



Glycerine as an External Source of Carbon Supporting Denitrification Process

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1. Introduction

Supplementation of wastewater under treatment with carbon from external sources often becomes essential to achieve high wastewater treatment plant efficiency as such plants must comply with very strict requirements regarding limitation of nitrogen concentration. Use of conventional carbon sources is associated with wastewater treatment plant high operating costs. The costs of external carbon source, and waste management, make in total more than 50% of all costs of wastewater treatment (Fernández-Nava et al. 2010, Ignatowicz et al. 2011). Furthermore, a period of microbial adaptation is often required after the introduction of a given carbon source into the wastewater treatment plant system (Elefsiniotis and Li 2006; Min et al. 2002). This became a premise for seeking of other alternative sources of organic carbon.

A waste product, showing high potential as an external source of carbon, is glycerine fraction being a by-product of biodiesel production. There are many reports on application of glycerine as a proper source of carbon for wastewater treatment (Bodik et al. 2009, Akunna et al. 1993, Torà et al. 2011) as well as about application of glycerine to reduce biomass generation (Kulikowska and Bernat 2015). Today, in many countries diesel oil is supplemented with biodiesel causing successive increase of its production, therefore, generation of some amount of glycerine fraction (Kulikowska and Bernat 2015, da Silva et al. 2009). Production of circa 10 litres of biodiesel generates 1 litre of glycerine (Johnson and Taconi 2007, Guerrero et al. 2012). The glycerine phase contains, apart from glycerol (propane-1,2,3-triol – 50-60%) also other substances such as methanol, mono-diacylglycerols, free fatty acids as well as soaps. Glycerol originating from biodiesel production contains many contaminants, therefore, with increase of its

production, glycerine prices decreased. Consequently, glycerol became waste, which should be rendered harmless and price of this product is more attractive compared to other substrates used as external sources of carbon in denitrification and dephosphatation processes (Yazdani and Gonzales 2007, Janczukowicz and Rodziewicz 2013).

The research work performed was aimed at demonstration that application of glycerine as external source of carbon in wastewater treatment process has positive impact on effectiveness of elimination of nitrogen forms from wastewater and may replace other alternative sources of carbon.

2. Methodology of research

Tests were performed during municipal wastewater treatment process performed in two independent reactors (R1 and R2) with SBR-type activated sludge. Their active volume was 10 dm³, whereof 6.5 dm³ was occupied by activated sludge, whereas the remaining volume was occupied by mechanically treated raw wastewater delivered from Białystok wastewater treatment plant.

Table 1. Work parameters of SBR reactors

Pos.	Indicator	Value	Unit of measure
1	Activate sludge concentration	3.5	kg/m ³
2	Sludge index	120-150	cm ³ /g
3	Chamber hydraulic load	1.4	m ³ /m ³ ·d
4	Load of organic compounds	0.2-0.3	kg COD/m ³ ·d
5	Decantation coefficient	0.3	–

A single reactor operating cycle lasted 6 hours and comprised the following stages: wastewater supply (2 min.), anaerobic mixing (60 minute), aeration (3.5 h), sedimentation (1 h) and decantation (0.5 h). During the stage of aeration performed via a diffuser located at reactor bottom, compressed air was supplied, depending on the operation stage, in amount from 0.1 up to 3.0 mg O₂/dm³; activated sludge concentration was 3.5 kg/m³, sludge index fluctuated from 120 to 150 cm³/g, chamber hydraulic load was 1.4 m³/m³·d and load of organic compounds was 0.2 kg COD/m³·d. Glycerine, as a source of easily assimilable organic compounds, in amount of 100 mg to 1 dm³ of wastewater was being added to one of the chambers (R2) in each cycle, after twenty minutes from wastewater filling. Table 1 shows operating parameters of SBR reactors.

Wastewater samples were filtrated, in each the following parameters were being determined, each time, in accordance with the applicable methodology:

- COD – dichromate method as per PN-74/C-04578.03 standard,
- BOD₅ – manometric method based on OxiTop standard,
- N-NH₄ – spectrophotometric method as per PN-ISO 7150-1:2002 standard,
- N-NO₃ – spectrophotometric method as per PN-82/C-04576/08 standard,
- N_{tot} – spectrophotometric method as per PN-EN ISO 6878:2006 standard,
- P_{tot} – spectrophotometric method as per PN-C-04576-00:1973P standard.

