationship ranged from 2.0 to 4.7.

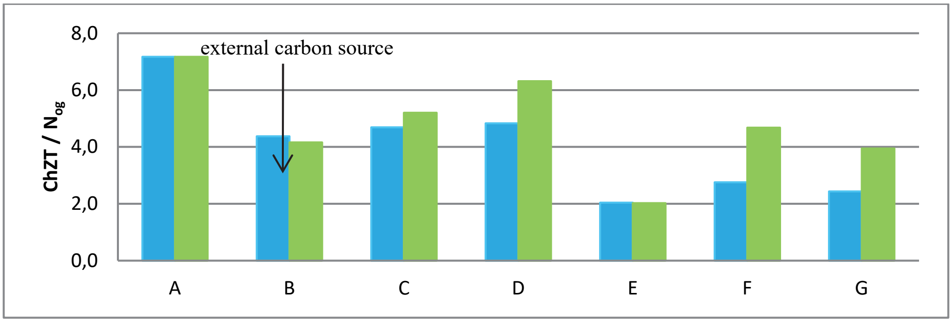

Fig. 1. Comparison of COD to total nitrogen at individual control points

During the anaerobic phase of wastewater treatment, the removal of organic compounds referred to as COD took place only in a control reactor (Fig. 2). The reason for this was the dosage of an external carbon source to a second reactor to increase the amount of organic compounds. During the processes of mixing and aeration of wastewater in the reactors, a decrease in the value of organic compounds referred to as COD was recorded (Fig. 3). In the reactor where molasses was introduced, the removal rate of organic matter measured as COD was found to be higher than in the control reactor. This rate was 61.43 mg COD/dm^{3}h (17.55 mg COD/g_{dm}h) and in the control reactor 54.86 mg COD/dm^{3}h (15.67 mg COD/g_{dm}h).

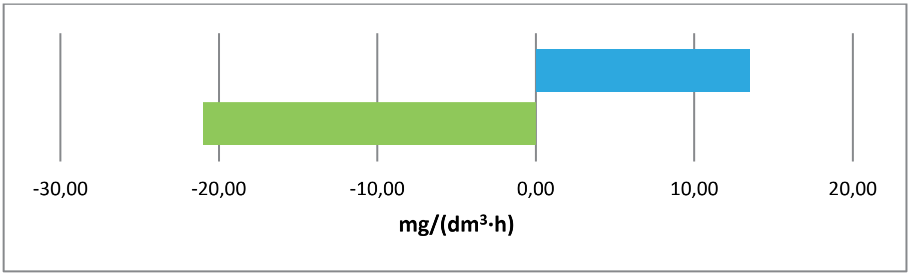

Fig. 2. Average removal rate of organic compounds, referred to as COD, during the anaerobic phase in SBRs

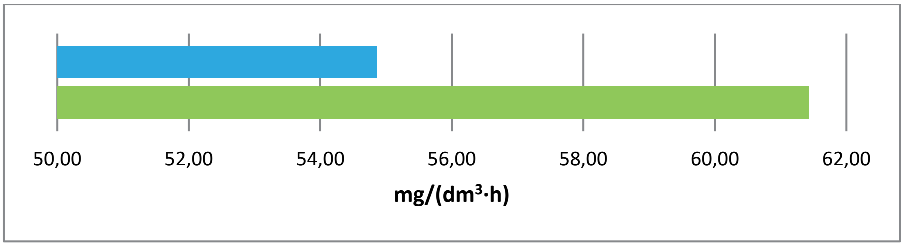

Fig. 3. Average removal rate of organic compounds, referred to as COD, during the mixing and aeration phase in SBRs

On the other hand, for both reactors, the same average removal rate of organic compounds ,defined as BOD_5, during the anaerobic phase of wastewater treatment was calculated – 22.50 mg BOD_5/dm^3h (6.43 mg $BOD/g_{dm}h$). (Fig. 4). The microorganisms absorbed the assimilable organic compounds at the same rate. During the process of mixing and aeration of wastewater, a decrease in the amount of organic compounds, defined as BOD_5, was recorded in all SBR reactors (Fig. 5). In the reactor where an external source of carbon was introduced, a slightly (by 1.43 mg BOD/dm^3h) faster process of organic matter removal, measured as BOD_5, was observed in comparison with the control reactor.

