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Nitrogen recovery from reject water by the production of nitrite concentrate via nitritation, membrane processes and ion exchange

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ABSTRACT

The digester reject water is an ammonium-rich sidestream produced from sludge dewatering at wastewater treatment plants (WWTPs). The removal or recovery of nitrogen from this kind of wastewater is conducted by means of biological and membrane processes, air stripping or cation exchangers. The aim of the presented research was to recover the nitrogen contained in digester reject water as nitrite concentrate so that it could be used as a fertilizer or inhibitor of H_2S formation in sewers. Digester rejects water that underwent nitritation, microfiltration, nanofiltration was fed through anion exchanger at Janówek WWTP Test Station. To the authors' knowledge, the recovery of nitrogen in the aforementioned processes from the real reject water as nitrite concentrate has not been performed yet. The conducted research demonstrated the usefulness of Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) to obtain at least 2% nitrite concentrate in most eluate samples throughout a few months of exploitation. Nevertheless, the significant changes of the feed constitution during storing and high concentration of chlorides and sulfates in the eluate (even during $NaHCO_3$ regeneration), reduced the possibility of its utility. Only the eluate from the first stage of NaCl regeneration could be used to check its impact on the inhibition of H_2S formation.

Keywords: Digester reject water; Anion exchange resin; Nitrogen recovery; Nitrite removal

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1. Introduction

The majority of municipal wastewater treatment plants (WWTPs) produce biogas through the anaerobic digestion of the sludge, which is dewatered before its utilization. The effluent from the sludge dewatering is called the reject water [1]. This kind of wastewater is rich in ammonium-nitrogen, which concentration can be as high as 1,000 mg/L with a negligible load of the organic compounds [2,3]. Due to the high nutrient concentration, such reject water cannot be directly discharged and typically is channeled back into the raw sewage for removal of nitrogen. The recirculation of the effluent from the digesters to the head of the WWTP disrupts the organic matter to nitrogen ratio, thereby increasing the pressure on microbial processes of the biological treatment part of WWTP [1,4].

The removal of nitrogen from the reject water may significantly improve the chemical oxygen demand (COD)/N ratio, which may result in the improvement of the nitrogen removal efficiency. The technologies to remove nitrogen from wastewater include biological processes (nitritation, nitrification/denitrification, deammonification – anammox process), struvite precipitation and treatment of air from thermal sludge drying. Biological processes convert

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nitrogen to gaseous form, which is lost to the atmosphere (not reused) and result in the increase of greenhouse effect by the emission of nitrous oxide (N_2O) [5–8]. Struvite production is mainly applied to recover phosphorus, despite ammonia precipitation in its structure. Since the molecular weight of struvite is 245 g/mol, 17.5 g $MgNH_4PO_4\cdot 6H_2O$ are theoretically formed as a precipitate when 1 g of NH_4^+–N is removed [9].

There exist many technologies to recover and reuse nitrogen directly from wastewater or digester reject water. These include concentrating processes (ion exchange (IE), membrane filtration, capacitive deionization, electrodialysis), urine or sludge treatment (evaporation, electrodialysis, reverse osmosis) and incorporation of nitrogen into biomass [6,9–12]. Most of these methods enable us to receive nitrogen in an application form and the expected concentration range (except for the IE and steam stripping) [6]. In digester reject water the nitrogen exists mostly as NH_4^+, thus biological processes, air stripping, membrane processes or cation exchangers are of interest in terms of nitrogen removal. The increase of pH (usually by means of lime or some other caustic substance) above 9.3 converts ammonium nitrogen from solution to its gaseous NH_3 form. In stripping tower the introduced air strips then ammonia. Air stream containing ammonia is led then to an absorber containing acid (H_2SO_4 or HNO_3) in which ammonium dissolves and ammonium salts are formed [9,10,12]. McLeod et al. used ammonia-rich wastewater as an absorbent to extract CO_2 from biogas and recovered nitrogen as a fertilizer NH_4HCO_3 [13]. Membrane separation also enables recovery of ammonium nitrogen as a fertilizer, for example, $(NH_4)_2SO_4$ or concentrated nitrogen (containing 13 g/L NH_3-N) [14,15]. The most popular ion exchanger or adsorbent for ammonia removal is zeolite. Natural zeolites are aluminosilicate minerals. As a result of the substitution of each Si^{4+} with Al^{3+} in the framework, the overall charge on the zeolite surface is negative. The negative charges within the pores are balanced by charged cations such as Na^+, K^+, Ca^{2+} and Mg^{2+} on their surface. These cations are exchanged with NH_4^+ in the solution. The exhausted zeolites can be applied directly onto agricultural fields as fertilizers [10,16–18].

In the literature, to the authors' knowledge, there is no information about the production of a nitrate or nitrite concentrate from a digester reject water by means of nitritation, prior to membrane separation and further IE. In the literature, there is also little research concerning nitrite and nitrate removal from real wastewater. On the contrary, there is plenty of laboratory tests conducted on synthetically prepared solutions containing these anions [19–23].