COD fractions: S_S (dissolved easily biodegradable), S_I (dissolved non-degradable biologically), X_S (organic suspension slowly degradable), X_I (organic suspension non-degradable biologically) were determined based on ATV-A 131 guidelines. Nitrates elimination velocity r_v , during SBR reactor process stages, was calculated from formula (1):

$$r_v = (C_0 - C_e) \cdot t^{-1} \quad [\text{mg N} \cdot \text{dm}^3/\text{h}] \quad (1)$$

where:

C_0 – nitrates concentration at the beginning of the process stage [mg N/dm³],

C_e – nitrates concentration at the end of the process stage [mg N/dm³],

t – process stage time [h].

3. Test results and interpretation

The results of wastewater tests performed without supplementation with carbon from an external source (R1 reactor) and with glycerine added as carbon from external source (R2 reactor) are presented in Table 2.

Figure 1 shows a listing of COD proportion to total nitrogen at particular check points. According to ATV, Henze, Szpindor, Łomotowski, Janczukowicz, Akunna, denitrification proceeds uninterruptedly if COD/N_{tot} proportion varies from 4 to 10. COD to N_{tot} proportion in wastewater in both SBR reactors was insufficient for denitrification process course and was below the recommended range. Supplementation of the reactor with glycerine improved this relationship and COD/N_{tot} proportion reached the recommended level.

In research work presented by Bernat et al. [12] on application of glycerine as an external source of carbon for elimination of nitrogen forms in SBR-type chambers, it was found that the optimal COD/N_{tot} proportion should be 3.0, as in such case, both elimination of nitrogen compounds proceeds in the best way and biomass generation in SBR-chambers is at the lowest level. COD/N_{tot} proportion in the tested raw wastewater was close to that recommended by the authors as it was 4.49, whereas just before supplementation with glycerine as the carbon source, COD/N_{tot} proportion was 3.11.

Table 2. Summary of wastewater results

	Reactor	COD	BOD ₅	N _{tot}	NO ₃	NO ₄ ⁺	P _{tot}
		[mg O ₂ /dm ³]	[mg O ₂ /dm ³]	[mg N/dm ³]	[mg N/dm ³]	[mg N/dm ³]	[mg P/dm ³]
Raw wastewater	R1	530	230	118	2.6	51.1	18.5
	R2	530	230	118	2.6	51.1	18.7
Wastewater after filling (20 min) after 20 min	R1	268	125	84.0	3.9	58.2	15.2
	R2	262	125	84.1	4.8	42.2	15.0
Denitrification process (20 min) after 40 min	R1	262	120	68.7	2.4	55.3	18.0
	R2	322	150	72.0	2.2	49.0	16.9
Denitrification process (20 min) after 60 min	R1	259	120	55.2	3.6	41.6	12.8
	R2	331	145	69.0	2.6	45.2	15.0
Nitrification process (1.5 h) after 2.5 h	R1	254	115	48.1	4.6	33.5	1.5
	R2	279	120	61.2	6.6	24.4	1.2
Nitrification process (2 h) after 4.5 h	R1	243	98	24.3	8.6	9.7	1.1
	R2	234	98	6.5	3.6	2.9	0.8
Decantation (0.5h) after 6 h	R1	35	6	14.4	8.6	1.8	0.8
	R2	28	2	5.6	3.2	0.6	0.5

