CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

No. 6 2011

REDUCTION OF POLLUTANT CONCENTRATIONS IN THE PLANT SYSTEMS WITH THE INERT FILTER BED. PART I: BIOLOGICAL ABSORBTION OF NITROGEN AND PHOSPHORUS IN NITROPHYTES IN MCRO - CULTIVATIONS FERTILIZED WITH DOMESTIC WASTEWATER

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The publication presents the experiment conducted on the nitrophyte plants of the species *Polygonum persicaria* L. and *Epilobium parviflorum* Schr., in the micro- cultivation with the inert filter bed filled in with an artificial aggregate, keramzite. The plants were fertilized with domestic wastewater separated in a well settling tank with the Čoanda effect separator. A chemical quantitative analysis for absorbents in the plant parts was performed after their spectrophotometric burning to ashes. The unification of the results was suggested by introducing a marker of the biological element absorption A_b, which was calculated as the ratio of the element in the plant ash to the content of the element in the plant growing in the soil. A water migration marker of the element K_x in the water solution was deduced from the ratio between the element content of dry water to its content of the eroding filter bed. A comparison was made between nitrogen and phosphorus absorption in the nitrophyte and macrophyte plants representing *Phragmites communis* Cov. and *Glyceria maxima* which revealed similarities in the absorption of biogenic elements in the vegetative parts of these plants.

Keywords: absorption, elements, migration, keramzite, nitrophytes, lithospheric clarke, separated wastewater

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1. INTRODUCTION

The beginning of 1990s originated in the use of the constructed wetlands as an alternative system to the biological wastewater treatment plants.[6,9] It needs mentioning that the first constructions of this type with phytotechnology development started in the 1950s in Israel. In Europe, the earliest works were performed in 1960s by Kathe Seidel, at Max Planc Institute of Limnology in Plon. In Poland, the beginnings were associated with the works at the Polish Academy of Sciences in 1980s. The current technical and technology level of constructed wetlands has been reached owing to numerous work of Polish experts from many centers in Poland. For the last two decades the constructed wetland technology developed with the use of the plant *Phragmites communis* Trin., and in 2009, Gajewska and Obarska - Pempkowiak shaped a new term; Hybryd Hydrophite System, HSH [5]. Numerous documented implementations of more than 1000 objects allowed for appropriate evaluation of the adopted phytotechnology [6]. At present, in parallel to the research on constructed wetlands HSH with heliophytes (the emerged plants from the phytopaludis group or the swamp plants), there have been research and experiments [4] on the nitrophytes of the generic name: *Epilobium* and *Balsaminacea,* at the The Research Station for Experimental Phytotechnologies in Młodziejowice near Kraków The experimental cultivations have been implemented on the artificial inert filter beds made of materials such as keramzite and porous clay. An application of the artificial aggregate based on materials of the natural origin like clay brings together peculiar implications. Popular aggregate types used as the film in filter beds of the hydrophyte constructed wetlands are mostly a rinsed gravel of different particle size (Brix's method) and soils with the extras (Kickuth's method). The most popular aggregate is the gravel. Additionally, Kickuth suggested using the peat, straw, bark, bentonite or iron filings. In gravel filter beds Gajewska, Obarska - Pempkowiak [5,7] suggested introducing the limestone coarse flour. It seems clear that such steps are not necessary in the case of using red ceramic scraps or more profitable material keramzite (porous clay) due to the thermo-insulation properties and wide range of metal ions inter alia iron, calcium and aluminum. The experiment was aimed at defining the intensity of biological absorption of nitrogen and phosphorus in the vegetative parts of selected nitrophytes that would be significant for their relation with popular macrophytes.