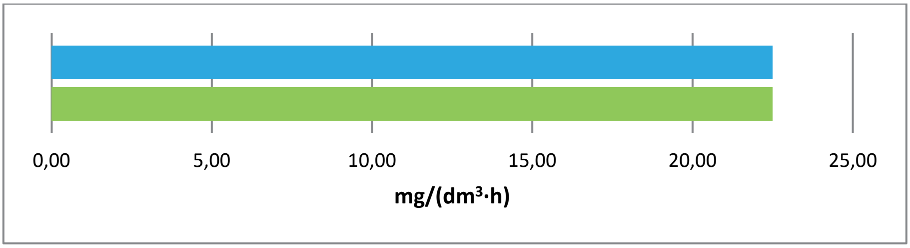

Fig. 4. Average removal rate of organic compounds, referred to as BOD_5, during the anaerobic phase in SBRs

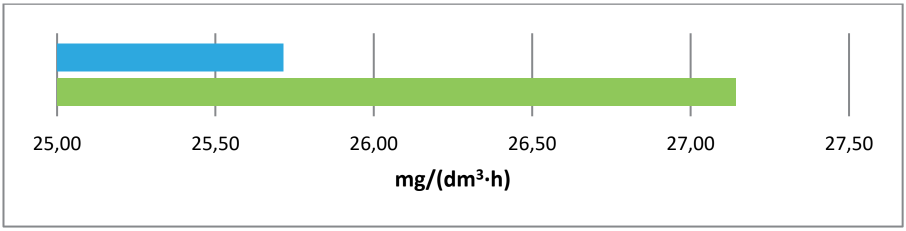

Fig. 5. Average removal rate of organic compounds, known as BOD_5, during the mixing and aeration phase of SBRs

During the anaerobic phase of wastewater treatment in the reactor with molasses, a much higher average rate of total nitrogen removal was found compared to the control reactor (Fig. 6). The removal of total nitrogen occurred here by 17.03 mg N/dm^{3}h faster than in the control reactor. During the process of mixing and aeration of wastewater in the reactor with molasses, the rate of removal of total nitrogen decreased from 28.58 to 8.81 mg N/dm^{3}h, but was still higher than in the control reactor (Fig. 7).

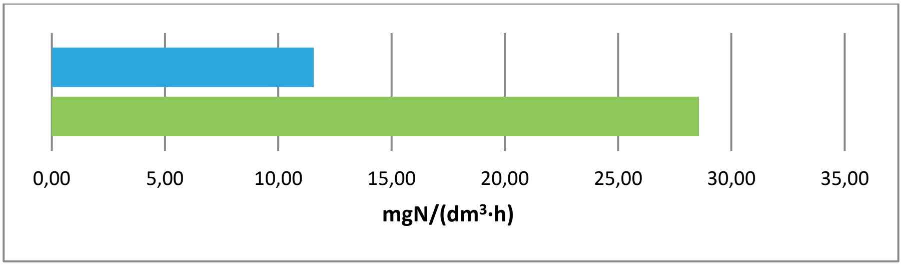

Fig. 6. Average removal rate of total nitrogen during anaerobic phase in SBRs

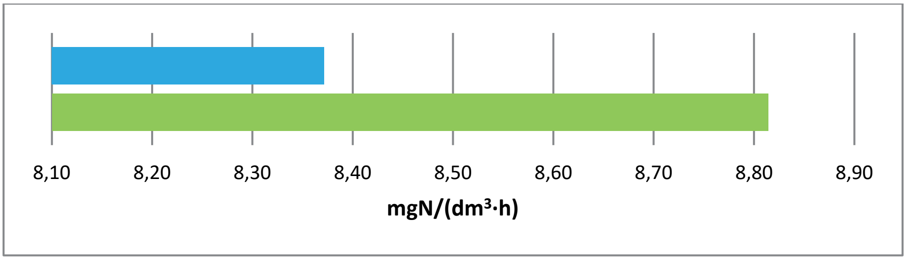

Fig. 7. Average removal rate of total nitrogen during the mixing and aeration phase in SBRs

The increased amount of easily assimilable carbon compounds in the form of molasses has also contributed to an increase in the NUR denitrification rate. Figure 8 shows the denitrification rate twenty minutes after the addition of the carbon source and the average rate of all denitrification. In the initial phase of denitrification with the addition of an external carbon source, no acceleration of nitrogen removal was observed. However, the average rate of the whole denitrification phase (Fig. 9) in a reactor without the addition of a carbon source was much lower, only 0.45 mg N/dm^3·h, while the difference in speed between reactors was 2.48 mg N/dm^3·h. The NUR rate in the molasses reactor was 2.93 mg N/dm^3·h (0.88 mg Nog/g$_{dm}$·h). Quan et al (2005) described the effect of hydrolysed molasses on the effectiveness of nitrogen removal in the SBR reactor treating synthetic wastewater. The authors obtained denitrification rates of 2.9-3.6 mg N_{tot}/(gsmo-h). Bernat and others. (2016) studied the removal of nitrogen compounds from wastewater in SBR reactors using molasses as a carbon source. In the 22-hour process of wastewater mixing with COD/N = 5.5, the authors obtained a nitrate (V) removal rate of about 22 mg N/(dm^3·h) (5.2 mg N/(gsmo·h)) for the initial 3 hours of the cycle, while during the further part of the SBR reactor cycle the rate decreased to 3 mg N/(dm^3·h) (0.71 mg N/(g_{dm}·h)). The authors obtained much higher denitrification rates in comparison to the presented own research, however, in their research they used model sewage produced on liquid mineral substrate and the only source of nitrogen in the sewage were nitrates(V) and nitrates(III) in the form of KNO_3 and $NaNO_2$ solutions respectively.

