Increasing biodegradation efficiency with the use of zeolite media in soil-filter beds

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Introduction

Rising energy tariffs and growing public awareness have resulted in severe developments of natural wastewater treatment methods, which have low investment and capital costs during the last decades.

Up to now several modifications of reed bed zones were revealed, in combinations with conventional wastewater treatment processes (e.g. settlers, chemical pretreatment etc.).

Majority of treatment plants in operation and under construction are found in settlement clusters of 100-1000 population equivalent (PE). In rural areas these plants are generally operated temporary. Natural wastewater treatment plant based on reed bed processes is generally built for the biological treatment of primary treated wastewater.

The key element of the reed bed wastewater treatment processes is the filter bed, which makes suitable environment for plant vegetation (e.g. reed in most of the cases). The plants grow and create an extensive root system in the filter bed: the water that passes through the filter bed undergoes biological treatment. Reed bed wastewater treatment systems are also characterized by as follows:

- The plants through their metabolic needs play marginal role in the treatment process. Major part of the pollutants is removed due to the bacterial biofilm development attached to the surface of reed. The roots improve oozing via the porous bed and contribute to increasing of oxygen transfer.
- The filter bed, that can be considered as a media for the development of reed has only limited nutrient removing potential. Biological degradation is accomplished by bacteria adhered to the filter bed. A non-permeable layer shall be at the bottom of the bed.

Concerning the flow directions, two basic types of reed-bed systems have been developed: the vertical and horizontal flow. The filter media in the beds are generally gravel, sand, pitch, and mixed material containing clay components. The bed depth is usually in range of 1,00-1,20 m. The area requirement is approximately 4-5 $m^2 \cdot PE^{-1}$. The first soil filters were designed to remove organic matter from the wastewater, by now intensive research is realized in the field of nitrification, denitrification and phosphorus removal.

Fleit (1988) made detailed evaluation of the leading design methods of reed beds and analyzed the efficiency of reed plantations and phosphorus adsorption on the base of literature review and experiments.

A wastewater treatment plant serving 1400 inhabitants is based on a reed bed process in Szügy, Hungary. The volume of the collected sewage is 180 $m^3 \cdot d^{-1}$. The process scheme of the plant is as follows: the chemically treated raw wastewater is pumped into the Imhoff tank and the settled water flows directly into the reed bed zone. The water thereafter enters the constructed wetland with area of 1 hectare. The BOD_5 and the ammonium removal efficiencies of the system are 86% and 46% respectively. *Szilágyi* (1996) suggested a flexible reactor configuration in which the filter beds can be operated in parallel, in series and in bypass mode. According to the suggestions revealed, fine break stone for process efficiency enhancement must replace the sand filter media.
Born et al., (2000) built an up flow soil filter bed for the treatment of storm water. Removal efficiencies of COD, NH_4-N and PO_4-P have exceeded 90%. Despite of the short distance from the surrounding houses, inhabitants living nearby have not felt intolerable odors in the air. *Engelmann et al.,* (2003) pointed out that clogging is the basic problem during operation of reed bed systems. The authors emphasized, that the water to be treated must have suspended solids concentration as low as possible in order to ensure long term and safe operation of filter beds. They suggested COD load lower than 20 - 25 g $COD \cdot m^{-2} \cdot d^{-1}$ and for the specific area demand of 3,2-4,0 $m^2 \cdot PE^{-1}$. *Hench et al.,* (2003) have monitored the treatment process efficiency through chemical (pH, Kjeldahl-N, TSS, BOD_5, O_2)

and biological (*Fecal coliform*, *Enterococci*, *Salmonella*, *Yersina*, *Shigella*) parameters. It was markedly proved, that in the case of filter beds covered with plant vegetation the chemical and biological parameters showed better treatment efficacy in comparison to the filter beds without vegetation. First of all the bacteria content of effluent was decreased by use of the beds covered with vegetation

Gray (2004) investigated the treatment mechanisms in a soil filter planted by reed: they found that suspended material is removed by the filtering mechanisms, the dissolved matters are eliminated by biological processes, and the ammonium conversion is fulfilled by nitrification in the filter bed. Adsorption played the dominant role in metal-ions and phosphorus removal, while in the decrease of pathogenic germs, the filtering and sedimentation effects, UV radiation, and the antibiotics released by the roots must be considered.

Obarska-Pempkowiak et al., (2005) investigated various soil filter applications in Poland. According to the results of experiments the suspended solids load must be kept below 15-115 kg $TSS \cdot ha^{-1} \cdot d^{-1}$ to reach BOD_5 removal efficiency about 76%. In the case of improper pretreatment, the plant operators would face to serious filter clogging. Combined filter systems (i.e. co-existence of vertical and horizontal flow patterns) have more reliable operation than the „one-direction" filter. The combined system, 86% of BOD5 removal efficacy and 7,8 obtained kgN·ha-1·d-1 ammonium elimination rates.