The aim of the conducted research was to produce nitrite concentrate through nitritation, membrane separation and IE from a digester reject water at Janówek WWTP Test Station (Wrocław, Poland), which could serve as a fertilizer or a reducer of H_2S nuisance, generated at putrefaction of sewage. To the authors' knowledge, the production of nitrite or nitrate concentrate by means of IE as well as the application of these products to decrease H_2S formation has not been performed yet. Normally nitrites are removed in the denitrification process, which demands the external carbon source. The advantage of the proposed solution is the lack of denitrification, thereby lack of demand for external carbon sources. Hydrogen sulfide is a highly toxic gas, which is a precursor of organic odorants. It significantly enhances microbially mediated corrosion of sewer pipes. The most common method to mitigate the souring (formation of H_2S by sulfidogens) is the addition of biocides to inhibit the growth of sulfate-reducing bacteria (SRB). SRB is present in the structure of biofilms which biocides do not penetrate effectively, thus this measure is of limited effectiveness [24,25]. In oxygen-deficient systems, nitrate is reduced preferentially over sulfate decreasing H_2S formation [26,27]. The addition of 1 g of nitrate per liter to sewage sludge inhibited sulfide production for at least 29 d, which was the longest period tested. The inhibition resulted from the increase in redox potential caused by the presence of nitrate (Jenneman [28]). The introduction of nitrate-reducing, sulfide-oxidizing bacteria (NR-SOB) such as *Thiobacillus denitrificans* with the addition of nitrite and/or nitrate may improve the efficacy of H_2S inhibition [25,29,30]. Jenneman et al. [31] proved that the addition of nitrate to sulfide-laden oil field brines could remove the sulfide from these waters. The oxidation of sulfide to sulfate by means of an alternative electron acceptor can be obtained only if a sufficient amount of this acceptor is added [32].

This research focused on the process of concentrating nitrites in digester reject water derived from the dewatering of sludge at Janówek WWTP. The digester reject water was subjected to separate treatment during the processes of nitritation in sequencing batch reactor (SBR), followed by microfiltration (MF), nanofiltration (NF) and IE at Janówek WWTP Test Station. The main objective of this research was to recover nitrogen from the digester reject water by the production of nitrite concentrate that could be used in practice to control H_2S formation in sewers or applied in the environment as a fertilizer. Such utilization of this kind of wastewater would allow us to avoid the problems associated with its recirculation to the head of the WWTP.

In this study, two experiments on the same strongly basic anion exchange resin Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) with the same operating conditions but different regenerants were conducted. The first experiment with 10% NaCl used as a regenerant had to check the potential of nitrite concentrate production with the desired amount of nitrites in the eluate. Knowing that in the waste brine beside nitrites also sulfates and chlorides may occur in high concentrations, the second experiment with 10% $NaHCO_3$ as a regenerant was conducted to decrease the amount of these aggressive anions in the eluate. The presence of these anions in waste brine may cause plumbing corrosion and salinity of the environment, thus may exclude its utility. The performance of chloride-form resins, unlike bicarbonate-form resins, is well-studied. Rokicki and Boyer [33] found that the bicarbonate-form MIEX resin had a similar affinity as the chloride-form MIEX resin for sulfate, nitrate, dissolved organic carbon, and ultraviolet-absorbing substances.

2. Materials and methods

The research on the production of nitrite concentrate was conducted with the use of Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) anion exchanger produced by Lanxess (Germany). The Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) is a strongly basic (quaternary amine, type 1), macroporous anion-exchange resin based on a cross-linked polyacrylate with a minimum total capacity of 0.85 val/L. The mean bead size ranges from 0.4 to 1.6 mm (min. 90%), the operating temperature cannot exceed 80°C and operating pH ranges from 0 to 12.

The digester reject water from the dewatering of sludge on filter presses at Janówek WWTP in Wrocław (Poland) was used in the experiments. Figs. 1 and 2 depict fragments of the test station situated at Janówek WWTP that was used in the research. In the first experiment, the reject water was subjected to separate treatment during the processes of nitritation in SBR, followed by MF, NF and IE. After nitritation in SBR, the digester reject water

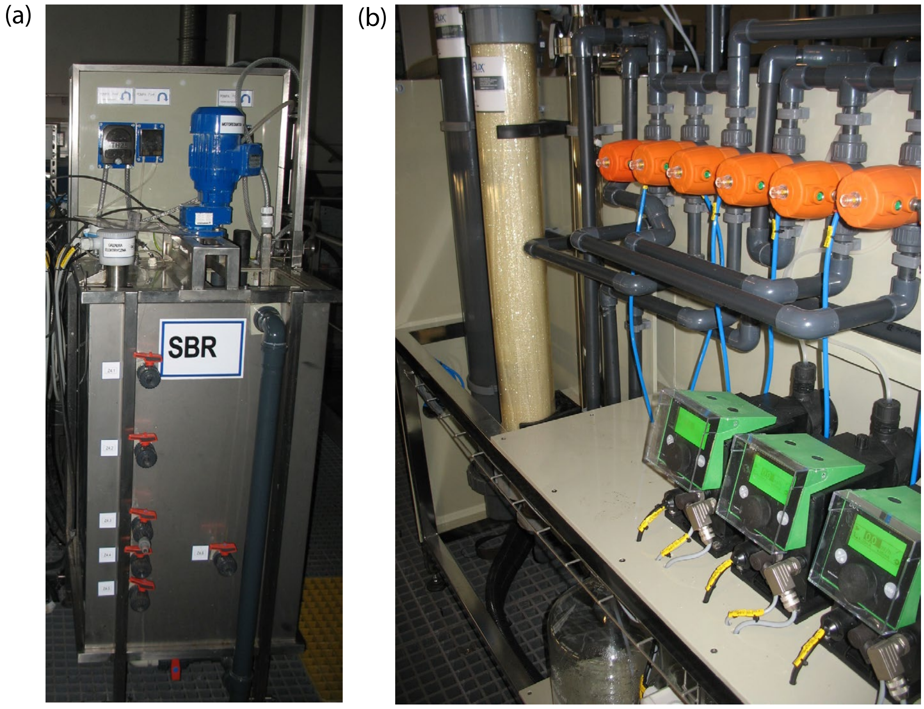

Fig. 1. SBR (a) and microfiltration system and (b) on the experimental stand at Janówek WWTP Test Station.

