Is Sludge Water Diluate Stream from Electrodialysis Suitable for Agricultural Purposes?

Michaela ČERVENKOVÁ[1)], Katrin CALÁBKOVÁ[2)]

[1)] VSB-Technical University of Ostrava, Faculty of Mining and Geology, 17. listopadu Str. 15, 708 33 Ostrava-Poruba, Czech Republic; email: michaela.cervenkova@vsb.cz
[2)] VSB-Technical University of Ostrava, Faculty of Mining and Geology, 17. listopadu Str. 15, 708 33 Ostrava-Poruba, Czech Republic; email: katrin.calabkova@vsb.cz

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Abstract

Sludge water, a product of drainage of primary and activated sludge from the municipal wastewater treatment process, is rich in nutrients, particularly nitrogen and phosphorus. Nitrogen and phosphorus are inorganic biogenic substances suitable for plant nutrition. Sludge water can be treated via electrodialysis. This process leads to two products, one is a diluate stream (solution less concentrated than the input, contains some nutrients) and the other is concentrate stream (solution in which nutrients are concentrated against the input). There is abundant research in nitrogen and phosphorus recovery from the concentrate stream, for example in the form of struvite used for fertilizing. However, little attention has been paid to the huge volumes of diluate stream. The diluate stream can be used in agriculture as water suitable for irrigation, where the bonus of this product is a partial fertilizing capacity. This way, wastewater can be used for irrigation and fertilizing having subjected the wastewater to agrochemical analyses. An important condition for the use of sludge water or diluate stream for irrigation is the absence of heavy metals and toxic substances. Still, if the water contains heavy metals, they can be removed with a relatively high success, for example by precipitation. Using wastewaster as water for agricultural purposes for irrigation is one of the new options to find new secondary sources of water. This theme is highly topical as it is important to reduce the consumption of quality water resources. These must primarily serve for drinking purposes, and therefore it is necessary to search for alternative water resources.

Keywords: sludge water, wastewater treatment, electrodialysis, irrigation water

Introduction

This paper deals with using of sludge water in the form of diluate stream from electrodialysis for agricultural purposes, especially for irrigation.

Sludge water is one by the wastewater treatment products and contains a huge amount of substances that have entered it after its use, for example, in man or in industry. In conjunction with agricultural use, it can contain substances beneficial as nutrients (nitrogen, phosphorus, calcium, magnesium or sodium), substances unsuitable for toxic substances, heavy metals and pathogenic organisms. Sludge water is not drained from the sewage treatment plant but is returned to the sewage treatment process or it can be further purified. One of today's discussed wastewater treatment processes is electrodialysis (Goodman, 2013). Electrodialysis is an electro-membrane process whose products are concentrate stream and diluate stream (MemBrain; Palatý, 2012; Nunes, 2006). Concentrate stream is a product in which substances are concentrated to several times. This product can be used for the gaining of concentrated substances, for example nitrogen and phosphorus can be precipitated to the form of a struvite which can be used as a fertilizer. Diluate stream is a product that is depleted by electrodialysis about excess concentrations of substances, but still can contain considerable concentrations of the substances removed. In agriculture, both the products of the concentrate stream as fertilizer as well as the diluate stream can be used, especially for its huge volume, for example water suitable for irrigation.

This use of waste products (in this case, the diluate stream) is being discussed today, as droughts are increasingly frequent and new sources are being sought (Akoto, 2015) but also because it may contain substances that are undesirable for plants or soil or do not comply the required limits for irrigation water. Surface water and groundwater are primarily determined for drinking purposes, so it is necessary to look for new alternative sources for other uses, for example for irrigation in agriculture.

Water suitable for use in agriculture for irrigation is important for the growth and production of plants. Irrigation water must comply legislative requirements, for example for the Czech Republic it is a document "ČSN 75 7143 Water quality. Water quality for irrigation". These waters must comply the maximum permissible values of physical (temperature), chemical (e.g. pH, dissolved substances at 105 °C or heavy metals), biological (e.g. pathogenic) and radioactive (e.g. radon and uranium) (Výživa rostlin, 2009; ČSN 75 7143).

Wastewater and sludge water used for irrigation are potential sources of heavy metals. The content of heavy metals in irrigation water may have impacts due to the accumulation in the environment (Barla, 2017), in agricultural land (Barla, 2017; Meng, 2016; Akoto, 2015), in groundwater (Balkhair, 2016), in cultivated crops (Barla, 2017; Ray, 2017; Balkhair, 2016; Akoto, 2015) and in food (Barla, 2017), may cause health risks (Meng, 2016; Balkhair, 2016), reduce microbial soil activity (Ray, 2017) and influence food safety (Meng, 2016).