Cooper et al. (2005) pointed upon the applicability of reed bed system as a tertiary treatment process. It was emphasized, that clogging might cause several operational problems, such as unsuitable water flow division and excessive vegetation of weed on the filter bed. Cooper (2005, in a distinct article) examined the oxygen supply conditions and the water flow characteristics in a vertical flow filter. The process efficiency was mostly influenced by the oxygen transfer rate. It was found, that good effluent water quality could be accomplished when the specific filter area was 2 $m^2 \cdot PE^{-1}$.

An Internet publication (see the link below, 2006) details the basics and several design criteria of soil filters.

Objectives

We hereby summarize the objectives of the experimental work carried out:

- Nitrification efficiencies were investigated in various types of filter media in laboratory scale experimental units treating wastewater of high ammonium nitrogen concentration. Suggestions were made on the basis of the results.
- Further experiments were conducted with the most efficient filter media to investigate the organic matter and nitrogen removal efficiencies with a primary settled wastewater under continuous flow operation.
- For comparison of the results, the filter media were not covered by vegetation in the experimental units.

Materials and Methods

Comparison of various filter media

Experiments were performed to compare COD degradation and ammonium conversion rates within six different types of filter media: natural zeolite, spherical shaped gravel, Biolite® (BIOFOR biofiltration system filter media), sand, mixture of gravel and sand, and mixture of zeolite and sand. In the case of mixed filter bed materials, the mass ratios of the components were 1:1. The characteristics of the filter beds are illustrated in *Table 1.* Among the used materials only the zeolite had ionic exchange capacity, and this material had the highest specific surface area (12,0 $m^2 \cdot g^{-1}$). Clinoptilolite content of the used zeolite was 45%. The volume of the experimental unit was 0,73 m^3, and the surface area of an individual filter bed was about 0,63 m^2.

Table 1. Characteristics of the filter beds investigated

Filter bed	Particle size (mm)	Ammonium ionic exchange capacity (mg NH_4-N· g^{-1})	Bacteria adhered to surface (g organic material · g filter material^{-1})	Density ($kg \cdot m^{-3}$)	Specific area (m^2·g filter material^{-1})
Natural zeolite	5,0 - 6,0	10,0	0,028	1000	12,0
Spherical gravel	8,0	-	0,005	1900	-
Biolite (filter media of Biofor process)	4,0 - 8,0	-	0,011	750	1,2
Sand	0,5 - 1,0	-	0,003	1700	-
Zeolite - sand mixture	0,5 - 6,0	5,0	0,016	900	-
Spherical gravel - sand mixture	0,5 - 8,0	-	0,004	1800	-

The schematic layout of and experimental filter unit is shown in *Figure 1.* The six individual units were filled up with filter bed materials as described in Table 1., and were operated in parallel. The filter beds were fed with reject water containing ammonium in high concentration (500-1800 $mg \cdot L^{-1}$). The reject water coming from an anaerobic digester had high organic (COD and BOD_5) contamination as well and the water quality showed significant variations during the experiments (see also Table 2.). Pumping of reject water into the experimental units was accomplished two times daily. Equal flow dispersion (over the cross-section of the filter) was obtained by the application of a peat layer with depth of 20 cm. Seeding of the filter beds was performed by the use of backwash water generated in a full-scale nitrification biofiltration unit. During seeding, feeding of reject water was administered at relatively low flow. Filter beds were aerated twice a week, for about ten minutes. Experiments were carried out for one year.

Continuous filtration experiments

Investigations were continued with the zeolite-containing filter that has showed the highest efficiencies in biodegradation and ammonium conversion rates. The filter was identical to that used in the previous experiments (shown in Figure 1.) The reactor was continuously fed with pre-settled wastewater from the South-Budapest Wastewater Treatment Plant. The filter bed was aerated twice a day for 5 minutes. The duration of this experiment was half a year.