Fig. 2. IE system (1) and NF modules (2) with spiral membranes on the experimental stand at Janówek WWTP Test Station.

passed through the Liqui-Flux B42 Membrane MF-PP (3 M, Germany) with a nominal pore size of 0.2 μm. The nitritated effluent subsequently fulfilled the NF feed tank (100 L, steel), from which it was directed onto NF membrane DK series with a minimum $MgSO_4$ rejection of 98% placed in a spiral module (Lenntech, The Netherlands). The permeate was collected in IE feed tank (100 L, steel) and fed through an IE column with the Lewatit S5428 resin (the depth in the column equaled to 800 mm) using peristaltic pump Watson-Marlow Qdos 30 Profibus (Watson-Marlow Limited, TR11 4RU, England). The permeate was loaded with the service flow rate of 10 BV/h (BV – bed volume). In the first experiment, the IE feed tank was completed with the fresh part of NF permeate before 6th, 10th and 15th IE cycle. In the second experiment, the fresh part of permeate completed the IE feed tank before the 10th IE cycle. The IE service cycles were conducted until the nitrite breakthrough point. The samples of filtrate from the column were taken for physicochemical analysis every 24 min (when 1 L of reject water passed through the column). The co-current regeneration was then performed by means of 10% NaCl. The resin bed was initially rinsed with distilled water, then the sodium chloride was introduced with the flow rate of 4 BV/h and finally, the residual brine was flushed out by means of distilled water. The samples of the eluate were collected when the sodium chloride washing started. The first sample was taken when 1 BV of regenerant had passed through the resin, the next after 2 BV and the third one at the end of distilled water rinsing. For the purpose of this article, these three subsequent samples of eluate will be further discussed and referred to as eluate 1, eluate 2 and eluate 3.

Before starting the second experiment all tanks were washed and membranes were regenerated by means of NaOH. The exhausted resin was replaced with fresh Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) (800 mm depth in the column). The operation and regeneration conditions as well as the procedure of taking samples were the same as in the first experiment with the exception of the regenerant – 10% NaCl was replaced by 10% $NaHCO_3$.

3. Results and discussion

The physicochemical constitution of the raw and the nitritated digester reject water in conducted experiments is presented in Table 1, whereas Tables 2 and 3 show the reject water after MF and NF. The constitution of NF permeates changed significantly in the IE feed tank due to the reduction and oxidation processes, which occurred throughout the storing (Figs. 3 and 4).

Subjecting the reject water to MF and NF did not eliminate organic compounds, which fouled Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen), although the resin is resistant to organic fouling. The Fourier-transform infrared spectroscopy enabled the recognition of the foulants as the humic acids [34]. The humic acids caused the reduction of ion exchange capacity (Figs. 5 and 6), as well as sulfates and phosphates present in the permeate. In the first experiment (resin regenerated with 10% NaCl) it could be observed that the whole process of IE was very unstable as breakthrough point occurred at different stages in subsequent cycles, which hindered the control over the IE process. Such a changeability of service cycle duration (Fig. 5) resulted from the changes of

Table 1
The chemical constitution of a nitritated digester reject water

Parameter	Unit	1 experiment	2 experiment
Ammonium	(mg NH_4^+/L)	9.24	10.76
Nitrate	(mg NO_3^-/L)	532.36	376.65
Nitrite	(mg NO_2^-/L)	1,605.47	5,062
Conductivity	(μS/cm)	9,042	6,157
pH	(–)	9.1	7.80
Turbidity	(NTU)	23.8	3.69
Sulphate	(mg SO_4^{2-}/L)	62.53	107.80
Phosphate	(mg PO_4^{3-}/L)	339	276.82
Chloride	(mg Cl^-/L)	242	240.00
Alkalinity	(mval/L)	73	28
Absorbance U_{254}	(1/cm)	0.247	0.184

Table 2
The chemical constitution of a reject water after MF and NF in the first experiment

Parameter	Unit	Reject water after MF	Variability of NF permeate composition during all tests
Ammonium	(mg NH_4^+/L)	21.56	0.14–186.72
Nitrate	(mg NO_3^-/L)	500.03	175.77–1,835.95
Nitrite	(mg NO_2^-/L)	1,421.14	67.72–3,060
Conductivity	(μS/cm)	8,119	2,705–7,283
pH	(–)	8.40	8.10–9.00
Turbidity	(NTU)	32.6	0.11–1.20
Sulphate	(mg SO_4^{2-}/L)	411.4	42.78–460.80
Phosphate	(mg PO_4^{3-}/L)	68.73	0.61–32.21
Chloride	(mg Cl^-/L)	167	139–341
Alkalinity	(mval/L)	44	11–29
Absorbance U_{254}	(1/cm)	0.190	0.042–0.109

Table 3
The chemical constitution of a reject water after MF and NF in the second experiment

Parameter	Unit	Reject water after MF	Variability of NF permeate composition during all tests
Ammonium	(mg NH_4^+/L)	10.607	0.026–17.79
Nitrate	(mg NO_3^-/L)	119.57	268.95–863.97
Nitrite	(mg NO_2^-/L)	3,703.92	733.63–3,381
Conductivity	(µS/cm)	4,972	3,098–4,209
pH	(–)	8	7.70–9.90
Turbidity	(NTU)	1.08	0.14–1.20
Sulphate	(mg SO_4^{2-}/L)	194.2	118.50–954.50
Phosphate	(mg PO_4^{3-}/L)	185.7	0.46–49.58
Chloride	(mg Cl^-/L)	183	129.8–302.00
Alkalinity	(mval/L)	21	7–15
Absorbance U_{254}	(1/cm)	0.146	0.006–0.115