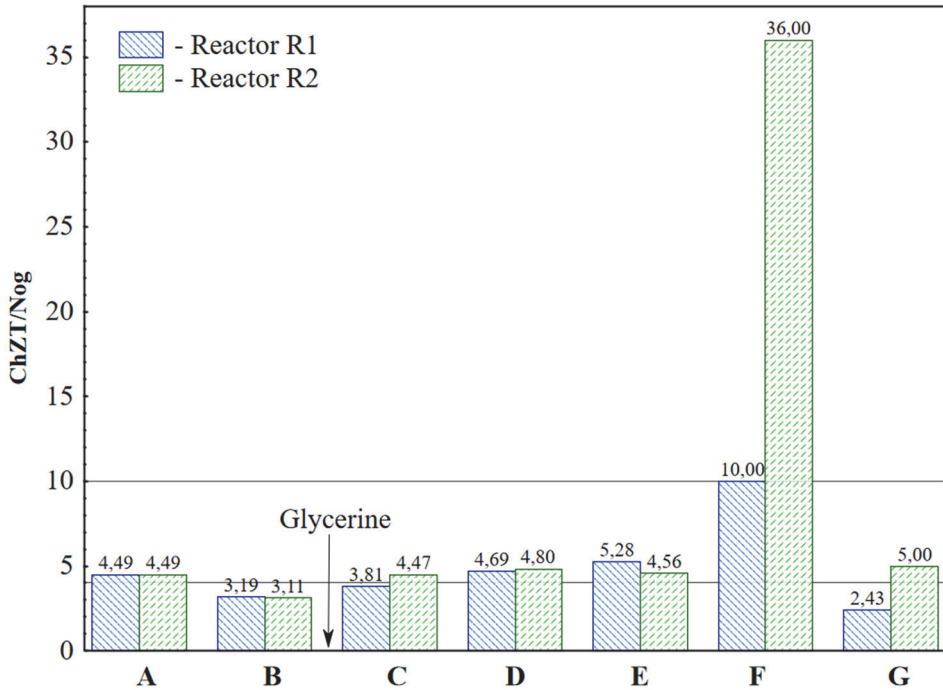


Fig. 1. Comparison of COD to total nitrogen at individual control points (A – raw wastewater; B – wastewater after filling (20 min); C – denitrification process (20 min); D – denitrification process (20 min); E – nitrification process (90 min); F – nitrification process (120 min); G – decantation (30 min))

Value of COD in raw wastewater was $530 \text{ mg O}_2/\text{dm}^3$, whereas BOD_5 – $230 \text{ mg O}_2/\text{dm}^3$. Total nitrogen concentration in raw wastewater was $118 \text{ mg N}/\text{dm}^3$, ammonium nitrogen – $51.5 \text{ mg N}/\text{dm}^3$, nitrates $2.6 \text{ mg N}/\text{dm}^3$ and total phosphorus – $18.5 \text{ mg P}/\text{dm}^3$.

After twenty minutes as of reactors filling, assimilable carbon was consumed by denitrification bacteria resulting in reduction of COD (by approximately 50%) and BOD_5 (by approximately 46%). COD value amounted to $268 \text{ mg O}_2/\text{dm}^3$ (in R1 reactor) and $262 \text{ mg O}_2/\text{dm}^3$ (in R2 reactor), whereas BOD_5 value amounted to $125 \text{ mg O}_2/\text{dm}^3$ (both in R1 and R2 reactors). Total nitrogen concentration in both reactors decreased to approximately $84 \text{ mg N}/\text{dm}^3$. Concentration of nitrates increased up to $3.9 \text{ mg N}/\text{dm}^3$ in R1 reactor, and up to $4.8 \text{ mg N}/\text{dm}^3$ in R2 reactor. Ammonium nitrogen concentration increase was noted for R1 reactor up to $58.2 \text{ mg N}/\text{dm}^3$, whereas in R2 reactor ammonia nitrogen concentration decreased down to $42.2 \text{ mg N}/\text{dm}^3$.

Then, glycerine was added to R2 reactor as carbon external source, and after twenty minutes of anaerobic denitrification process, subsequent samples were taken. Glycerine supply to R2 reactor resulted in increase of COD up to $322 \text{ mg O}_2/\text{dm}^3$, and BOD_5 – up to $150 \text{ mg O}_2/\text{dm}^3$. However, in R1 reactor, to which no glycerine was supplied, further insignificant decrease of COD to $262 \text{ mg O}_2/\text{dm}^3$ and BOD_5 to $120 \text{ mg O}_2/\text{dm}^3$ was noted. The denitrification process resulted also in reduction of total nitrogen concentration in both reactors – in R1 down to $68.7 \text{ mg N}/\text{dm}^3$, whereas in R2 – down to $72 \text{ mg N}/\text{dm}^3$. Similar decreasing trend was noted for nitrates – in R1 reactor the concentration was $2.4 \text{ mg N}/\text{dm}^3$, and in R2 reactor – $2.2 \text{ mg N}/\text{dm}^3$. Ammonium nitrogen concentration decreased insignificantly in R1 reactor down to $55.3 \text{ mg N}/\text{dm}^3$, whereas in R2 reactor a reverse situation was noted, i.e. ammonium nitrogen concentration increased up to $49 \text{ mg N}/\text{dm}^3$, but this concentration was still lower than in R1 reactor.