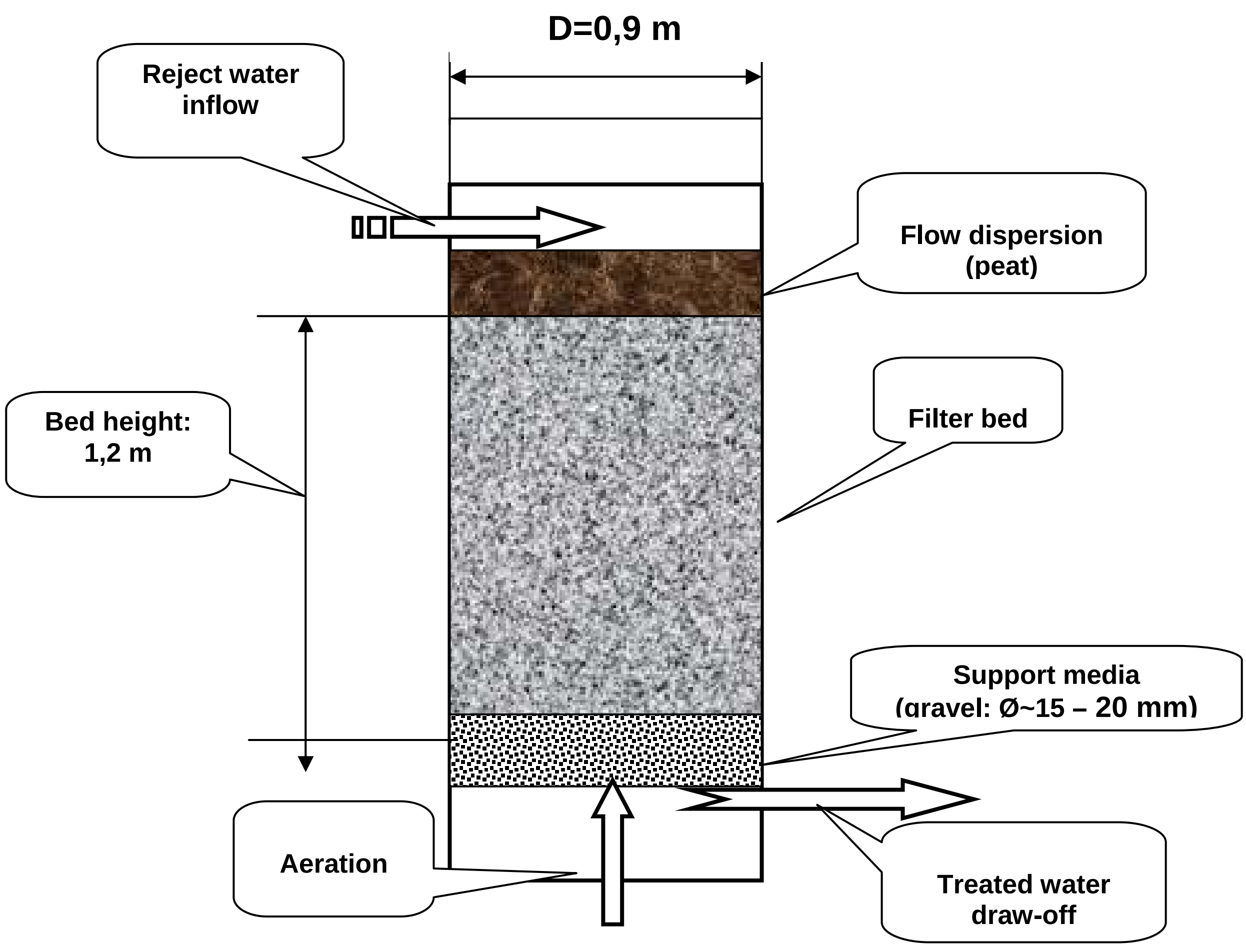

Figure 1. Schematic layout of the experimental unit

Results and Discussion

Comparison of degradation efficiencies obtained in different filter media

Th influent rejects water-contained ammonium between 1156-1662 mg N·L^{-1}, and the organic matter measured as COD was between 1608-2908 mg·L^{-1}. The ammonium load of the filters was in the range of 13,6-120 g NH_4-N·m^{-3}·d^{-1}. These values refer to hydraulic surface loads between 3,4 and 68,8 m·year^{-1}.

Table 2. Composition of dewatered reject water used in experiments

Component	Unit	Concentration
pH	(-)	7,8 - 8,5
Ammonium-nitrogen	mg·L^{-1}	1156 - 1 662
COD	mg·L^{-1}	1608 - 2908
BOD_5	mg·L^{-1}	700 - 1 500
Total suspended solids	mg·L^{-1}	400 - 1 000
Volatile suspended solids	mg·L^{-1}	200 - 500

Alkalinity (as $CaCO_3$)	$mg \cdot L^{-1}$	5 000 - 7 000
Total volatile acid, as acetic acid	$mg \cdot L^{-1}$	300 - 1 500

Results of the continuous flow experiments of three filter media (zeolite, zeolite+sand and sand) are summed in *Tables 3/1.-3/3.* The attached biomass on the support material showed different COD and ammonium removal efficiencies. Zeolite and zeolite+sand media removed these components efficiently, while the sand containing media efficacy was relatively low. Elimination efficiencies in gravel, gravel+sand and Biolite media were found in between the zeolite and sand media efficiencies.

Table 3/1. Summary of the experimental results of zeolite media filtration

NH_4-N ($mg \cdot L^{-1}$)		**COD ($mg \cdot L^{-1}$)**		**Effluent NO_3-N ($mg \cdot L^{-1}$)**	**Filter load**		**Temp. (°C)**
Influent	**Effluent**	**Influent**	**Effluent**		**(g NH_4-N $\cdot m^3 \cdot d^{-1}$)**	**Hydraulic surface load ($m \cdot year^{-1}$)**	
1 662	3 [99]	2 296	432 [81]	279	13,6	3,4	10 - 12
1 280	4,0 [99]	2 908	476 [83]	795	26,3	8,6	12 - 15
1 156	4 [99]	1 923	306 [84]	700	47,5	17,2	20 - 25
1 462	11 [99]	1 608	330 [79]	725	81,3	34	20 - 25
1 619	20 [98]	2 148	356 [83]	549	120	68,8	15 - 18

Note: Numbers signed in [ ] refer to the elimination efficiencies

Table 3/2. Summary of the experimental results of zeolite + sand media filtration