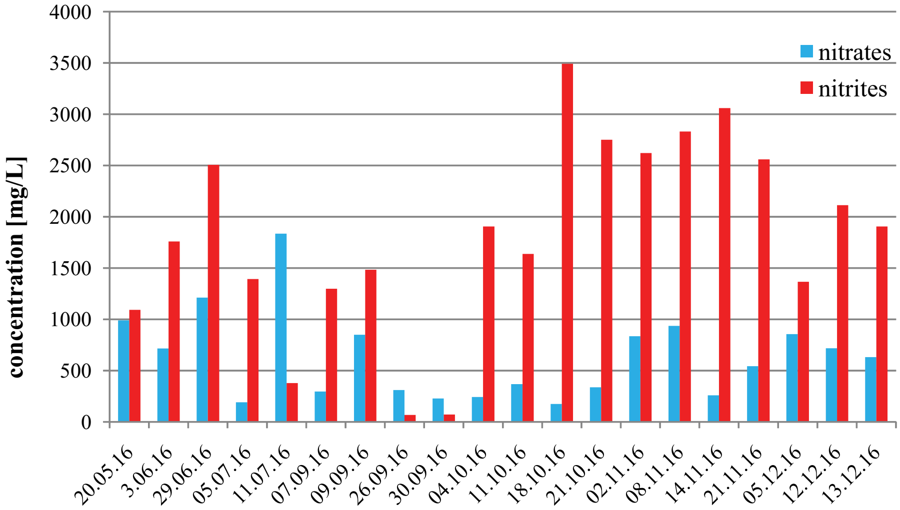

Fig. 3. Changes of nitrates and nitrites concentration in the IE feed tank in the first experiment.

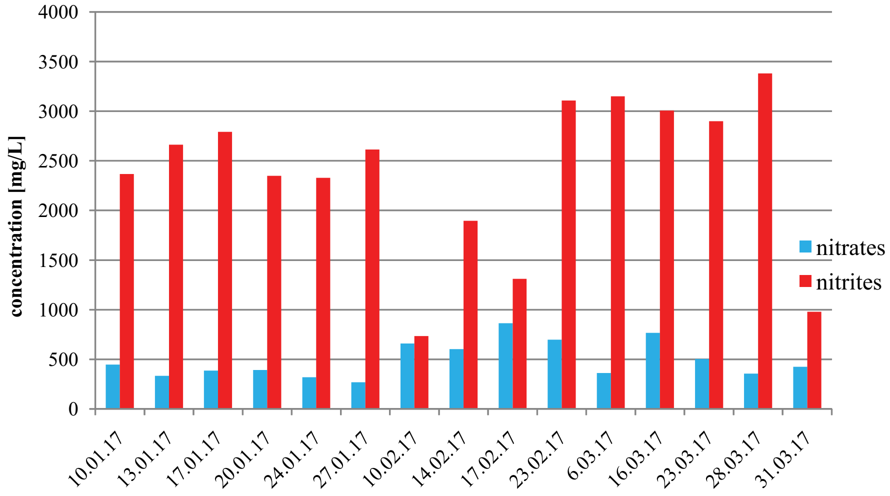

Fig. 4. Changes of nitrates and nitrites concentration in the IE feed tank in the second experiment.

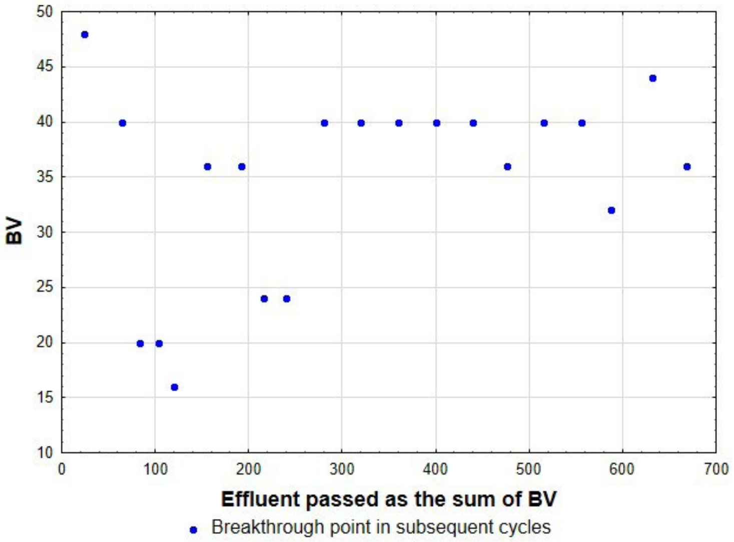

Fig. 5. The changes in total capacity in the first experiment.

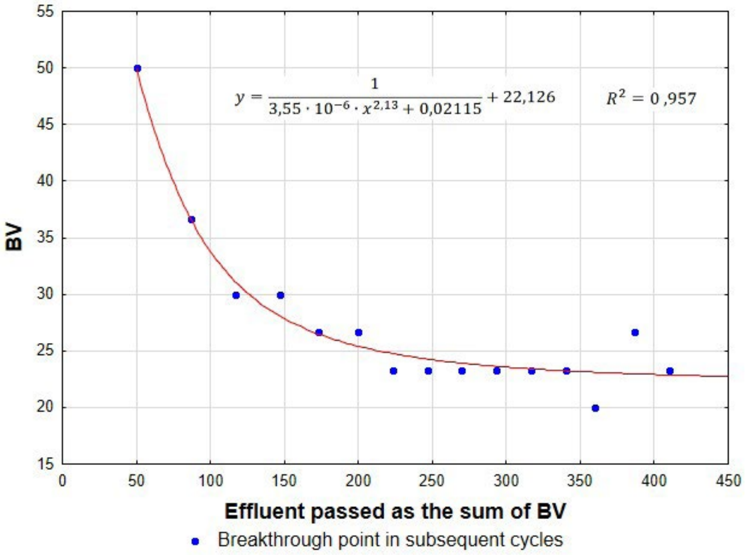

Fig. 6. Decrease of total capacity in the second experiment.

nitrogen forms in the IE feed tank (Fig. 3). On the contrary, in the second experiment (resin regenerated with 10% $NaHCO_3$) the differences in the number of nitrites in the feed were much lower, which enabled to describe the decrease of the total capacity of the anion exchanger by means of non-linear regression function (Fig. 6). The experimental data were fitted to the regression function, expressed by Eq. (1):

$$y = \frac{1}{a \cdot x^b + c} + d \tag{1}$$

where x = effluent passed through an anion exchanger as the sum of BV; y = nitrite breakthrough point in subsequent cycles as BV; a, b, c, d = estimated parameters.