2. METHODS

The research was conducted during the years 2009-2010, at the Affiliated Research Station for Experimental Phytotechnologies in Młodziejowice near Kraków. Micro- cultivation was achieved with an under surface flow (HF-CW), in the separated area. An overflow threshold of 1.5 x 2.0 meters was constructed in a cavity of 35 centimeters below the ground level. Hydraulic insulation consisted of a polyethylene film, PE HD, 1.0 mm thick. The first basic filter layer 10 cm thick, was prepared, made of the concentrated fat clay. The second layer of known permeability at a thickness of 25 cm was an inert aggregate[1] keramzite with a grain size of 8 to 16 mm (bulk density is 740±25 $kg \cdot m^{-3}$, pH reaction equal to 6.2, thermal conductivity at the temperature 23^{o}degrees centigrade varies from 0.141 to 0.07 $W \cdot mK^{-1}$ and absorption capacity of 21.3±2.1%). Application of the micro - cultivation was achieved (in the plug-flow system) by fixing the boundary drain to a shorter side of the overflow threshold rectangle, next to the inlet. The bottom fall in the direction of the infiltrating drain pipe on the opposite and shorter threshold side was constructed for *i* equal to 1.0 %. The drain pipes were made of polyethylene (PCV 70). The sewage was transported from the well settling tank (OS) with the Čoanda effect separator through the pipe (PCV 110) to the threshold.[1,2]. The wastewater with the pollution parameters: BOD_5 280 $mgO_2 \cdot dm^{-3}$, COD 385 $mgO_2 \cdot dm^{-3}$, total suspension 216 $mg \cdot dm^{-3}$, TN 45,90 $mgTN \cdot dm^{-3}$, NH_4-N 30.74 mg $NH_4\text{-}N \cdot dm^{-3}$, TP 3.36 mg $TP \cdot dm^{-3}$ was transported from the OS (for four person family household) in every two hours with the time lasting 120 seconds and flow intensity *i* equal $8 \cdot 10^{-2}$ $dm^3 \cdot s^{-1}$. The transport was performed in intervals during the daytime. The plant cultivation included the seedlings of *Polygonum persicaria* L. in 2009 and *Epilabium parviflorum* Schr. in 2010. They were planted manually in April, in the keramzite holes filled up with 5 cm^3 of peat each and a reaction pH equal to 6.5. In an area of 3 m^2 were planted 12 seedlings. For the purpose of chemical tests the sample plants were collected. In June 5 plants were gathered (the cultivation plants reached the following heights for *P. persicaria* of 90 cm while the standard is 60 cm and for *E. parviflorum* of 195 cm while the standard is 80 cm) and 5 more plants were collected in September (in September the plants grew up to 95 cm for *P. persicaria*, and 203 cm for *E. parviflorum*) [3]. Their vegetative parts were dried at the temperatures of 105^{o}C, grinned mechanically, burnt to ashes in the muffle furnace at the temperatures of 520^{o}C, mineralized and given the chemical quantitative analysis. Kjeldahl nitrogen was analyzed with the Nessler reagent test (reduced titanium tri-chloride) and total phosphorus with the cuvette test (CLK) using phosphorus molybdenum blue. For the analysis the spectrophotometer HACH DR2800 ECO was used according to the standard procedures HACH LANGE.

[1] Inert materials- materials which originate in ceramics technological processes which give them final product demanded features

3. RESULTS AND DISCUSSION

In the experiment the focus was on the growth and examination of plants growing at the keramzite filter bed to search for significant features of biological intensity for biogenic nutrients absorption from the filter bed solution. The amount of elements absorbed in the bed was analyzed as related to their average content in the plant parts, as seen in Table 1.

Table 1. The Kjeldahl nitrogen and phosphorus contents in vegetative parts of macro and nitrophyte plants [mg·g^{-1} s.m.]

The plant species	Parts of the plant	The amount of biogenic elements in the plant	
		Total Kjeldahl Nitrogen TKN	Total phosphorus TP
Polygonum persicaria L.	root	45.6	4.0
	rhizome	-	-
	stem	21.8	3.9
	leaves	48.4	4.1
Epilobium parviflorum Schr.	root	28.7	7.8
	rhizome	25.8	6.8
	stem	19.7	5.8
	leaves	42.5	5.5
Phragmites australis Cov.	root	9.0	1.0
	rhizome	6.0	0.8
	stem	9.0	0.8
	leaves	35.0	1.5
Glyceria maxima L.	root	24.0	5.5
	rhizome	20.5	5.0
	stem	29.4	4.2
	leaves	46.0	8.0

Absorption of Total Kiejldahl nitrogen (TKN) and total phosphorus (TP) from the ash plants vegetative parts were related to the content of the elements in the soil. This relation was called a parameter of the element biological absorption intensity and assigned to the symbol A_p. According to the definitionthe value of this parameter in the filter bed solution is determined by the relation of the element quantity in the plant ash to the element quantity in the soil. Mathematical interpretation of this relation is shown below:

$$A_p = l_p / n_g, \qquad (3.1)$$

where: l_p - defines the amount of an element n in the plant ash shown as the percentage %

n_g - estimates the amount of an element n in the soil of the growing plant shown as the percentage %

For the approximate calculations of A_p, the value of the parameter n_g can be taken from a lithospheric clarke[2]. The values of the parameter A_p (dimensionless, in absolute units) for the selected plants were collected in Table 2.