NH_4-N ($mg \cdot L^{-1}$)		**COD ($mg \cdot L^{-1}$)**		**Effluent NO_3-N ($mg \cdot L^{-1}$)**	**Filter load**		**Temp. (°C)**
Influent	**Effluent**	**Influent**	**Effluent**		**(g NH_4-N $\cdot m^3 \cdot d^{-1}$)**	**Hydraulic surface load ($m \cdot year^{-1}$)**	
1 662	10 [99]	2 296	631 [72]	286	13,6	3,4	10 - 12
1 280	12 [99]	2 908	729 [74]	818	26,3	8,6	12 - 15
1 156	19 [98]	1 923	441 [77]	736	47,5	17,2	20 - 25
1 462	71 [95]	1 608	417 [74]	594	81,3	34	20 - 25
1 619	96 [94]	2 148	441 [79]	500	120	68,8	15 - 18

Table 3/3. Summary of the experimental results of sand media filtration

NH_4-N ($mg{\cdot}L^{-1}$)		COD ($mg{\cdot}L^{-1}$)		Effluent NO_3-N ($mg{\cdot}L^{-1}$)	Filter load		Temp. (°C)
Influent	Effluent	Influent	Effluent		(NH_4-N g/m^3 d)	Hydraulic surface load ($m{\cdot}year^{-1}$)	
1 662	78 [95]	2 296	1176 [48]	166	13,6	3,4	10 - 12
1 280	103 [92]	2 908	1 617 [44]	387	26,3	8,6	12 - 15
1 156	219 [81]	1 923	1271 [33]	328	47,5	17,2	20 - 25
1 462	340 [76]	1 608	1 200 [25]	379	81,3	34	20 - 25
1 619	369 [72]	2 148	1 244 [42]	249	120	68,8	15 - 18

Filter load data indicated in the tables were calculated from average values of the influent and effluent concentrations. However, the composition of the influent leaching water fed into the filter varied significantly in time that resulted in fluctuations in the treated water quality. Due to the composition changes, the specific load parameter (dimension in g NH_4-N $m^{-3}{\cdot}d^{-1}$) and the hydraulic surface load ($m{\cdot}year^{-1}$) were harmonized with the by dilution. Ammonium and organic matter concentrations in the effluent water for every investigated filter media are shown in *Figure 2. and 3.* Influent and effluent COD concentrations are described in Figure 4.

Figure 2. shows the effluent ammonium concentrations as a function of influent load. In the case of ammonium load higher than 47,5 g NH_4-N$\cdot m^{-3}{\cdot}d^{-1}$, the effluent water ammonium content has increased sharply in the Biolite, the sand, and the gravel filter media, while the zeolit and zeolite + sand media showed better ammonium conversion efficiencies. Below the abovementioned ammonium load, all filters operated at about 80% ammonium elimination efficacy. Increasing the load (up to 120 g NH_4-N$\cdot m^{-3}{\cdot}d^{-1}$), the effluent ammonium concentration exceeded 300 $mg{\cdot}L^{-1}$ in the Biolite, sand, gravel, gravel+sand media. The zeolite and zeolite+sand filters provided better effluent water quality: the measured ammonium concentrations were 20 and 96 $mg{\cdot}L^{-1}$ respectively.

The nitrate concentrations in the effluent water as a function of nitrogen load are shown in Figure 3. Nitrate nitrogen content has increased up to 26,3 g NH_4-N$\cdot m^{-3}{\cdot}d^{-1}$ ammonium load; however, further load enhancement resulted in smaller increase. Above this load, (until 120 g NH_4-N$\cdot m^{-3}{\cdot}d^{-1}$) the nitrate level has remarkably decreased in the water. The high ammonium load has probably caused substrate inhibition on the nitrification process that resulted in lower nitrate levels in the effluent. In the case of lower ammonium loads the treated water nitrate content were between 500 and 800 $mg{\cdot}L^{-1}$ in every filter units. Nitrite was not measured in the samples. The nitrate generated and the oxidized ammonium, however, were not in accordance: at lower loads nitrification efficiency was better, but the nitrate generated was maximum 60% of the oxidized ammonium content. Despite of the occurrence of dissolved oxygen in the filters denitrification occurred in the aerobic reactors.

The COD concentration of the reject water (originated from an anaerobic digester) was between 1600-2900 $mg{\cdot}L^{-1}$. The reject water contained slowly biodegradable organic matters. This was also proven by the filter experiments: the effluent COD concentration never decreased below 300 $mg{\cdot}L^{-1}$, neither in the zeolite filter that showed the highest biological activity.