After subsequent twenty minutes of anaerobic wastewater treatment in R1 reactor, further slight decrease of COD down to $259 \text{ mg O}_2/\text{dm}^3$ was noted, whereas BOD_5 value remained unchanged – $120 \text{ mg O}_2/\text{dm}^3$. In R2 reactor with glycerine added, a reverse situation occurred, i.e. further increase of COD up to $331 \text{ mg O}_2/\text{dm}^3$ was noted. BOD_5 decreased down to $145 \text{ mg O}_2/\text{dm}^3$, but those values were higher than in the reactor without supplementation with carbon source. Total nitrogen concentration continued to decrease and in R1 reactor was $55.2 \text{ mg N}/\text{dm}^3$. In the case of R2 reactor, total nitrogen concentration was higher than in R1 reactor and amounted to $69 \text{ mg N}/\text{dm}^3$. In both reactors increase of nitrates concentrations up to $3.6 \text{ mg N}/\text{dm}^3$ in R1 reactor and $2.6 \text{ mg N}/\text{dm}^3$ in R2 reactor was noted. Ammonium nitrogen concentration decreased in R1 reactor down to $41.6 \text{ mg N}/\text{dm}^3$, whereas in R2 reactor – down to $45.2 \text{ mg N}/\text{dm}^3$. The difference of ammonium nitrogen concentration at this check point between reactor without carbon source (R1) and reactor with glycerine (R2) was $3.6 \text{ mg N}/\text{dm}^3$.

Subsequent samples were taken after 1.5 h of wastewater aeration. COD value in R1 reactor was $254 \text{ mg O}_2/\text{dm}^3$, whereas BOD_5 was $115 \text{ mg O}_2/\text{dm}^3$. In reactor R2, despite reduction of COD value by $52 \text{ mg O}_2/\text{dm}^3$ (15.7%) down to $279 \text{ mg O}_2/\text{dm}^3$ and BOD_5 value by $25 \text{ mg O}_2/\text{dm}^3$ down to $120 \text{ mg O}_2/\text{dm}^3$, those values were higher than in R1 reactor without glycerine added. Also total nitrogen concentration in reactor without carbon source added was lower and amounted to $48.1 \text{ mg N}/\text{dm}^3$. In the case of R2 reactor, concentration of total nitrogen was $61.2 \text{ mg N}/\text{dm}^3$. The difference of total nitrogen concentrations between R1 and R2 reactors was $13.1 \text{ mg N}/\text{dm}^3$. Due to oxygen supply to the reactors, retardation of the denitrification process had happened, therefore, concentration of nitrates in R1 reactor increased up to $4.6 \text{ mg N}/\text{dm}^3$. In R2 reactor increase of nitrates

concentration up to 6.6 mg N/dm^3 was also noted. Ammonium nitrogen concentration decreased in R1 reactor down to 33.5 mg N/dm^3 , whereas in R2 reactor – down to 24.4 mg N/dm^3 . The difference in ammonium nitrogen concentrations at this check point between R1 reactor without carbon source and R2 reactor containing glycerine was 9.1 mg N/dm^3 .

Due to further wastewater aeration (2 h), COD value in R1 reactor was $243 \text{ mg O}_2/\text{dm}^3$. In glycerine containing reactor, further consumption of assimilable organic compounds proceeded, which resulted in lower COD value being approximately $234 \text{ mg O}_2/\text{dm}^3$. BOD₅ value decreased in both reactors down to $98 \text{ mg O}_2/\text{dm}^3$. Total nitrogen concentration in R1 reactor was 24.3 mg N/dm^3 , whereas in R2 reactor it was lower by 17.8 mg N/dm^3 and amounted to 6.5 mg N/dm^3 . Nitrates concentration in R1 reactor continued to increase up to 8.6 mg N/dm^3 , whereas in R2 reactor it decreased down to 3.6 mg N/dm^3 . Long wastewater aeration time caused considerable decrease of ammonium nitrogen concentration in both reactors compared to the previous check point. In R1 reactor, concentration of this nitrogen form was 9.7 mg N/dm^3 , whereas in R2 reactor – 2.9 mg N/dm^3 . The difference in ammonium nitrogen concentrations between R1 reactor without carbon source and R2 reactor containing glycerine was 6.8 mg N/dm^3 .

