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RESEARCH REPORT NO. 3
**Experimental tests regarding water treatment technologies to
reduce ammonium concentrations**

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Abbreviations and acronyms

NH₄⁺ - Ammonium

NO₂⁻ - Nitrites

NO₃⁻ - Nitrates

P – Phosphorus

Cond. - Conductivity

DO – Dissolved oxygen

T – Temperature

RW – Raw water

SRW – Synthetic raw water

BFWS – Biologically filtered water on sand

BFWS UL- Biologically filtered water on sand in the upper layer

BFWS LL - Biologically filtered water on sand in the lower layer

BFWCG – Biologically filtered water on ceramic granules

BFWCG UL – Biologically filtered water on ceramic granules in the upper layer

BFWCG LL– Biologically filtered water on ceramic granules in the lower layer

BFWAC – Biologically filtered water on granular activated carbon

1 General data

Ammonium is an inorganic compound, present in water at pH <9. Ammonium has no toxic effects on consumers' health, but its presence in water may indicate water pollution [1].

In water supply systems, the presence of excess ammonium in raw water is undesirable because it can cause many problems such as: unpleasant odors, microbial development in the water distribution system and reduced chlorine disinfection efficiency because ammonium reacts with chlorine used in water disinfection which leads to chlorine consumption increase and degradation of water quality by changing its taste and smell [2][3][4][5].

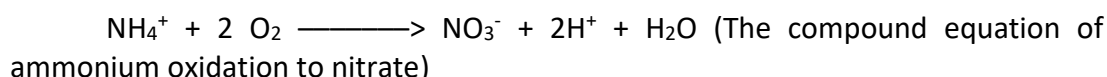
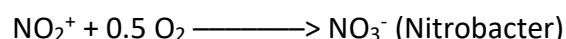
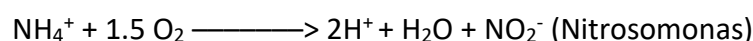
In Romania, the maximum allowable limit for ammonium in drinking water, according to law 458/2002 is 0.50 mg/l. The guideline level for ammonium, according to the World Health Organization (WHO 1993) is 1.5 mg/l.

Over time, several methods have been developed to reduce the concentration of ammonium in water, namely physical, chemical, biological methods or a combination of these methods. These mainly include: ion exchangers and adsorption, biological filtration, air stripping, breakpoint chlorination and reverse osmosis [6].

The biological process of ammonium oxidation to nitrate with the intermediate form of nitrite, is called nitrification. Nitrification is realised by species of bacteria called Nitrosomonas and Nitrobacter [7]. These specific bacteria are distinguished from each other by the ability to oxidize only certain nitrogen compounds. Nitrosomonas can oxidize ammonium to nitrite and Nitrobacter oxidizes nitrite to nitrate. Both species of bacteria are classified as autotrophic organisms (they do not need a source of organic carbon, they use carbon dioxide for synthesis) [8] [9].

Nitrifying bacteria are present everywhere in the soil, in aquatic, fresh and marine basins, in wastewater treatment systems, in landfills..

The stoichiometric equations of nitrification for Nitrosomonas and Nitrobacter are [8]:



The nitrification process is influenced by certain inhibitory factors such as pH, dissolved oxygen concentration, temperature and concentrations of inhibitors [8][9].

The biological processes used to reduce ammonium in water for human consumption are mainly processes with biomass attached. Biofilters are characterized by the presence of microorganisms that adhere to the filtration media in the form of a fixed film (biofilm) [10].

For any filtration media used, all biofilters follow the same principle, namely: biological degradation of pollutants by microorganisms fixed on the filtration media surface.

2 Ammonium reduction by biological filtration

In the experimental tests it was proposed to reduce the ammonium concentration in water using biological processes with attached biomass.

The experimental tests were performed at laboratory level on a biofilter installation with fixed bed and ascending flow, which is part of the Colentina Laboratory Complex and aimed to determine the biofilters efficiency in reducing ammonium in raw water depending on the biofilter support media/filtration media.

In the biofiltration process within the tests performed, three types of support media were analyzed, used for the attachment of biomass (microorganisms): sand, ceramic granules, granular activated carbon.

The following figure shows the support media used.