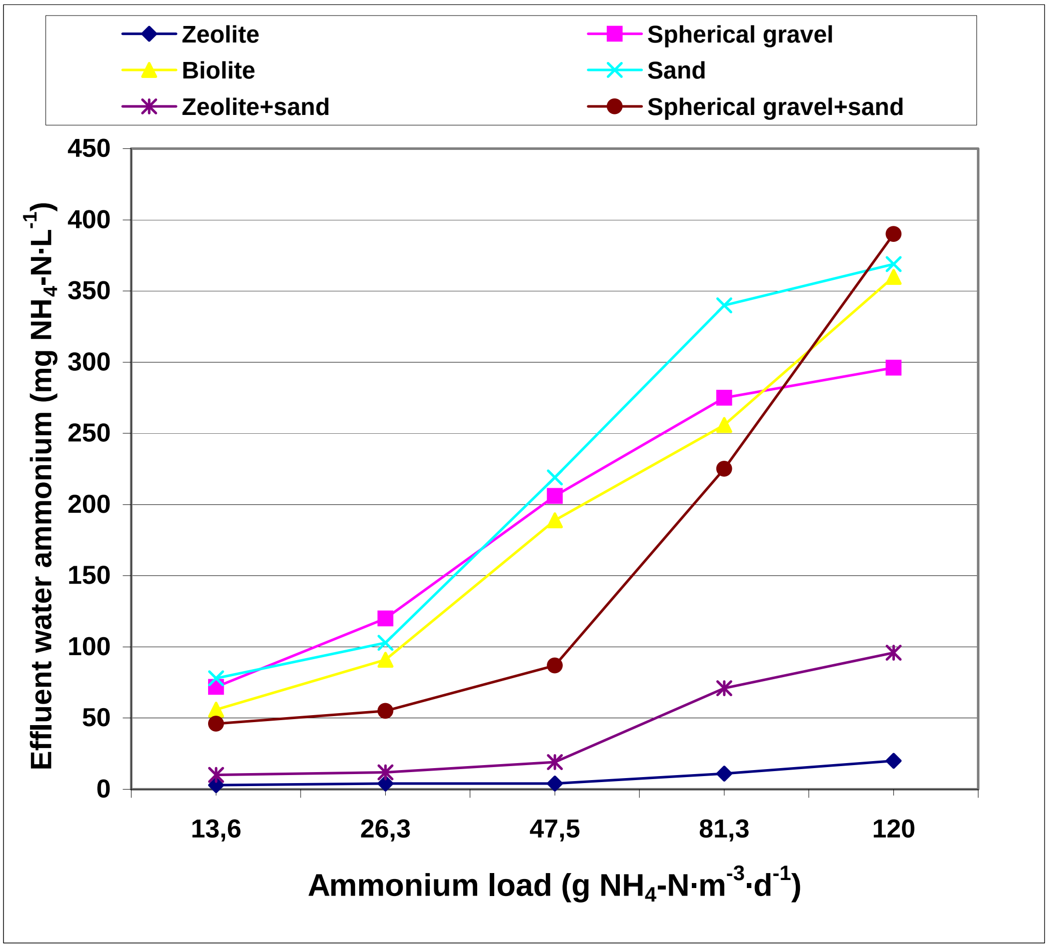

Figure 2. Effluent water ammonium concentration as a function of ammonium load in the filters

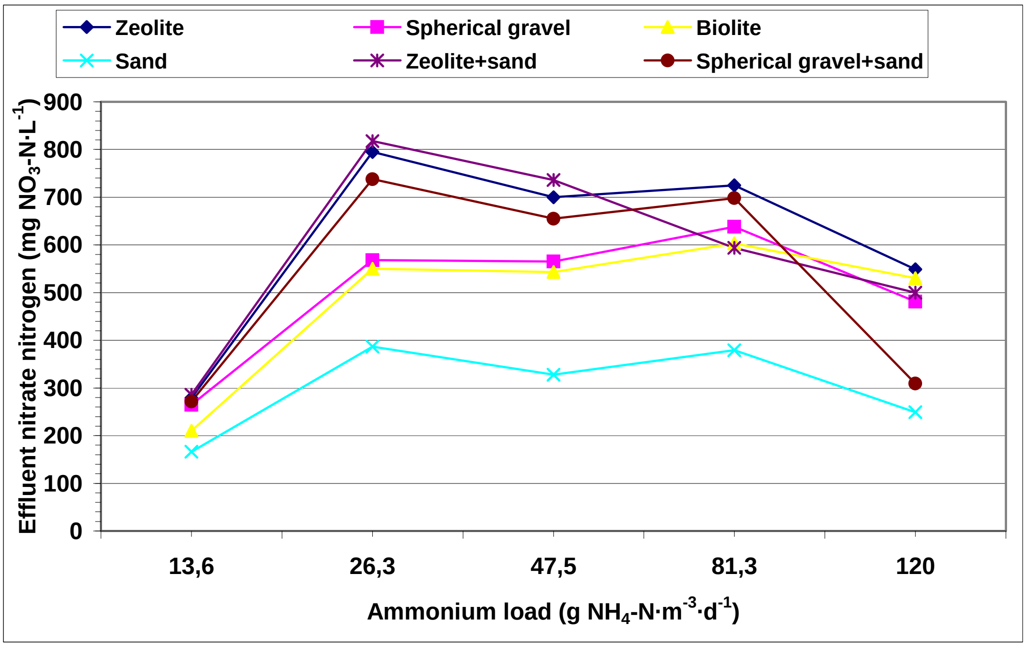

Figure 3. Effluent water nitrate concentration as a function of ammonium load in the filters

Biodegradation efficiency was dependent on the influent water COD concentration, as seen in *Figure 4*. Increasing COD concentration from 1608 to 2296 $mg \cdot L^{-1}$ in the influent water, the COD in the treated water was between 300 and 500 $mg \cdot L^{-1}$. It can be stated, that zeolite, or the zeolite containing filter media have the highest organic matter removal potential in comparison to the other materials used in the experiment.