COD value in treated wastewater from R1 reactor decreased, after decantation process, down to $35 \text{ mg O}_2/\text{dm}^3$, whereas BOD₅ value decreased down to $6 \text{ mg O}_2/\text{dm}^3$. Despite addition of carbon from external source, COD in treated wastewater with added glycerine amounted to $28 \text{ mg O}_2/\text{dm}^3$, and BOD₅ – $2 \text{ mg O}_2/\text{dm}^3$. These are lower values with relation to R1 reactor where no additional source of carbon was used. Total nitrogen concentration in treated wastewater from R1 reactor decreased down to 14.4 mg N/dm^3 , ammonium nitrogen decreased down to 1.8 mg N/dm^3 , but the decantation process had no impact on nitrates concentration, value of which amounted to 8.6 mg N/dm^3 . Wastewater treatment in R1 reactor caused elimination of total nitrogen in 87.8%, as well as ammonium nitrogen, in 96.5%. In the case of the glycerine containing reactor, total nitrogen concentration in treated wastewater was reduced to 5.6 mg N/dm^3 , ammonium nitrogen concentration was reduced down to 0.6 mg N/dm^3 and nitrates concentration was reduced down to 3.2 mg N/dm^3 . Wastewater treatment in R2 reactor caused elimination of total nitrogen in 95.3% and ammonium nitrogen – in 98.8%. Application of glycerine in R2 reactor had impact on higher efficiency of the wastewater treatment process than in R1 reactor, where no supplementation with carbon from external source was applied. Despite increase of nitrates concentration in treated wastewater, nitrates concentration in the reactor in which external source of carbon was applied, was lower by

as much as 5.4 mg N/dm^3 . Concentration of total phosphorus in treated wastewater decreased down to 0.8 mg P/dm^3 .

Just like in the paper of Bodik et al. (2009), where test results in laboratory and technical scale on use of glycerine fraction in denitrification process performed in SBR chambers were presented, no increased values of COD concentrations were noted in the outflow, which proves correctly selected glycerine dose and its application in the denitrification process.

COD fractions in wastewater were determined in order to establish their quantitative share and percentage. Determination of COD fractions allows for evaluation of wastewater susceptibility to biological treatment, additionally indicating hardly decomposable contaminants reducing effectiveness of wastewater biological treatment. Easily biodegradable, hardly (slowly) biodegradable and non-biodegradable (undecomposable) compounds are distinguished.

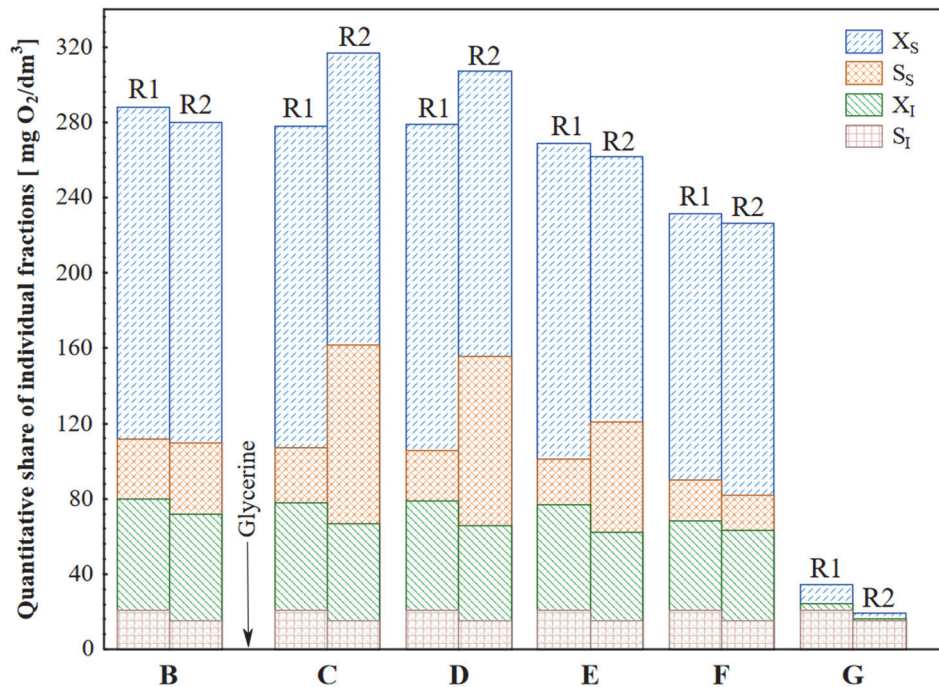


Fig. 2. Quantitative share of individual fractions in a reactor without addition of a carbon source (R1) and a reactor with the addition of glycerine (R2) (B – wastewater after filling (20 min); C – denitrification process (20 min); D – denitrification process (20 min); E – nitrification process (90 min); F – nitrification process (120 min); G – decantation (30 min))