Tab. 1. Measured selected indicators and values from the Czech legislation (ČSN 75 7143)
[* water suitable for irrigation, ** water conditionally suitable for irrigation, *** water unsuitable for irrigation]
Tab. 1. Mierzone wybrane wskaźniki i wartości z czeskiego ustawodawstwa (ČSN 75 7143)
[* woda odpowiednia do nawadniania, ** woda warunkowo odpowiednia do nawadniania, *** woda nieodpowiednia do nawadniania]

Selected indicators	Input	Diluate stream	Efficiency of removal (%)	ČSN 75 7143 category I*	ČSN 75 7143 category II**	ČSN 75 7143 category III***
t (°C)	20.3	20.6	-	35	40	>40
pH (-)	7.46	6.10	-	5 to 8.5	4.5 to 9	<4.5 to >9
DS105 ($g.l^{-1}$)	1057.2	218.0	79.38	800	1200	>1200
Cd ($mg.l^{-1}$)	<0.005	<0.005	-	0.01	0.02	>0.02
Co ($mg.l^{-1}$)	<0.01	<0.01	-	0.5	1	>1
Cr_{total} ($mg.l^{-1}$)	<0.01	<0.01	-	0.2	0.5	>0.5
Cu ($mg.l^{-1}$)	0.04	0.02	50	0.5	2	>2
Mn ($mg.l^{-1}$)	21.67	0.07	99.68	3	5	>5
Ni ($mg.l^{-1}$)	0.03	0.03	0	0.1	0.2	>0.2
Pb ($mg.l^{-1}$)	<0.01	<0.01	-	0.05	0.1	>0.1
Zn ($mg.l^{-1}$)	0.03	0.03	0	1	2	>2
Fe ($mg.l^{-1}$)	0.99	1.03	-4.04	10	100	>100

Tab. 2. Measured selected indicators suitable for agriculture for plant growth
Tab. 2. Mierzone wybrane wskaźniki odpowiednie dla rolnictwa dla wzrostu roślin

Selected indicators	Input	Diluate stream	Efficiency of removal (%)
$N\text{-}NH_4^+$ ($mg.l^{-1}$)	70.62	69.36	1.78
$N\text{-}NO_2^-$ ($mg.l^{-1}$)	0.77	0.44	40.26
$N\text{-}NO_3^-$ ($mg.l^{-1}$)	0.88	0.32	63.64
P_{total} ($mg.l^{-1}$)	52.97	7.80	85.27
Ca ($mg.l^{-1}$)	44.77	0.10	99.78
Mg ($mg.l^{-1}$)	21.67	0.07	99.68
Na ($mg.l^{-1}$)	122.77	40.40	67.09

Beneficial indicators of proper concentration in irrigation water are, for example, nitrogen, phosphorus, calcium, magnesium, sodium, but also some heavy metals in trace amounts. In irrigation waters, concentrations of heavy metals, toxic substances and pathogenic organisms which have a phytotoxic effect on the growth and germination of cultivated plants are not suitable. For water use in agriculture, agrochemical analysis of water is required. For example, pH, nitrogen (ammonia, nitrite and nitrate), phosphorus, calcium and magnesium, organic contaminants (polychlorinated biphenyls) and microbiological indicators are monitored (Výživa rostlin, 2009).

This paper summarizes and compares the parameters as pH, temperature, dissolved substances and selected heavy metals (iron, manganese, lead, zinc, copper, chromium, cadmium, cobalt and nickel), but also nitrogen (ammonia, nitrite and nitrate), calcium, magnesium and sodium.

The sludge water, respectively the diluate stream contains nitrogen and phosphorus, which are important for plant growth. If it contains heavy metals and toxic substances can not be used in agriculture or have to be removed, heavy metals for example by precipitation at the appropriate pH.

Irrigation water is water that serves to irrigate the plants in order to grow them. It is a water that does not influence the state of health of people and animals, the amount of yields and crop quality, soil properties, the quality of surface water and groundwater and other environmental compartments. The quality of irrigation water depends on the soil and climatic conditions, the way of irrigation and the type of crops to be grown. Irrigation water is divided into three categories (ČSN 75 7143):

- category I – water suitable for irrigation; water for irrigation of all cultures without restrictions.
- category II – water conditionally suitable for irrigation; water that can be used provided that the degree and character of water pollution or local conditions are determined. It is necessary to register the amount and composition of irrigation water
- category III – water unsuitable for irrigation; this water that can be used for irrigation only after treatment to obtain the quality of the above-mentioned categories or to be used for irrigation according to the assumption of wastewater utilization.

The results of selected sludge water quality indicators are recorded and compared with normative values (ČSN 75 7143) when this water is suitable or unsuitable for use in agriculture as water for irrigation. Only physical and chemical indicators were determined for this research.

Another research that can be continue on the subject is, for example, testing the phytoxicity of the diluate stream on plants (Garden cress – Lepidium satuvum or Mustard white – Sinapis alba) or testing nutrients for soil and cultivated plants.

Materials and methods

For this paper, sludge water was used in the form of a diluate stream from electrodialysis. The electrodialysis was carried out on the waters collected at the sewage treatment plant. Samples were taken in three terms.