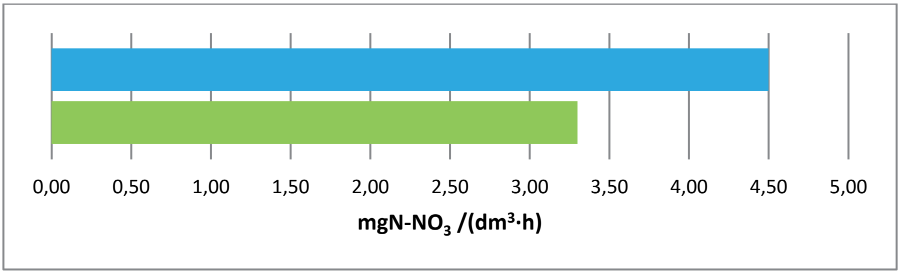

Fig. 8. NUR denitrification rate twenty minutes after the addition of a carbon source in an SBRs

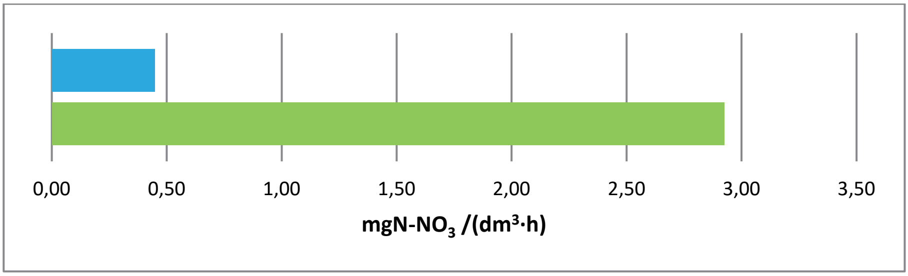

Fig. 9. Average rate of NUR denitrification in SBRs

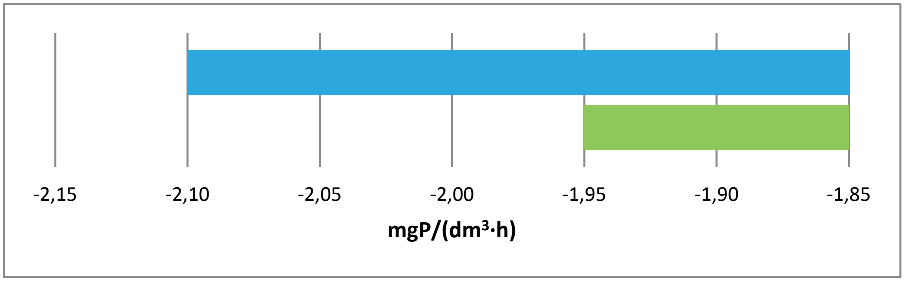

Fig. 10. Average release rate of total phosphorus PRR during anaerobic phase in SBRs

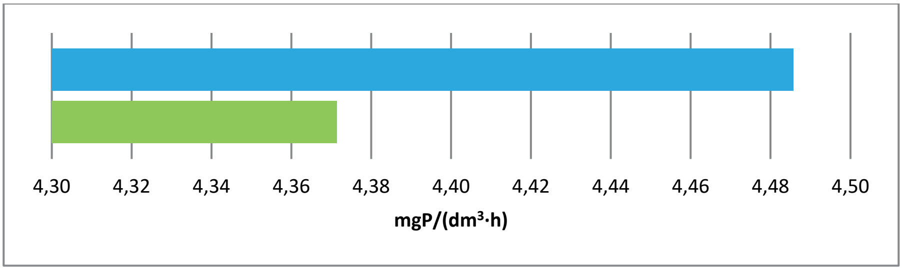

Fig. 11. Average PUR total phosphorus removal rate during the mixing and aeration phase in SBRs

During the anaerobic phase of wastewater treatment, an increase in total phosphorus concentration was observed in all reactors due to the secondary release of phosphorus from PAO phosphorus bacteria (Fig. 10), which translates into a negative value of phosphorus compounds removal rate. This phenomenon occurred much faster in the control reactor. Therefore, it can be concluded that an increased amount of easily assimilable organic compounds from molasses inhibited the release of phosphorus from PAO bacteria. During the process of mixing and aeration of wastewater, a decrease in total phosphorus concentration in all reactors was recorded (Fig. 11). The process speed was comparable in both reactors and was 4.40 and 4.37 mg P/dm^3 h respectively.

