



Recovery of Nutrients from Wastewater via Electrodialysis

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Abstract

The need to treat wastewater in a sustainable way to minimize contamination and maximize the recovery of nutrients is widely recognized. The focus is mainly on the removal and recovery of nutrients because of eutrophication problems in receiving waters, limitations of mining resources and high costs affiliated with nutrient production. Removal of nutrients is also a growing problem for water authorities, as authorities often tighten standards of discharged waters to avoid unnecessary discharge of nutrients into water bodies.

The universally used technologies for nitrogen and phosphorus removal involve biological nitrification and denitrification and metal salt precipitation. However, applying these technologies nutrients are made unrecoverable for fertilizing. Electrodialysis (ED) is a membrane process capable of concentrating and separating ions from wastewater. Thanks to the applied current, the migration of ions occurs, and ions are concentrated in the concentrate solution. Laboratory scale ED showed the potential of nutrient recovery from wastewater sources.

In this study, nutrients were recovered in concentrate solution from wastewater sludge liquid discharge by using electrodialysis. Calcium and sodium values in concentrated solution increased 10 times, values of potassium and chloride 5 times. The amount of ammonia nitrogen raised from 60 mg/l to 1700 mg/l. The concentrate enriched by nutrients may be used in further processes, e.g. phosphorus and ammonia nitrogen can be precipitated into the form of struvite.

Keywords: electrodialysis, nutrient recovery, wastewater sludge, ammonia recovery

Introduction

The biologically treated secondary effluent from existing wastewater treatment plants still contain a certain amount of nutrients (such as NO_3^- and HPO_4^{2-}) (Zuo, 2014) and salinity (such as Na^+ , Ca^{2+} , K^+ , Mg^{2+} and Cl^-). The insufficient treatment could lead to eutrophication (Wang, 2015) and influence the reuse of reclaimed water (Liang, 2013). Moreover, phosphorus is an important mineable resource (Wang, 2013), and recovering phosphorus (P) from wastewater streams for reuse can alleviate the problem of limited phosphate resource supply (O'Neal, 2013).

N and P contents in wastewater and surface water are increasing, while the reservation resources of them are being depleted, especially for phosphorus. N and P may thus be recovered from wastewater or surface water. After making a general survey of activated sludge process, interests in recovering nitrogen and phosphorus focus on the excess sludge developed based on some additional reforming operation and newly introduced technologies (Tong, 2009; Wang, 2013). Anaerobic digestion process can achieve the degradation of organic matters and the formation of biogas, and it has been widely used to treat the excess sludge. Sidestreams, or "return liquors", typically have a very high concentration of ammonia and phosphorus because they are released in the anaerobic digestion process: Ammonia is produced by the biological degradation of the nitrogenous matter, such as bacteria, proteins and urea; Phosphorus is produced by re-solution of

the part incorporated into bacterial biomass in the enhanced biological phosphorus removal (EBPR) process (Münch, 2001). It is unwise to return the solution rich in ammonia and phosphorus back to the sewage treatment plant, because the containing nutrients will be aggregated in the newly produced excess sludge rather than through decontamination.

Recently, membrane filtration technologies, such as reverse osmosis (RO), nanofiltration (NF) and electrodialysis (ED), have drawn much attention to desalinate and recover useful materials in wastewater treatment (Werner, 2013). Pressure membrane processes, such as RO and NF, need a quite complex pretreatment to alleviate the membrane fouling (Jamaly, 2014; Byun, 2015), resulting in needless capital cost and energy consumption. Furthermore, RO is ion uncontrollable and highly relying on the size of molecules (Kwak, 2013). However, as an electrochemical membrane separation process, ED is capable of separating undesired ions from wastewaters more energy-efficient (Vaselbehagh, 2015) with an applied electric field as the driving force to get a higher water recovery (Kwak, 2013).

Materials and Methods

Feed water for this experiment consisted of wastewater sludge liquid discharge. The samples of wastewater were recovered three times over period of six weeks. Each sample was analyzed and run through electrodialysis (ED). The chemical analysis of the feed water used in this experiment is

Tab. 1. Physicochemical analysis of feedwater
 Tab. 1. Analiza fizykochemiczna wody zasilającej instalację

Physicochemical characteristics	Sample A	Sample B	Sample C
pH [-]	6.56	7.83	7.99
Turbidity [FNU]	110.58	103.91	116.63
Conductivity [mS/cm]	2.03	5.67	5.80
COD [g/l]	438.59	316.87	331.18
Dissolved particles [mg/l]	1.11	0.95	1.12
Ammonia nitrogen [mg/l]	59.01	753.21	776.50
Phosphorus [mg/l]	55.42	52.81	50.68
Chloride [mg/l]	95.48	97.50	92.18

Tab. 2. AAS analysis of feedwater
 Tab. 2. Analiza AAS wody zasilającej

Chemical elements	Sample A	Sample B	Sample C
Zn [mg/l]	0.027	0.036	0.012
Cu [mg/l]	0.071	0.031	<0.010
Ni [mg/l]	0.026	0.037	0.028
Fe [mg/l]	0.073	1.880	1.030
Mn [mg/l]	0.048	0.036	0.060
Ca [mg/l]	29.500	64.200	40.600
Mg [mg/l]	29.800	16.500	18.700
K [mg/l]	107.000	80.100	98.100
Na [mg/l]	171.000	95.300	105.000

shown in Table 1. The feed water was pre-treated by vacuum filtration.

Feed water was also analyzed by atomic absorption spectroscopy (AAS) to find out if the samples contained heavy metals. The AAS analysis is shown in Table 2.