Fraction of dissolved organic substances that are easily biodegradable S_S as well as fraction of insoluble slowly biodegradable organic substances X_S are counted to the biodegradable fraction. To non-biodegradable fraction, fractions of dissolved non-biodegradable substances S_I are counted, likewise, insoluble organic non-biodegradable substances X_I (Sadecka et al. 2011, Myszograj 2017).

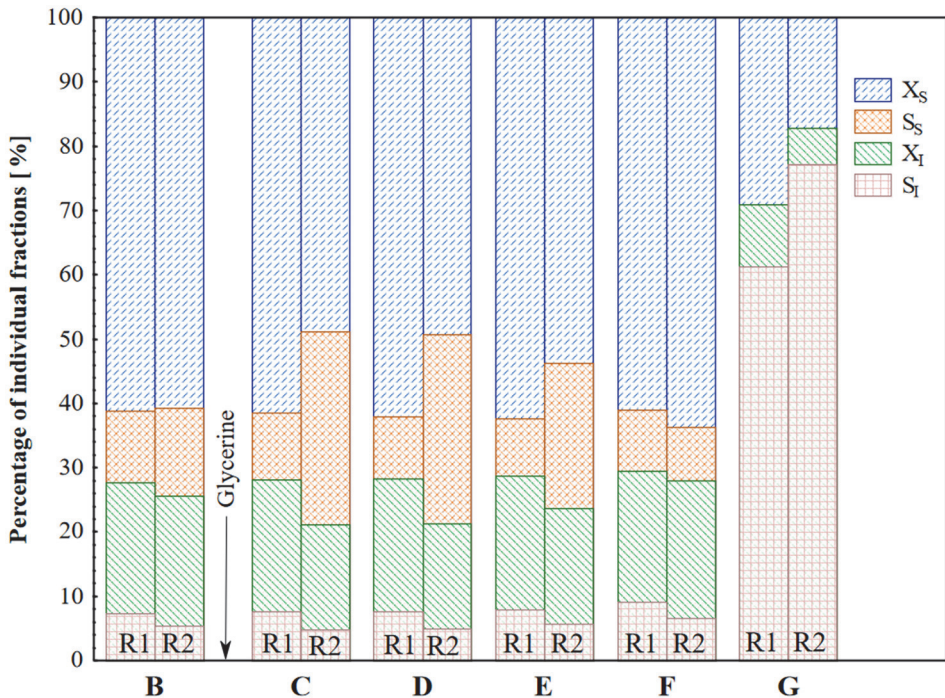


Fig. 3. Percentage of individual fractions in a reactor without addition of a carbon source (R1) and a reactor with the addition of glycerine (R2) (B – wastewater after filling (20 min); C – denitrification process (20 min); D – denitrification process (20 min); E – nitrification process (90 min); F – nitrification process (120 min); G – decantation (30 min))

Figure 2 shows quantitative share, whereas Figure 3 qualitative share of particular fractions in R1 reactor to which no carbon source was added and R2 reactor with glycerine supplied. Introduction of carbon from external source in form of glycerine to municipal wastewater caused increase of S_S fraction by $57 \text{ mg O}_2/\text{dm}^3$ thus increasing the percentage of easily biodegradable dissolved organic compounds from 10% to 30%.

Increased volume of easily assimilable carbon compounds contributed to increase of denitrification velocity. Figure 4 shows velocity of denitrification after twenty minutes from supply of carbon source and the average denitrification velocity.