To sum up, the studies confirmed a high potential for the use of waste substances (molasses) as an alternative external carbon source in the process of municipal wastewater treatment. The use of waste substances contributed to an increase in the amount of easily assimilable organic compounds required by activated sludge microorganisms and to a higher removal efficiency of nitrogen forms than in the control reactor while maintaining a high efficiency of removing organic compounds.

4. Conclusions

1. The use of an external source of waste carbon in the treatment of municipal wastewater has resulted in a higher removal efficiency of nitrogen forms than in a control reactor while maintaining a high removal efficiency of organic compounds.
2. The use of molasses as an external source of carbon during wastewater treatment resulted in an increased removal rate during waste water treatment.
3. The rate of NUR denitrification in the molasses reactor increased by 2.48 mg $N/dm^3 \cdot h$ compared to the control SBR.
4. Molasses as a waste product can be successfully used as an external source of carbon in the denitrification process.

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Abstract

Providing external sources of carbon to the treated wastewater often becomes necessary to achieve high efficiencies of wastewater treatment plants. The use of conventional sources of carbon brings high operating costs for wastewater treatment plants. This has become a prerequisite for the exploration of other, alternative, sources of organic carbon. The aim of the research was to confirm the effectiveness of the use of waste products, for example molasses, in the denitrification process, as well as to determine their influence on the rate of changes in pollutant concentrations during wastewater treatment. The studies were carried out during the process of municipal sewage treatment in two independent SBR-type activated sludge chambers on a laboratory scale. A single reactor operating cycle lasted 6 hours and included the following phases: wastewater supply

(2 min), mixing (anaerobic) (60 min), aeration (210 min), sedimentation (60 min) and decantation (30 min). Molasses was added to one of the chambers in each cycle twenty minutes after filling the wastewater as a source of easily assimilable organic compounds. The use of a waste external carbon source during treatment of municipal wastewater resulted in a higher efficiency of removing nitrogen forms than in the control reactor while maintaining a high efficiency of removing organic compounds. The use of molasses during wastewater treatment resulted in an increased removal rate during waste water treatment. The rate of NUR denitrification in the molasses reactor increased by 2.48 mg $N/dm^3 \cdot h$ compared to the control SBR. Molasses as a waste product can be successfully used as an external carbon source in the denitrification process.

Keywords:
external carbon source, molasses, SBR reactor

Wpływ odpadowego zewnętrznego źródła węgla na szybkość zmian stężenia zanieczyszczeń podczas oczyszczania ścieków

Streszczenie

Dostarczanie do oczyszczanych ścieków zewnętrznych źródeł węgla często staje się niezbędne do osiągnięcia wysokiej wydajności oczyszczalni ścieków. Wykorzystywanie konwencjonalnych źródeł węgla niesie za sobą wysokie koszty eksploatacyjne oczyszczali ścieków. Stało się to przesłaną do poszukiwań do innych, alternatywnych źródeł węgla organicznego. Celem prowadzonych badań było potwierdzenie skuteczności stosowania produktów odpadowych na przykładzie melasy w procesie denitryfikacji, a także określenie ich wpływu na szybkość zmian stężenia zanieczyszczeń podczas oczyszczania ścieków. Badania prowadzono podczas procesu oczyszczania ścieków komunalnych w dwóch niezależnych komorach osadu czynnego typu SBR w skali laboratoryjnej. Pojedynczy cykl pracy reaktora trwał 6 godzin i obejmował fazy: doprowadzenia ścieków (2 min), mieszania (beztlenowa) (60 min), napowietrzania (210 min), sedymentacji (60 min) i dekantacji (30 min). Do jednej z komór w każdym cyklu po dwudziestu minutach od napełnienia ścieków dodawano melasę jako źródło łatwo przyswajalnych związków organicznych. Zastosowanie odpadowego zewnętrznego źródła węgla podczas oczyszczania ścieków komunalnych przyczyniło się do wyższej skuteczności usuwania form azotu niż w reaktorze kontrolnym przy zachowaniu wysokiej efektywności usuwania związków organicznych. Zastosowanie melasy podczas oczyszczania ścieków spowodowało zwiększenie szybkości usuwania zanieczyszczeń podczas oczyszczania ścieków. Szybkość denitryfikacji NUR w reaktorze z melasa wzrosła o 2,48 mg $N/dm^3 \cdot h$ w porównaniu do SBR kontrolnego. Melasa jako produkt odpadowy z powodzeniem może być stosowany jako zewnętrzne źródło węgla w procesie denitryfikacji.

Słowa kluczowe:
zewnętrzne źródło węgla, melasa, reaktor SBR