The quality of the sludge water (input) and the diluate stream itself has been evaluated by the laboratory analysis using selected physical and chemical parameters. Chemical parameters were pH, temperature, dissolved substances, ammoniacal nitrogen, nitrite nitrogen, nitrate nitrogen, total phosphorus, calcium, magnesium, sodium and selected heavy metals (cadmium, cobalt, total chromium, copper, manganese, nickel, lead, zinc and iron).

The sludge water was treated by electrodialysis to produce two products: concentrate stream and diluate stream, which is the aim of this research. Since three sampling was performed, the averages of these measured values were reported in the tables.

The diluate stream was subjected to laboratory analysis. Selected heavy metals, calcium, magnesium and sodium were analyzed by atomic absorption spectrophotometry (AAS), total phosphorus and nitrogen forms by traditional titration methods, pH and temperature by pH probe and dissolved substances drying at temperature 105°C.

The determination results were registered in the tables.

Results and discussion

This section summarizes the measured results of the input values and the dilution stream from electrodialysis of selected sludge water indicators.

Table 1 summarizes measured and legislative physical and chemical indicators. Depending on the measured values, the diluate stream can be used as water suitable for irrigation and this falls according to the standard in category I. Sludge water (input) before electrodialysis comply Category I requirements in pH, Cd, Co, Crtotal, Cu, Ni, Pb, Zn and Fe; Mn and dissolved substances (DS105) do not comply the conditions but can be removed from the diluate stream. The temperature indicator does not comply the limits because it is influenced by the temperature in the laboratory.

The removal efficiency for manganese was 99.68% for dissolved substances 79.38% and for copper 50%. Concentrations of cadmium, cobalt, total chromium and lead were very small and undetectable.

The nickel and zinc indicators have not been removed, yet they meet the limits for irrigation water. Conversely, the iron concentration increased during the electrodialysis process, maybe due to iron precipitation on the surface of the membranes.

Table 2 summarizes indicators that are suitable for plant growth in a reasonable amount, i.e. ammoniacal nitrogen, nitrite nitrogen, nitrate nitrogen, total phosphorus, calcium, magnesium and sodium. These are substances that are found in traditional fertilizers. By electrodialysis, the concentrations of all indicators were reduced in sludge water: calcium and magnesium with very high efficiency (99.68% and 99.78%), total phosphorus with an efficiency of 85.27%, sodium with an efficiency of 67.09%. Particular forms of nitrogen have also been removed, but it is very likely that the various forms are transformed among themselves.

Conclusion

This paper is related with possible using sludge water in the form of a diluate stream from electrodialysis based on selected physical and chemical indicators; biological and radioactive indicators were not explored in this research. On the base of the selected legislative regulation (ČSN 75 7143) and selected indicators, the diluate stream was evaluated as a product comping the chemical indicators for irrigation water. Nutrients (nitrogen forms, total phosphorus, calcium, magnesium and sodium) remain in the diluent stream and can therefore be considered water suitable for irrigation with fertilizer effect.

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Czy strumień rozrzedzonej cieczy znad elektrodializy nadaje się do celów rolniczych?

Woda ze szlamów, produkt drenażu osadu pierwotnego i aktywnego z procesu oczyszczania ścieków komunalnych, jest bogata w składniki odżywcze, w szczególności azot i fosfor. Azot i fosfor to nieorganiczne substancje biogenne nadające się do żywienia roślin. Woda szlamowa może być oczyszczana przez elektrodializę. Proces ten prowadzi do powstania dwóch produktów, jeden to strumień rozcieńczony (roztwór mniej skoncentrowany niż wsad, zawiera pewne składniki odżywcze), a drugi to strumień skoncentrowany (roztwór, w którym składniki odżywcze są skoncentrowane). Istnieje wiele badań nad odzyskiwaniem azotu i fosforu ze strumienia koncentratu, na przykład w postaci struwitu (fosforan magnezowo-amonowy) używanego do nawożenia. Jednak niewiele uwagi poświęcono ogromnym ilościom strumienia rozcieńczalnika. Strumień rozcieńczony może być wykorzystywany w rolnictwie jako woda do nawadniania, gdzie wartością dodaną tego produktu jest częściowa zdolność nawożenia. W ten sposób ścieki można wykorzystać do nawadniania i nawożenia, poddając ścieki analizom agrochemicznym. Ważnym warunkiem stosowania wody z szlamu lub strumienia rozcieńczonego do nawadniania jest brak metali ciężkich i substancji toksycznych. Jeśli woda zawiera metale ciężkie, można je usunąć ze stosunkowo dobrym powodzeniem, na przykład przez strącanie. Wykorzystanie wody odpadowej do celów rolniczych do nawadniania jest jedną z nowych opcji w poszukiwaniu nowych wtórnych źródeł wody. Temat ten jest bardzo aktualny, ponieważ ważne jest zmniejszenie zużycia wysokiej jakości zasobów wodnych. Woda czysta musi służyć do picia, dlatego konieczne jest poszukiwanie alternatywnych zasobów wody do celów rolnych.

Słowa kluczowe: woda nadosadowa, oczyszczanie ścieków, elektrodializa, woda do nawadniania