The highest concentration of nitrites was determined in the samples of eluate 2 in both experiments (Figs. 7 and 8). The nitrites concentration in the eluate 2 from 10% NaCl regeneration varied from ca. 8,600 mg/L to ca. 51,850 mg/L with median value of ca. 43,500 mg/L. 85% of the eluate samples contained more than 20,000 mg NO_2/L, and 30% (6 samples) more than 50,000 mg NO_2/L. Only in three samples of the eluate, the concentration of nitrites was below 2%.

Nitrites concentration in the eluate 2 from 10% $NaHCO_3$ regeneration varied from ca. 9,950 to 44,535 mg/L with median value of ca. 26,210 mg/L. 67% of the eluate samples contained more than 20,000 mg NO_2/L, and 20% (3 samples) more than 35,000 mg NO_2/L. In five samples of the eluate, the concentration of nitrites was below 2%.

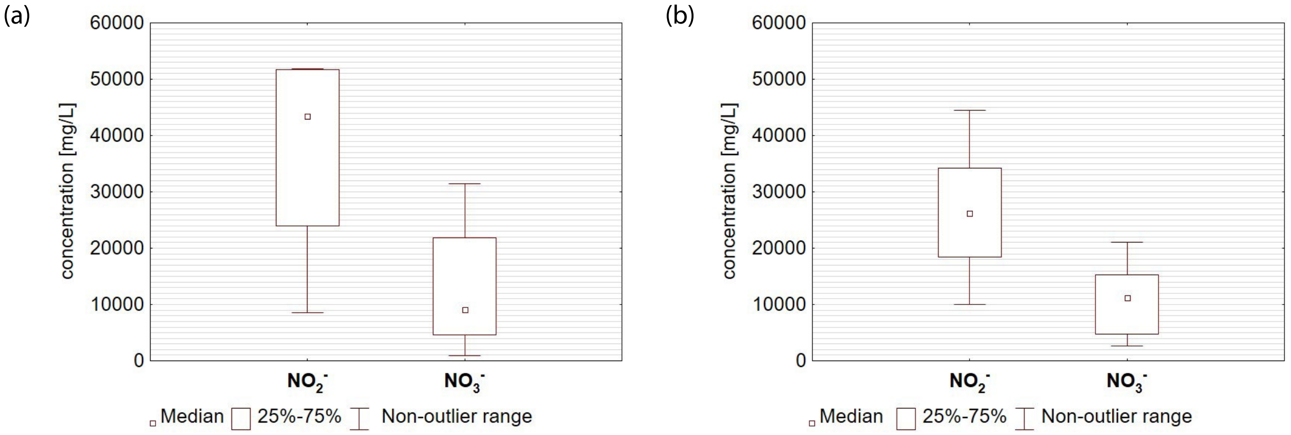

Fig. 7. Nitrite and nitrate concentration in eluate 2 from (a) 10% NaCl and (b) 10% $NaHCO_3$ regeneration.

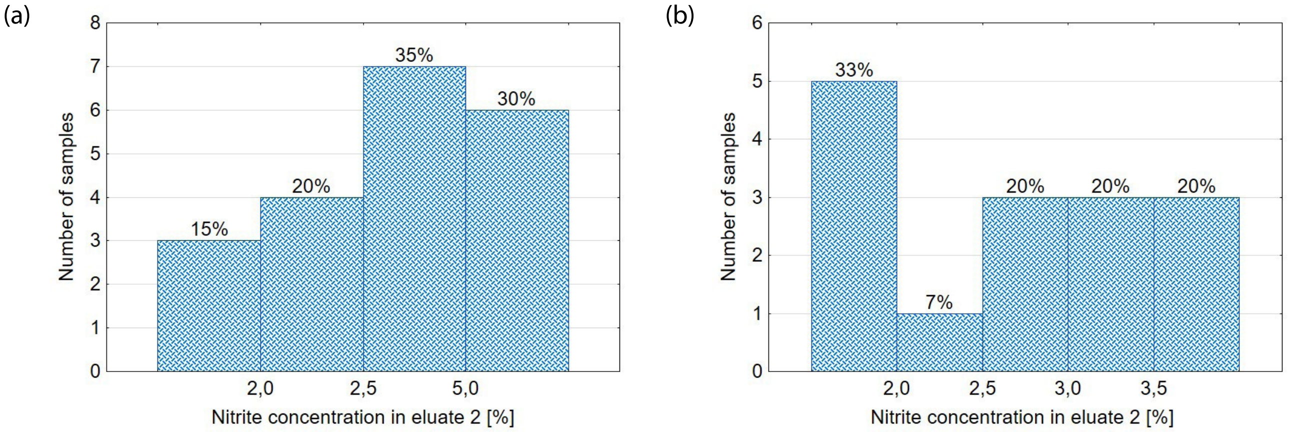

Fig. 8. Frequency distribution of nitrite concentration in eluate 2 from (a) 10% NaCl and (b) 10% $NaHCO_3$ regeneration.