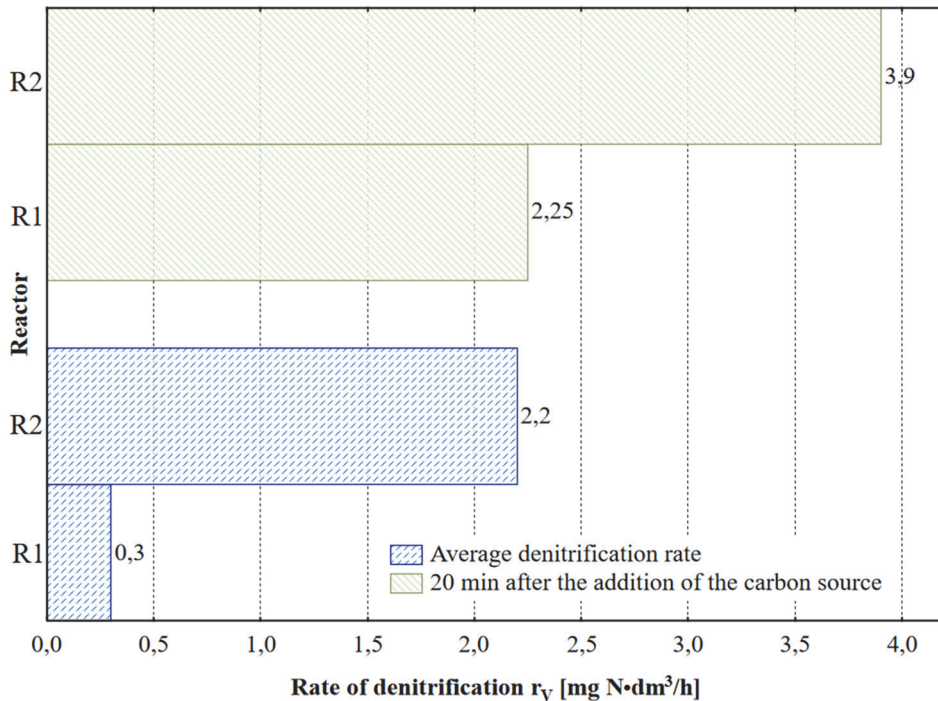


Fig. 4. Rate of denitrification 20 min after the addition of the carbon source and average denitrification rate

In the initial stage of denitrification, with addition of external carbon source i.e. glycerine, acceleration of nitrogen compounds elimination by $1.65 \text{ mg N}\cdot\text{dm}^3/\text{h}$ compared to R1 control reactor, was noted. In the case of the average denitrification velocity in the reactor without carbon source added, the velocity was much lower and it was only $0.3 \text{ mg N}\cdot\text{dm}^3/\text{h}$, whereas the difference in velocity between both reactors was $1.9 \text{ mg N}\cdot\text{dm}^3/\text{h}$.

3. Conclusions

1. Application of glycerine as an external source of carbon during wastewater treatment resulted in higher efficiency of nitrogen forms elimination compared to that reactor in which no carbon from an external source was used, with simultaneously achieved low level of COD values in treated wastewater.
2. Application of glycerine to municipal wastewater treatment caused decrease of nitrates concentration in treated wastewater by 3.2 mg N/dm³ compared to that reactor in which no carbon from external source was used.
3. The addition of glycerine to municipal wastewater caused increase of volume of easily biodegradable dissolved organic compounds defined as S_S fraction in R2 reactor by 57 mg O₂/dm³ (from 10% to 30%).
4. Glycerine, which is a waste product, can successfully be used as an external source of carbon in the denitrification process.

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Abstract

Supplying external carbon sources to treated wastewater is often necessary to achieve high efficiency by wastewater treatment plants that must meet very strict requirements for reducing the nitrogen concentration. The use of conventional carbon sources brings high operating costs for wastewater treatment. It became a reason to look for other, alternative sources of organic carbon.

The paper presents the effectiveness of nitrogen removal from wastewater with the use of glycerol as an external carbon source. The research was carried out during the municipal wastewater treatment process in two independent SBR-type activated sludge chambers on a laboratory scale. A single cycle of the reactor operation lasted 6 hours and included the following phases: sewage supply (2 min), mixing (anaerobic) (60 min), aeration (3.5 hours), sedimentation (1 hour) and decantation (0.5h). To one of the chambers in each cycle, after twenty minutes of the sewage supply, glycerol was added as a source of easily available organic compounds. Tests have shown that the use of glycerol as an external carbon source during wastewater treatment resulted in higher nitrogen removal efficiency than in the reactor where no external carbon source support was applied with a low level of COD value in treated wastewater. Wastewater treatment in the reactor

without the addition of a carbon source resulted in the total nitrogen removal in 87.8% and ammonium nitrogen in 96.5%, whereas wastewater treatment in the reactor with the addition of glycerol resulted in the removal of total nitrogen in 93.6% and ammonium nitrogen in 98.8%. Despite the increase in the final nitrate concentration in both reactors, the nitrate concentration in the reactor using an external carbon source was lower by as much as 3.4 mg N/dm³.