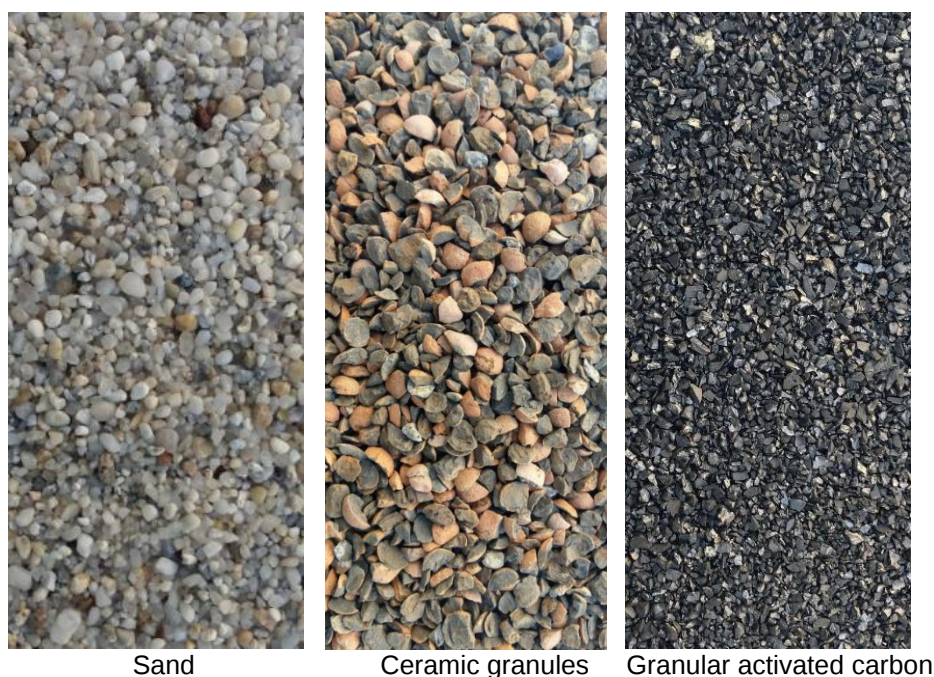


Figure 2.1. Support media.

The tests were performed in three phases:

- Phase I - raw water with three different ammonium concentrations and a flow rate of 20 l/h on each biofilter was introduced in the installation;
- Phase II - raw water with three different ammonium concentrations and a flow rate of 35 l/h on each biofilter was introduced in the installation.
- Phase III - raw water with an ammonium concentration of approximately 5 mg/l and a flow rate of 20 l/h on each biofilter was introduced into the installation.

Nitrosomonas and Nitrobacter nitrifying bacteria do not need an external source of organic carbon for cell synthesis, so the tests were performed without an external source of organic carbon.

Given the results obtained in the first two phases (results presented in the following chapters), in phase III has been tried the efficiency increase of ammonium reduction by adding phosphoric acid.

2.1 Biological filtration installation

2.1.1 Technological objects of the installation

The biofilters pilot installation on which the experimental tests were performed has the following technological objects:

- 2 tanks:
 - raw water tank $V= 200$ l;
 - biologically filtered water tank $V= 200$ l;
- raw water pump;
- raw water pipes;
- raw water flow meter;
- raw water distributor;
- 3 biofilters made of PVC columns with an inner diameter of 100 mm.
- they have inside on a height of 1 m, the support media supported by drainage (each biofilter having a plate with a single nozzle and a single type of support media):
 - biofilter 1 – sand ($H=1$ m);
 - biofilter 2 – granular activated carbon ($H=1$ m);
 - biofilter 3 – ceramic granules ($H=1$ m);.
- compressor to ensure dissolved oxygen;
- air flow meter;
- air distributor;
- air pipes;
- filtered water pipes;
- wash water pipes.

The following figure shows the technological scheme of the biological filtration installation (biofilters) used.



Figure 2.2. Technological scheme of biological filtration installation.

2.1.2 Installation operation

The biological filtration installation can be used with open circuit, in which the water is pumped directly from the well or with closed circuit, in which after each filtration cycle, in the biologically filtered water, ammonium chloride is added and it is used as raw water.

In the experimental tests it was worked with the variation of ammonium concentration in the raw water, and the circuit used was a closed circuit.

Operation mode of biological filtration installation with closed circuit:

- The raw water is pumped into the distributor, and from the distributor flows gravitationally to the inlet point at the bottom of each filter. From the inlet, the water flows upwards through each filter (due to the pressure difference between the water level in the distributor and the water level in the filter), to the biologically filtered water collection point. The filtered water is collected at the top of the filters and then it is transported gravitationally to the biologically filtered water tank (during the priming of the biological process, the biologically filtered water was also transported in the raw water tank). At the same time, with the help of a compressor, air is introduced into each filter at the bottom.
- At the end of each biological filtration cycle (after the raw water tank is emptied), the pump suction is moved to the filtered water tank. Ammonium chloride is added to the filtered water and after it is used as raw water for the next filtration cycle.
- The filters are washed when the filtered water flow reaches a maximum of 10 l/h (on a filter), due to the head loss increase generated by the accumulation of biomass detached from the support media in filter layer. The filters washing is realised by pumping the washing water (biologically filtered water) at the bottom part of the filters, and the water collection from the filters washing is realised on the upper part of the filters and then it is transported gravitationally and discharged into the sewer.