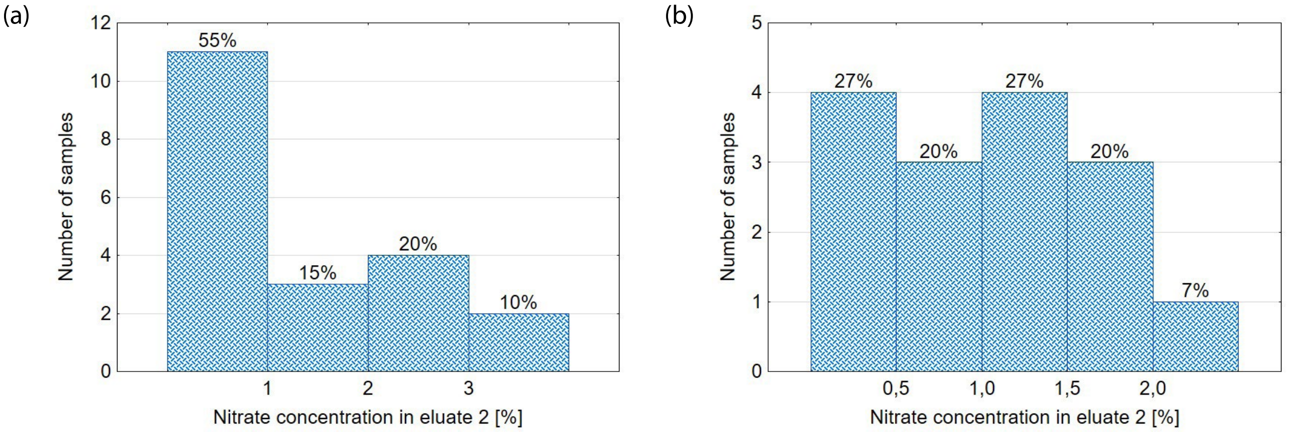

Fig. 9. Frequency distribution of nitrate concentration in eluate 2 from (a) 10% NaCl and (b) 10% $NaHCO_3$ regeneration.

At this stage of regeneration in ca. 50% of eluate 2 samples (in both experiments) nitrate concentration exceeded 1% (Figs. 7 and 9).

The nitrite concentration in eluate 2 samples was 9.5 to 46.6 times higher than in feed in the first experiment and 4.2 to 26.7 times higher than in feed in the second experiment. To the authors' knowledge, there is a lack of research on concentrating on nitrites in wastewater by means of ion exchange. Häyrynen et al. [35] applied reverse osmosis (RO) membrane to separate ammonium and nitrate from mine water prior to further treatment in bioreactors. Nitrate was enriched 5.7 times by RO (from 20.7 mg N–NO_3/L in feed mine water to 118 mg N–NO_3/L after RO).

Better results in terms of producing the nitrite concentrate were obtained in the first experiment when 10% NaCl was used to regenerate the resin, but the eluate was more aggressive to the environment and sewer pipes due to higher concentration of chlorides and sulfates. The chlorides concentration (Figs. 10–12) amounted to (median values): ca. 340 mg/L (eluate 1), ca. 6,660 (eluate 2) and 100 mg/L (eluate 3). In the eluate samples taken at the same stages of regeneration conducted with the aid of 10% $NaHCO_3$ (Figs. 13–15) the concentration of chlorides (median values) was: 780 mg/L (eluate 1), 1 770 mg/L (eluate 2) and ca. 12.5 mg/L (eluate 3). In the samples of eluate 2 the concentration of ca. 470 mg/L and ca. 5,370 mg/L of sulfates (median values) was determined in the first and the second experiment respectively. Such a high amount of chlorides and sulfates (2nd experiment) in eluate 2 disqualified it from the environmental utility as a fertilizer (acidification of soil and aquifer) and alternative electron acceptor for inhibition of H_2S formation in sewers (pipes corrosion). A similar quantity of sulfates was measured in the eluates 1 and 3, although the number of nitrites in the eluate 1 from 10% $NaHCO_3$ regeneration was nearly twice as high as the number of nitrites during 10% NaCl regeneration (Figs. 10 and 13) with median values of ca. 8,000 mg/L and ca. 4,000 mg/L respectively. Unfortunately, the number of chlorides in the eluate 1 sample from 10% $NaHCO_3$ regeneration was also twice as high as from 10% NaCl regeneration.

To the authors' knowledge, there is a lack of research on nitrite concentrate (produced from real wastewater) application to limit the H_2S formation in sewers. There are investigations conducted on a laboratory scale in which prepared solution of sodium nitrate was applied to control H_2S emission [28,36,37] as well as in the pilot or plant scale in which concentrated calcium nitrate (Nutriox™) was applied [27,38,39]. Hobson and Yang [38] obtained elimination of 95% of sulfide (concentration in upstream of 9.6 mg S/L) by the addition of Nutriox™ (where N–NO_3 to S was added in a ratio of 0.6:1 by weight). Einarsen et al. [39] in plant scale eliminated 95%–100% of sulfide (concentration in upstream of 70 mg S/L) by means of Nutriox™ (where N–NO_3 to S was added in a ratio of 2.5:1 by weight) [39]. Taking into account that in these investigations prepared nitrate solutions and not the real wastewater was used to eliminate H_2S nuisance, it is difficult to anticipate how the presence of other anions (chloride, sulfate) in produced concentrate would affect the inhibition of H_2S formation in sewers.

Since the addition of 1 g/L of nitrate to sewage sludge enabled prevention of sulfide production [28], the only eluate, which could be potentially applied to inhibit H_2S formation is the eluate 1 from 10% NaCl regeneration. In 90% of samples of this eluate, the nitrite concentration was higher than 1 600 mg/L (Fig. 16) and the average amount of other anions reached the values close to the maximum ones determined in municipal sewage [40]. Therefore, this first eluate from 10% NaCl regeneration could be used to check whether the formation of H_2S would cease.