Table 2. The parameter of biological absorption A_p for nitrogen and phosphorus in the plants

The plant species (according to USDA)	Parts of the plant	The values of the parameter A_p	
		Total Kjeldahl Nitrogen TKN	Total Phosphorus TP
Polygonum persicaria L. genus- Polygonaceae (POPE 3)	root rhizome stem leaves	24.00 - 11.47 25.47	0.43 - 0.42 0.44
Epilobium parviflorum Schr. genus – Balsaminaceae (EPPA 5)	root rhizome stem leaves	15.10 13.57 10.36 22.36	0.84 0.73 0.62 0.59
Phragmites Australis Cov. genus – Festuceae (PHCO 15)	root rhizome stem leaves	4.73 3.15 4.73 18.42	0.11 0.09 0.09 0.16
Glyceria maxima L. genus – Festuceae (GLMA 3)	root rhizome stem leaves	12.63 10.78 15.47 24.21	0.59 0.54 0.45 0.86

Unifying the results of the elements biological absorption, in vegetative parts for different plant species from the experimental cultivations and not only, the

[2] clarke – the term introduced by the Russian professor A. E. Fersman, to honor American geochemist F. Clarke. It defines the percentage of the element in the litosphere.

parameter A_p was determined starting with the geochemical lithospheric clarke - n_g. For the purpose of the experiment the selected values of the lithospheric clarke n_g were collected and juxtaposed in Table 3.

Table 3. Chosen litospheric clarke values n_g [%]

Chemical element	Litospheric clarke	Chemical element	Lithospheric clarke	The element	Lithospheric clarke
P	$9.3 \cdot 10^{-3}$	N	$5.80 \cdot 10^{-3}$	Mn	0.1
K	$3.0 \cdot 10^{-5}$	Fe	4.65	Na	2.50
Ca	2.50	Al	8.05	S	$4.7 \cdot 10^{-2}$
Mg	1.87	Cu	$1.47 \cdot 10^{-3}$	Cl	$1.7 \cdot 10^{-2}$

Analyzing the results obtained from the plants in the experimental micro-cultivation Table 1. (conducted in the open-air area) it was noticed that in the plants, the photosynthesis resulted in a partial lock of just made organic substances. It happened due to energy and biological changes, characteristic for the period of the nutritive substances surplus in water migrants. Their characteristic is the water migration coefficient of the element K_x (3.2) which represents the relation of the element x in dry mass (mineral) of water content to the element content in the soil (exchangeable in the lithosphere) eroding with this water (the sewage in the filter bed) If the element x is defined as m_x [$g \cdot dm^{-3}$] and the lithospheric clarke n_g as n_x in [%], the formulae will have the following pattern:

$$K_x = \frac{m_x \cdot 100}{n_x \cdot a} \tag{3,2}$$

where: a – the sum of the substances concentrated in the sewage entered to the filter bed [$g \cdot dm^3$]

The coefficient is measured in absolute units. The bigger is K_x the more intensively the element is lixiviated from the sewage in the filter bed and the more intensive is its water migration in the filter bed solution. The elements present in the filter bed solution undergo transformations and they are accumulated in the vegetative parts of the plants. The intensive demand for the nitrogen compounds in the microorganisms processes in the filter bed have been confirmed by Gajewska and Obarska – Pempkowiak [6], Sadecka noticed the significance of the energy transformation processes which occurred in the nitrous salts synthesis [7]. Likewise, Vymazal et al. [10] confirmed the validity of energetic transformations in the synthesis of nitrous salts. Hence, the important feature becomes a well settling tank which allows the removal of a vast part of organic substance from the separating wastewater, which is susceptible to biochemical decomposition (BZT_5) [2]. After two years of the experiment the nitrates concentration in the micro-cultivation filter bed solution reached:

- in 2009 - TKN 30.90 mg·dm^{-3}, NH_4-N 10.36 mg·dm^{-3}, N_{org} 20.54 mg·dm^{-3}
- in 2010 - TKN 25.85 mg·dm^{-3} NH_4-N 5.23 mg·dm^{-3} N_{org} 20.62 mg·dm^{-3}

In reactions with the participation of nitrogen and phosphorus in the ecosystem domestic wastewater treatment system - keramzite is a significant ally (processes of sorption and precipitation). Its possessing strong iron cations (Fe^{+}), aluminum ($Al.^{+}$) and calcium (Ca^{+}) appears as encouraging for accumulation of phosphorus not only in the form of phosphates absorbed by plants but mainly, in compounds with iron, at the increased pH [3]. The intensity of biological elements absorption in the plants vegetative parts is presented in the formulae (3.1). Using the biological absorption parameters from table 2 and replacing the parameter n_g with the values of its content in the soil taken from the lithoshperic clarke as seen in table 3 unifies the calculations for all burned plants are compared. The data shown in table 2 implicates that the biological absorption of nitrogen is most effective in the leaves of POPE 3, A_p= 25.47 and GLMA 3, A_p= 24.21. However, in the roots, nitrogen is absorbed in the maximum amounts in POPE 3, A_p = 24.00 and EPPA 5, A_p= 15.10. According to this method phosphorus has the maximum absorption in the leaves of GLMA 3, A_p= 0.87 and (EPPA 5) A_p= 0.59. If the parameter $A_p < 1$, it should be regarded as the element minimum biological absorption due to the antagonistic ions present in its water environment. For $A_p>1$ it needs monitoring the track of all the biological processes which have occurred in the plant and filter bed solution. The elements for which the parameter A_p is more than one can be called biological accumulation elements.