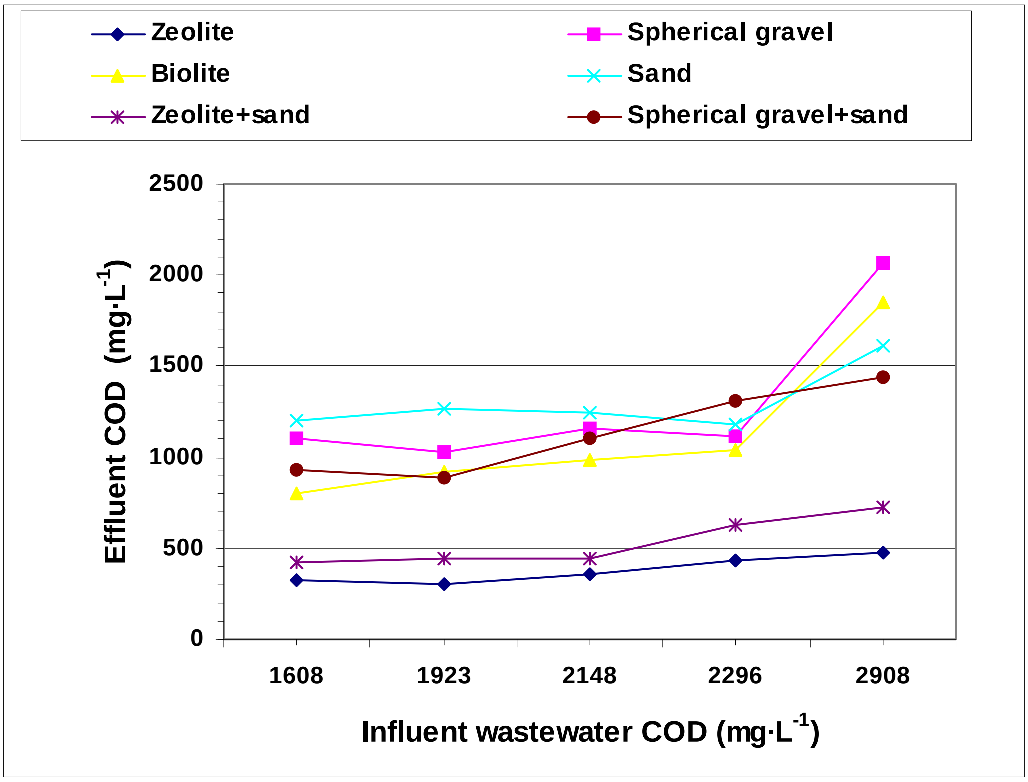

Figure 4. Influent and effluent COD concentrations in the experimental units

From the six different types of filter media examined, the best effluent water quality was obtained by the zeolite and zeolite+sand filter media. High elimination efficiency of the zeolite based filter material can be explained by its large specific area (12 $m^2 \cdot g^{-1}$), which enables faster biomass growth (at least 8-9 times higher) than in other (sand or gravel) filter media. Ion exchange capacity of zeolite (10 mg NH_4-N$\cdot g^{-1}$) significantly increases nitrification as the adsorbed ammonium can be easily utilized by the nitrifying bacteria adhered to the surface. Certainly, the adsorption of heterotrophic bacteria on the zeolite surface can contribute to the high COD degradation rate.

The filter media was aerated for 5 minutes duration once weekly in the case of lower (13,6-47,5 g NH_4-N$\cdot m^{-3} \cdot d^{-1}$) and twice a week at higher (83,1-120 g NH_4-N$\cdot m^{-3} \cdot d^{-1}$) ammonium load. Due to aeration, the dissolved oxygen concentration in the filter pores was above 1,5 mg $O_2 \cdot dm^{-3}$ during the experiments.

Evaluation of the continuous flow experiments

Composition of the presettled wastewater from the South-Budapest Wastewater Treatment Plant used in the experiments is shown in *Table 4.* It can be stated that the settled wastewater contains ammonium equal to average values measured in middle-sized settlements in Hungary. In smaller settlements, however, the raw wastewater contains ammonium nitrogen in higher concentrations: ammonium pollution may exceed 100 $mg \cdot L^{-1}$ in several cases.