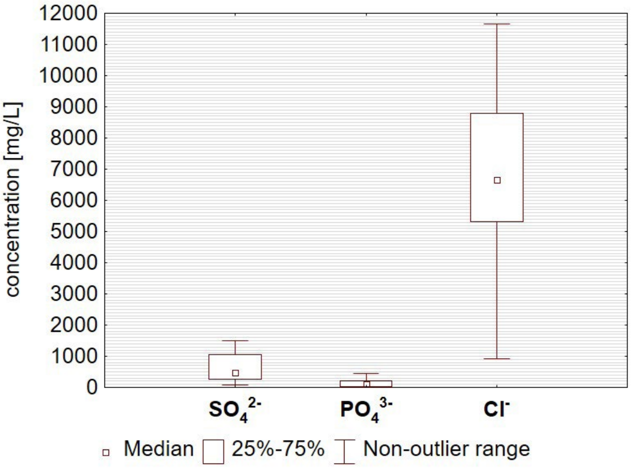

Fig. 11. Anions concentration in eluate 2 from 10% NaCl regeneration.

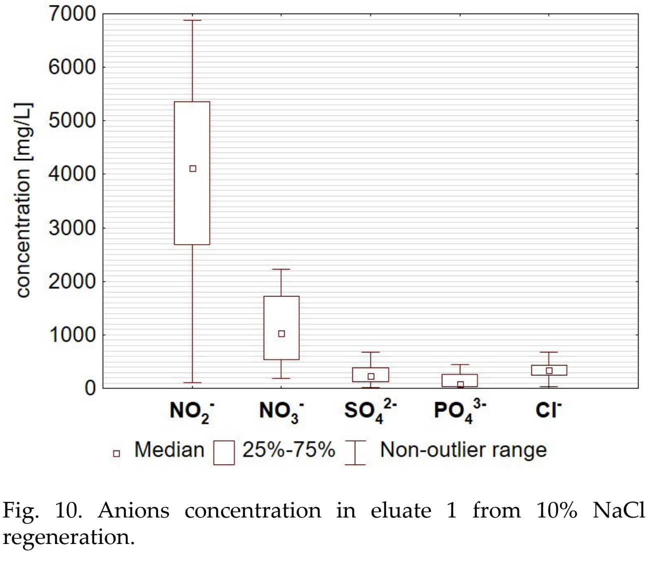

Fig. 10. Anions concentration in eluate 1 from 10% NaCl regeneration.

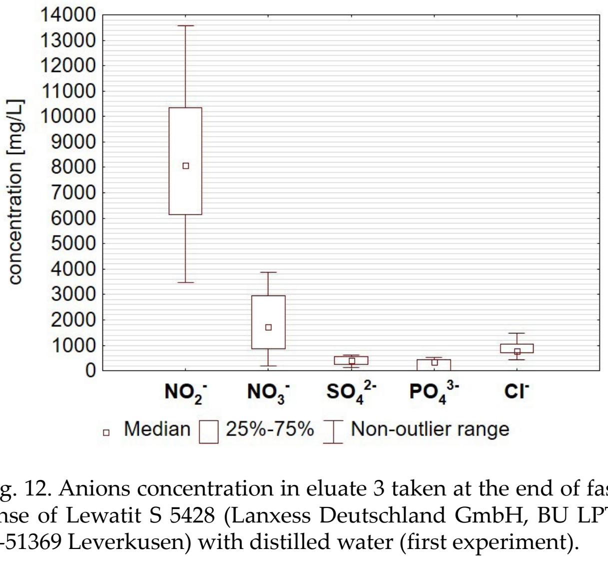

Fig. 12. Anions concentration in eluate 3 taken at the end of fast rinse of Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) with distilled water (first experiment).

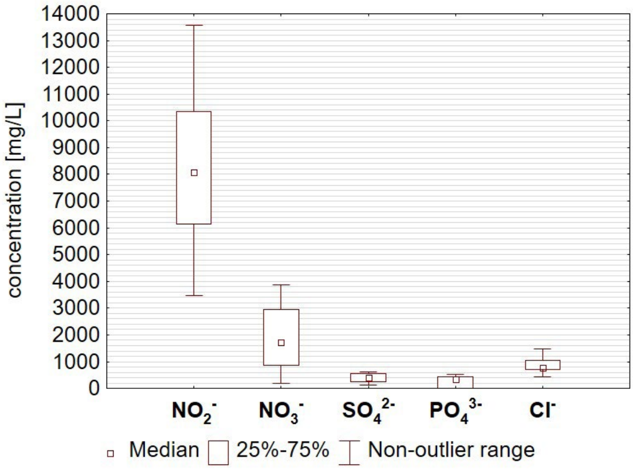

Fig. 13. Anions concentration in eluate 1 from 10% $NaHCO_3$ regeneration.

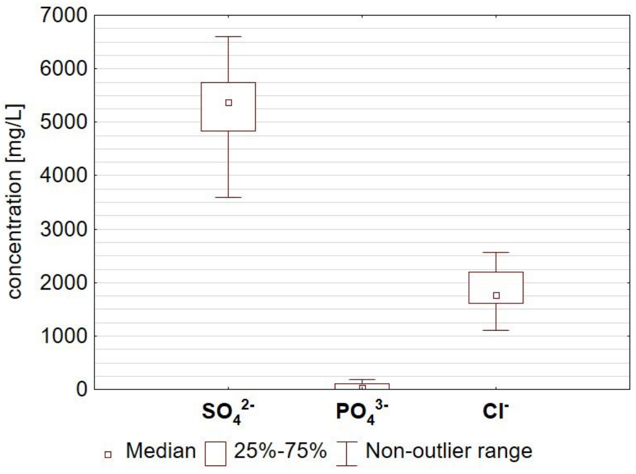

Fig. 14. Anions concentration in eluate 2 from 10% $NaHCO_3$ regeneration.