The ion absorption by the plant organisms is intensive for strong cations representing the group with Ca, Mg, Na and K but it is tens times less intensive than absorption by strong anions such as: Cl, S and P. It relates to phyto-physiology and plant systematics, either. Thus, it depends on a family, order, and species the plant belongs to, as seen in table 2. Therefore, a chemical composition of the plant ash will reflect not so much a chemical composition of the soil in which the plant is growing but the medium of all the soils in which previous generations of the particular species representative have developed [4].

4. CONCLUSIONS

The experiment carried out and performed comparative analysis have implicated the following:

1. Nitrogen contents in the vegetative parts of the plants, for both macrophytes and nitrophytes, differ very much. The differences occur for the element absorption in the individual vegetative parts of the plants.
2. The macrophyte plants absorb the elements such as: nitrogen and phosphorus in their leaves. For four observed plants all had the maximum values for absorption in their leaves. Only the nitrophytes showed a large nitrogen absorption in their root parts which can be explained as storing the phosphorus (in detrytus) by the time of spring phosphorus hunger for the ancestor plants.
3. Biological phosphorus absorption is the biggest in the leaves of *Glyceria Maxima* L.. Phosphorus absorption in the roots is the biggest for *Epilobium Parviflorum* Schr.
4. The results obtained in the experimental micro-cultivations show that plants of the species: *Phragmites Australis* Cov., *Glycea Maxima* L. and *Epilobium Parviflorum* Schr. can create alternative populations in the constructed wetlands.

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REDUKCJA STĘŻEŃ ZANIECZYSZCZEŃ W ROŚLINNYCH SYSTEMACH ZE ZŁOŻEM INERTNYM
Część pierwsza
ABSORPCJA BIOLOGICZNA AZOTU I FOSFORU W NITROFITACH Z MIKROUPRAW NAWOŻONYCH ŚCIEKAMI BYTOWYMI

S t r e s z c z e n i e

W pracy przedstawiono badania roślin nitrofitowych *Polygonum persicaria* L. oraz *Epilobium parviflorum* Schr. w mikrouprawie ze złożem inertnym wypełnionym sztucznym kruszywem, keramzytem. Rośliny nawożono separowanymi ściekami bytowymi z osadnika szybowego z separatorem fazy stałej z efektem Coandy. Chemiczną analizę ilościową, azotu i fosforu wykonywano testami saszetkowymi na roztworzonych spopielonych częściach roślin, spektrofotometrem DR 2800 ECO HACH LANGE. Dla zunifikowania wyników w stosunku do innych badań, zaproponowano wprowadzenie wskaźnika A_p, stosując wskaźnik biologicznej absorpcji pierwiastków n_p z klarku litosfery. Wskaźnik obliczano ze stosunku ilości pierwiastka w popiele rośliny do ilości pierwiastka rośliny rosnącej w glebie. Zdefiniowano również K_x współczynnik migracji wodnej pierwiastków w roztworze złoża. Jako stosunek danego pierwiastka w suchej (mineralnej) zawartości wody, do jego zawartości w złożu (litosferze), erodowanym przez (tę wodę) roztwór wodny złoża. Opisano analizowane rośliny, porównując ich absorpcję wskaźnikiem A_p. Analizowano istotne różnice makrofitów z gatunku *Phragmites australis* Cov.oraz *Glyceria maxima* L. w stosunku do nitrofitów. Stwierdzono, że rośliny porównywane, mają maksimum absorpcji azotu występujące w liściach. Stwierdzono najwyższą absorpcję fosforu w korzeniach *E.Parviflorum,* oraz w liściach *G.maxima.* Zauważno, że nitrofity absorbują azot w liściach, a fosfor w korzeniach. Natomiast makrofity absorbuja azot i fosfor w liściach. Również odnotowano, że absorpcja azotu z przemiany biochemicznej substancji organicznej, ma swoje pozytywne podłoże w zastosowaniu osadnika szybowego z separacją fazy stałej. Zastosowanie osadnika szybowego nie przeciąża złoża, zanieczyszczeniami pochodzącymi z procesów biochemicznych w ściekach doprowadzonych do złoża z kruszywem inertnym. Zdefiniowano pojęcie kruszywa inertnego.