The COD fractions and their changes in wastewater were determined in order to find out their quantitative and percentage share. Determination of COD fraction allows to assess the susceptibility of wastewater to biological treatment, additionally indicating impurities that are difficult to decompose, which reduce the effectiveness of biological wastewater treatment. Introduction of an external carbon source in the form of glycerol to municipal sewage caused an increase in the S_S fraction by 57 mg O₂/dm³, thus increasing the percentage of readily biodegradable dissolved organic compounds from 10% to 30%. The increased amount of easily available carbon compounds has contributed to the increase of denitrification rate. In the initial phase of denitrification with the addition of an external carbon source in the form of glycerol, an acceleration in the removal of nitrogen compounds by 1.9 mg N·dm³/h compared to the control reactor, was observed.

Keywords:

SBR reactor, external carbon source, denitrification, glycerine, wastewater treatment

Gliceryna jako zewnętrzne źródło węgla wspomagające proces denitryfikacji

Streszczenie

Dostarczanie do oczyszczanych ścieków zewnętrznych źródeł węgla często staje się niezbędne do osiągnięcia wysokiej efektywności oczyszczania ścieków, które muszą spełniać bardzo surowe wymagania dotyczące ograniczenia stężenia azotu. Zastosowanie konwencjonalnych źródeł węgla niesie za sobą wysokie koszty eksploatacyjne oczyszczalni ścieków. Stało się to przesłanką do poszukiwań innych, alternatywnych źródeł węgla organicznego.

W artykule przedstawiono skuteczność usuwania azotu ze ścieków z wykorzystaniem gliceryny jako zewnętrznego źródła węgla. 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 takie fazy jak: doprowadzenie ścieków (2 min), mieszanie (beztlenowa) (60 min), napowietrzanie (3,5 h), sedymentację (1 h) i dekantację (0,5 h). Do jednej z komór w każdym cyklu po dwudziestu minutach od napełnienia ścieków dodawano glicerynę jako źródło łatwo przyswajalnych związków organicznych. Przeprowadzone badania wykazały, że zastosowanie gliceryny jako zewnętrznego źródła węgla podczas oczyszczania ścieków spowodowało wyższą skuteczność usuwania azotu niż w reaktorze, gdzie nie zostało zastosowane wspomaganie zewnętrznym źródłem węgla przy jednocześnie uzyskanym niskim poziomie wartości ChZT w ściekach oczyszczonych. W reaktorze bez dodatku źródła węgla usunięcie azotu ogólnego wynosiło 87,8% oraz azotu amonowego w 96,5%. Oczyszczanie ścieków

w reaktorze z dodatkiem gliceryny spowodowało usunięcie azotu ogólnego w 93,6% oraz azotu amonowego w 98,8%. Pomimo wzrostu końcowego stężenia azotanów w obu reaktorach, w reaktorze z zastosowaniem zewnętrznego źródła węgla stężenie azotanów było niższe aż o 3,4 mg N/dm³.

Wyznaczono frakcje ChZT i ich zmiany w ściekach w celu ustalenia udziału ilościowego i procentowego. Wyznaczenie frakcji ChZT pozwala na ocenę podatności ścieków na oczyszczanie biologiczne, wskazując dodatkowo zanieczyszczenia trudno rozkładalne, zmniejszające efektywność biologicznego oczyszczania ścieków. Wprowadzenie zewnętrznego źródła węgla w formie gliceryny do ścieków komunalnych spowodowało wzrost frakcji S_s o 57 mg O₂/dm³, zwiększając tym samym procentową zawartość związków organicznych rozpuszczonych łatwo biodegradowalnych z 10 do 30%. Zwiększona ilość łatwo przyswajalnych związków węgla przyczyniła się do zwiększenia szybkości denitryfikacji. W początkowej fazie denitryfikacji z dodatkiem zewnętrznego źródła węgla w postaci gliceryny zauważono przyśpieszenie usuwania związków azotu o 1.9 mg N·dm³/h w porównaniu do reaktora kontrolnego.

Słowa kluczowe:

reaktor SBR, zewnętrzne źródło węgla, denitryfikacja, gliceryna, oczyszczanie ścieków