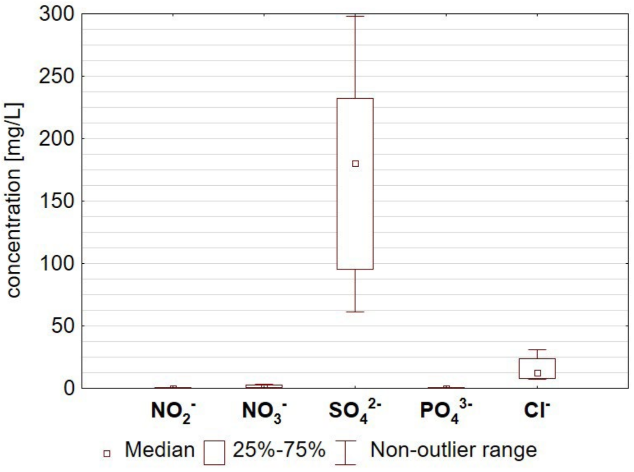

Fig. 15. Anions concentration in eluate 3 taken at the end of fast rinse of Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) with distilled water (second experiment).

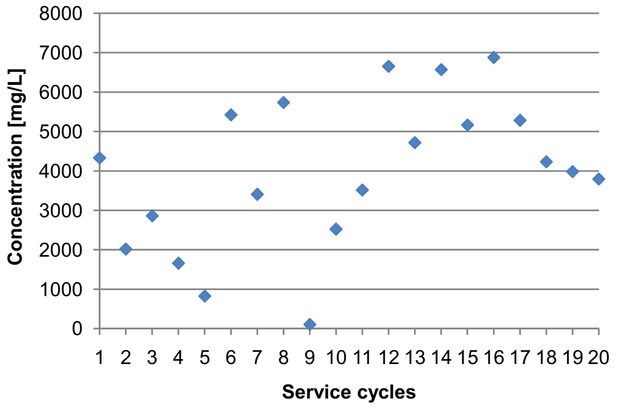

Fig. 16. Nitrite concentration in eluate 1 from 10% NaCl regeneration.

The conducted research demonstrated that the main goal of producing the concentrate with a high concentration of nitrites (above 2%) from a digester reject water at the municipal WWTP was achieved regardless of the regenerant (NaCl or $NaHCO_3$) used in Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) regeneration. Unfortunately, despite receiving the concentration of nitrites at the desired level, plenty of difficulties characteristic for the treatment of the real wastewater, not the prepared solution occurred. The first difficulty was associated with the presence of competitive ions such as chlorides, sulfates and phosphates in the effluent, which caused the decrease of the total capacity of the anion exchanger. In addition, the presence of humic acids, responsible for organic fouling, irreversibly decreased the total capacity of the resin, despite the application of NF prior to IE, which was the subject of the studies published in the other work [34]. The storing of NF permeate in the tank, prior to its further direction onto the IE column, significantly altered its constitution because of the occurrence of the reduction and oxidation processes. Moreover, the necessity of completing the IE feed tank with the fresh permeate additionally hindered the control over the IE process, which was therefore very unstable. Another hindrance associated with the utility of produced concentrate resulted from the high amount of chlorides and sulfates in the eluate, despite obtaining a high concentration of nitrites (4.35% and 2.62% during the main stage of 10% NaCl and 10% $NaHCO_3$ regeneration, respectively). Consequently, the environmental utility of the produced nitrite concentrate as a fertilizer was excluded. The only sample of eluate which could be applied in practice was the eluate 1 from the sodium chloride regeneration. In this case, the concentration of nitrites was lower than in eluate 2, but the number of aggressive anions was much lower, which enables to check its impact on the reduction of H_2S nuisance.

4. Conclusions

The main goal of the conducted research, which was the recovery of nitrogen contained in digester reject water as nitrite concentrate with a high amount of nitrites (above

2% of concentration) from digester reject water at the municipal WWTP was achieved regardless of the regenerant (NaCl or $NaHCO_3$) used in Lewatit S 5428 (Lanxess Deutschland GmbH, BU LPT, D-51369 Leverkusen) regeneration. Unfortunately, despite receiving the concentration of nitrites at the desired level, plenty of difficulties characteristic for the treatment of the real wastewater, not the prepared solution occurred. These included changes of the effluent constitution during storing (disruption of the control over the IE process), the presence of competitive anions and humic acids (changes of IE service cycles duration, organic fouling), high amounts of aggressive anions (chlorides, sulfates) in the eluate, even during $NaHCO_3$ regeneration. The aforementioned difficulties caused the proposed method of nitrite concentrate production to be very unstable. Furthermore, the presence of high amounts of chlorides and sulfates in eluate excluded its environmental utility as fertilizer (due to salinity of soil and aquifer). However, the eluate 1 from 10% NaCl regeneration could be used to check its impact on the reduction of H_2S nuisance in sewers because the obtained concentration of nitrites was high (in 90% of samples higher than 1,600 mg/L) and aggressive anions were at the levels present in municipal sewage.

Further research should be targeted at the elimination of storing of IE feed. The whole process would be then more stable, as there would be no problems with changes of IE feed constitution during storing and no necessity of periodic completion of IE feed tank with fresh part of effluent. Therefore the whole process of producing nitrite concentrate should be conducted continuously, so NF permeate would be directed straight on the IE column.

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