Table 4. Composition of the presettled wastewater

Component	Unit	Value
pH	(-)	7,4 - 7,8
Ammonium-N	$mg \cdot L^{-1}$	50 - 70
TKN	$mg \cdot L^{-1}$	60 - 90
COD (filtered)	$mg \cdot L^{-1}$	130 - 300
BOD_5	$mg \cdot L^{-1}$	80 - 160
TSS	$mg \cdot L^{-1}$	100 - 150

Results of continuous flow experiments are summarized in *Table 5*. The filters were operated between 2,4-26 g NH_4-$N \cdot m^{-3} \cdot d^{-1}$ load, which referred to 22,2-166,8 $m \cdot year^{-1}$ hydraulic surface loads. The composition of presettled wastewater was characterized by as follows: COD concentration below 160-281 $mg \cdot L^{-1}$, NH_4-N was 46-66 $mg \cdot L^{-1}$, TSS 95-120 $mg \cdot L^{-1}$, and the pH between 7,2-7,6. The NH_4-N: TKN ratio in the influent wastewater was about 80-90%, which indicates, that the dissolved organic nitrogen fraction in relatively small. The water temperature was between 21-22 ºC during the low load period, and 13-14 ºC during higher loads. Therefore worsening of removal efficiencies in the case of high pollutant loads was partly due to the decrease of water temperature·

In the 2,4-10,6 g NH_4-$N \cdot m^{-3} \cdot d^{-1}$ load range the treated water NH_4-N concentration was found to be between 1,2-2,0 $mg \cdot L^{-1}$, the TKN was 0,6-6,5 $mg \cdot L^{-1}$, and the COD was 38-48 $mg \cdot L^{-1}$, and the TSS was between 8-12 $mg \cdot L^{-1}$. It must be mentioned, the water quality obtained by filtration complies with the most stringent effluent water criteria as well. In the case of higher loads (18,3-26,0 g NH_4-$N \cdot m^{-3} \cdot d^{-1}$) the deterioration of the effluent water quality was be explained by the decreasing temperature (13-14 °C) as well. The treated water composition was the following: 10-12,3 mg NH_4-$N \cdot L^{-1}$, 9,2-11,0 mg $TKN \cdot L^{-1}$, and 63-64 mg $COD \cdot L^{-1}$.

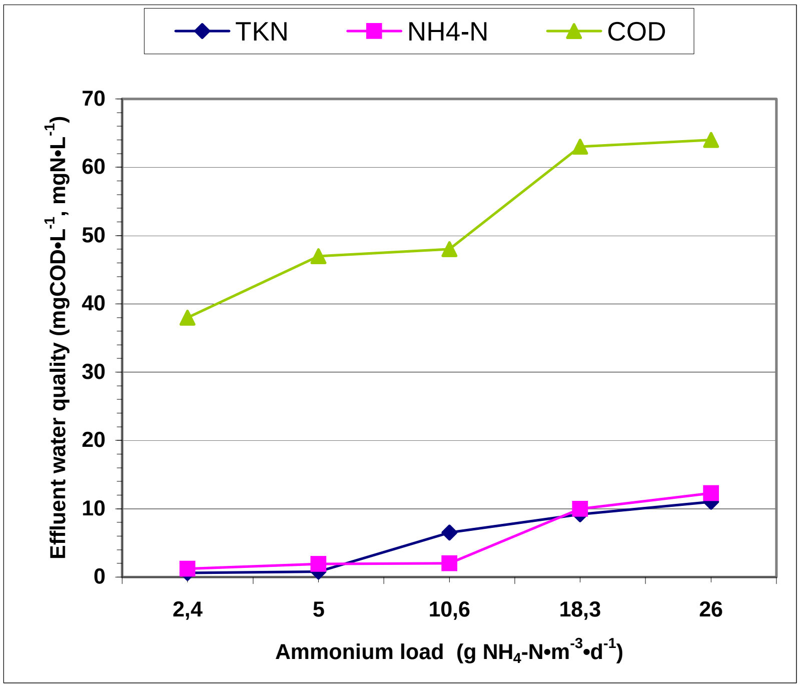

Figure 5. Treated water composition as a function of the filter load

Figure 5. shows the treated water composition (NH4-N, COD and TKN concentrations) as a function of the filter load. The quality of the effluent water deteriorated (i.e. all the measured parameters were measured in higher concentrations) as the pollutant load of filter increased.

Design of filter bed area

Gray (2004) has introduced an empirical relationship for designing of a soil filtration system:

$$F = \frac{Q(\ln C_o - \ln C_1)}{v_1} \quad (1)$$

Hereby an example will be shown for designing a treatment plant for a small size settlement (1000 PE). Notation is as follows: ***F*** horizontal section of filter bed (m^2); ***Q*** influent wastewater flow (150 $m^3 \cdot d^{-1}$); $\boldsymbol{C_0}$ influent BOD_5 concentration (300 $mg \cdot L^{-1}$); $\boldsymbol{C_1}$ effluent BOD_5 concentration (10 $mg \cdot L^{-1}$); $\boldsymbol{v_1}$ BOD_5 biodegradation rate (0,1). Calculation with data above will result in 3750-m2 surface areas. Equation (1) was used for calculation of nitrification with the following data: C_o = 100 mg NH_4-N$\cdot L^{-1}$; C_1=10 mg NH_4-N$\cdot L^{-1}$; and v_1=0,07. Result of calculation will give 4928-m2-filter area. This example clearly demonstrates that filter designed for BOD5 removal will not fulfill that ammonium oxidation. Completing nitrification would certainly result in proper organic matter removal, but in this case requires at least 20% larger filter areas. Experience revealed, that 5 $m^2 \cdot PE^{-1}$ specific filter areas must be considered for safe operation. This specific area in the case of zeolite filter media guarantees proper organic matter removal and nitrification.