A laboratory-scale electro dialysis module ED(R)-Z setup was used in this study, and it was composed of electrode compartments, concentrated compartments, and diluted compartments. Compartments were separated by cation/anion exchange membranes, silicone gaskets and plastic partition nets. In addition, the specific parameters are summarized in Table 3. The membranes used in electro dialysis included cation exchange membranes and anion exchange membranes.

Result and Discussion

Concentrated solution from electro dialysis was obtained in total volume 0.5 l per sample and was analyzed, along with dilute (2 l per sample), in laboratory and by AAS. Samples of concentrated solutions were kept in a dark and cold place. Analysis was conducted the next day in the laboratory. Results of the concentrated solution analysis are shown in Table 4.

Samples were preserved with nitric acid and analyzed by AAS. Results of the concentrated solution analysis are shown in Table 5.

As it is clear from the presented results, the ED process was successful in concentrating elements, such as ammonia nitrogen, chloride, calcium, potassium and sodium. These elements, along with phosphorus, are essential plant macronutrients.

K can occur in unavailable, slowly available, or readily available forms in soils. Only a small amount of slowly avail-

able K is available for plant uptake during a single growing season. Readily available K is dissolved in the soil solution and readily taken up by plants. Potassium uptake is affected by soil moisture content, soil aeration and oxygen level, soil temperature, and competing ions.

Like K, Ca and Mg in soils originate from decomposition of bedrock and minerals that contain these elements. Compared to other minerals, Ca weathers relatively quickly and can become unavailable to plants via leaching in highly weathered (mature) soils.

Sodium is not an essential element for plants but can be used in small quantities, similar to micronutrients, to aid in metabolism and synthesis of chlorophyll. In some plants, it can be used as a partial replacement for potassium and aids in the opening and closing of stomates, which helps regulate internal water balance. Chloride is needed in small quantities and aids in plant metabolism, photosynthesis, osmosis (movement of water in and out of plant cells) and ionic balance within the cell.

Conclusion

The results demonstrate that a concentrated product could be achieved by concentrating nutrient ions from wastewater sludge liquid discharge to concentrate product stream via the ED process. The concentrated solution contains ions in a soluble form, therefore there is a need to continue this research and precipitate the said ions into forms that may be used as fertilizers.

Ammonia nitrogen and phosphorus could be precipitated into the form of magnesium ammonium phosphate, which is known to be an ideal alternative fertilizer since it is a non-odorous, non-sludgy crystal which releases nutrients slowly.

Tab. 3. Parameters of the electro dialysis module ED(R)-Z

Tab. 3. Parametry modułu do elektrodializy ED (R)-Z

Item	Parameters	Item	Parameters
Number of membrane pairs	10 pairs	Number of electrode cells	2
Number of dilute cells	10	Installed membrane area	2646 cm ²
Number of concentrate cells	10	Effective membrane area	1344 cm ²

Tab. 4. Physicochemical analysis of concentrated solution

Tab. 4. Analiza fizykochemiczna stężonego roztworu

Physicochemical characteristics	Sample A	Sample B
pH [-]	8.06	7.99
Turbidity [FNU]	46.32	43.13
Conductivity [mS/cm]	16.99	17.68
COD [mg/l]	410.00	381.18
Dissolved particles [g/l]	5.79	3.27
Ammonia nitrogen [mg/l]	1 739.36	2 795.40
Phosphorus [mg/l]	73.54	71.72
Chloride [mg/l]	489.62	480.39

Tab. 5. AAS analysis of concentrated solution

Tab. 5. Analiza AAS stężonego roztworu

Chemical elements	Sample A	Sample B
Zn [mg/l]	0.025	0.029
Cu [mg/l]	0.032	0.019
Ni [mg/l]	0.047	0.033
Fe [mg/l]	0.064	0.300
Mn [mg/l]	<0.010	<0.0100
Ca [mg/l]	290.000	608.450
Mg [mg/l]	68.100	19.700
K [mg/l]	439.000	375.000
Na [mg/l]	1660.000	693.000

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Odzyskiwanie składników odżywczych ze ścieków przez elektrodializę

Powszechnie uznaje się potrzebę oczyszczenia ścieków w zrównoważony sposób w celu zminimalizowania zanieczyszczenia i maksymalizacji odzysku składników odżywczych. W artykule skupiono się na usuwaniu i odzyskiwaniu składników odżywczych ze względu na problemy z eutrofizacją w wodach, ograniczenia zasobów górniczych i wysokie powiązania z produkcją składników nawozowych. Usunięcie składników nawozowych jest również coraz większym problemem dla gospodarki wodnej z uwagi na coraz bardziej rygorystyczne wymagania prawne i zaostrzające się standardy. Powszechnie stosowane technologie usuwania azotu i fosforu to biologiczna nityfikacja i denityfikacja i strącanie soli. Jednakże tak uzyskane składniki stają się niezdadne dla nawożenia. Elektrodializa (ED) jest procesem membranowym służącym do koncentracji i wydzielania jonów ze ścieków. Dzięki zastosowanemu prądowi następuje migracja jonów i są one skoncentrowane w roztworze. Badania w skali laboratoryjnej wykazały potencjał odzysku składników odżywczych ze ścieków za pomocą elektrodializy. W przeprowadzonych badaniach wykazano efektywność odzysku składników odżywczych w procesie elektrodializy. Zawartości wapnia i sodu w stężonym roztworze wzrosły 10 razy, zawartości potasu i chlorku 5 razy. Ilość azotu amoniakalnego wzrosła z 60 mg/l do 1700 mg/l. Koncentrat wzbogacony w składniki odżywcze można stosować w dalszych procesach, np. azotan fosforu i amoniaku można wytrącić do postaci struwitu.

Słowa kluczowe: elektrodializa, odzyskiwanie składników odżywczych, osad ściekowy, odzysk amoniaku