Conclusions

On the basis of experimental results the following conclusions can be drawn:

1. Ammonium and COD elimination efficiencies was measured in various (natural zeolite, spherical shaped gravel, Biolite, sand, gravel+sand and zeolite+sand) filter media. Results showed, that the highest efficiency was obtained with the natural zeolite containing filter media.
2. High elimination efficiency of the zeolite based filter material can be explained by its large specific area (12 $m^2 \cdot g^{-1}$), which enables fast biomass growth (at least 8-9 times higher) than in other filter media.
3. Favorable ionic exchange capacity of the zeolite contributes to better nitrification performance, as the attached bacteria can easily utilize the adsorbed ammonium.
4. Regular aeration (for 5-10 minutes duration per day) and the porous material contributed to the oxygen supply in every filter media.
5. Zeolite filter media showed the highest removal efficiency in the continuous flow experiments. The results proved, that
   - In the 2,4-18,3 g NH_4-N$\cdot m^{-3} \cdot d^{-1}$ filter load range (and on 18 ºC) ammonium oxidation was obtained with high efficacy (>90%), and the effluent COD concentration decreased below 50 $mg \cdot L^{-1}$,
   - In the case of higher ammonium loads (>18,3 g NH_4-N$\cdot m^{-3} \cdot d^{-1}$) and lower temperature complete nitrification was achieved in the zeolite filter that was designed for 5 $m^2 \cdot PE^{-1}$ specific surface areas.

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Abstract

Keywords: soil filter, filter media, natural zeolite, nitrification, filter load

Oragnic matter and ammonium removal efficiencies were compared in experimental units treating reject water with the application of six different filter media (natural zeolite, spherical shaped gravel, Biolite, sand, gravel-sand mixture and sand-zeolit mixture). Amongst the used materials, only the zeolite has ammonium ion exchanging property, furthermore zeolite has relatively large specific surface area (12,0 $m^2 \cdot g^{-1}$).
Up to 47,5 g NH_4-N·m^{-3}·d^{-1} load, every filter media provided more than 80% ammonium conversion efficiencies. Further increase of ammonium load (to 120 g NH_4-N·m^{-3}·d^{-1}) the treated water concentration exceeded 300 mg NH_4-N·L^{-1} in the Biolite, sand, gravel and gravel+sand media. Meanwhile the zeolite and zeolite+sand media filters provided effluent ammonium concentrations of 20 mg·L^{-1} and 96 mg·L^{-1} respectively, which represents more than 90% nitrification efficiency. Amongst the six different types of filter media, the zeolite containing filter beds have given the best-treated water quality.

Experiments were performed in a continuously fed reactor with the filter media showing the highest organic matter removal efficiency. In the ammonium load range of 2,4-18,3 g NH_4-N·m^{-3}·d^{-1} and on 18

ºC, the ammonium oxidation showed high efficiency (>90%) and the treated water contained organic matter in less, than 50 mg $COD \cdot L^{-1}$. Higher loads (>18,3 g NH_4-$N \cdot m^{-3} \cdot d^{-1}$) resulted in deterioration of the water quality: 10 mg NH_4-$N \cdot L^{-1}$, 65 mg $COD \cdot L^{-1}$ and 9,2-11 mg $TKN \cdot L^{-1}$ concentrations were measured in the effluent water.

Ammonium oxidation was not observed in the filter designed for BOD_5 degradation because of the non-sufficient filter bed volume. Significant bed expansion would result in efficient ammonium oxidation and simultaneously it may obviously enhance organic matter removal efficiency, however significant filter bed volume enhancement would be necessary in this case.

Table 5. Summary of results of the continuous flow experiments

Load		Retention time (d)	NH_4-N ($mg \cdot L^{-1}$)		COD ($mg \cdot L^{-1}$)		TKN ($mg \cdot L^{-1}$)		Effluent NO_3-N ($mg \cdot L^{-1}$)	Suspended solids ($mg \cdot L^{-1}$)		pH	Temp. (°C)
(g NH_4-N$\cdot m^3 \cdot d^{-1}$)	Hydraulic surface load ($m \cdot year^{-1}$)		Influent	Effluent	Influent (filtered sample)	Effluent	Influent	Effluent		Influent	Effluent		
2,4	22,2	19	46	1,2	160	38	55	0,6	95	95	12	7,2	21
5,0	69,5	10	51	1,9	151	47	59	0,8	66	110	15	7,6	22
10,6	83,4	5	54	2,0	234	48	62	6,5	32	120	8	7,4	18
18,3	125,0	3,3	62	10,0	245	63	75	9,2	21	80	20	7,3	13
26,0	166,8	2,5	66	12,3	281	64	78	11,0	20	125	6	7,3	14