2.2 *Raw water and prepared raw water*

The raw water used in the experimental tests comes from a well in the area of Bucharest (F1 well).

The following figure shows the location of F1 well.

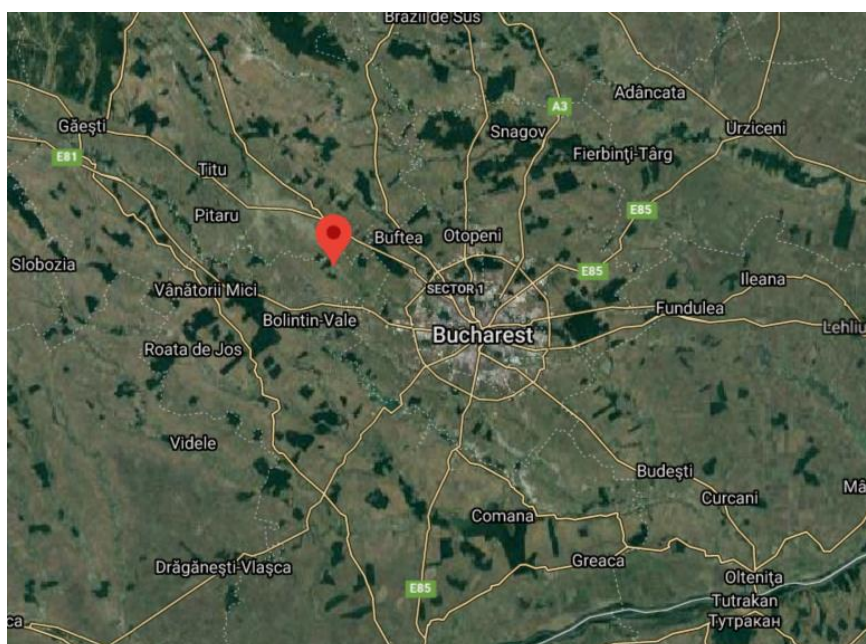


Figure 2.3. F1 well location.

The raw water collected from the F1 well near Bucharest was transported to the Colentina Laboratory Complex, where the used biofilter installation is located.

The raw water volume of a transport was 150 l. Both the transport and the raw water supply of the biofilter installation were done 3-4 times per week (once per day) during the priming period of the biological process and daily during the experimental tests realization period.

The water used had an essential role in biological process priming and in maintaining its stability until the end of the experimental tests because it was a raw (untreated) water with bacteriological development potential.

The following table shows the quality parameters of the raw water used.

Table 2.1 Raw water quality parameters.

Nr.	Water quality parameter	Minimum values	Average values	Maximum values
1	Ammonium [mg/l]	0.17	0.63	1.12
2	Nitrates [mg/l]	91.80	146.40	230.10
3	Nitrites [mg/l]	0.040	0.285	0.575
4	Phosphorus [mg/l]	0.029	0.032	0.036
5	Iron [mg/l]	0.020	0.025	0.030
6	Alkalinity [mval/l]	2.65	3.54	4.500
7	pH	6.71	7.78	8.24
8	Conductivity [μ S/cm]	845.00	1089.38	1327.00

Iron was determined in only 4 tests and varied from 0.02 to 0.03 mg/l. Due to the low concentration of iron in raw water, it was not determined in the rest of the experimental tests.

In order to have the most accurate concentrations of dissolved oxygen in the water, it was determined at the time of each water sample.

The concentration of ammonium in the raw water from F1 well varied during the tests between 0.17-1.12 mg/l. In order to increase the concentration of ammonium in the raw water, up

to the concentration of ammonium necessary for the test, synthetic raw water was prepared by adding ammonium chloride in the water taken from the well.

2.3 *Biological process priming*

Given that biological filtration involves the reduction of contaminants in raw water with bacteria help, the experimental tests required a period for biological process priming, respectively a period of bacteria growth needed to reduce ammonium in water (*Nitrosomonas* and *Nitrobacter*).

During the biological process priming, the raw water used in the biological filtration process was replaced 3-4 times per week with fresh water from F1 well. Due to the low concentration of ammonium in the raw water (0.17-1.12 mg/l), ammonium chloride was added into the raw water during priming period.

The biological process prime began in October 2019, but it was difficult because it was affected by the appearance of SARS-COV-2 virus, respectively the state of emergency. The state of emergency generated the interruption of raw water transport necessary to supply the installation in order to prime the process and further led to the degradation of the biomass already formed.

This led to the extension of biological process priming until the beginning of August 2020.

3 Experimental tests

3.1 Experimentale phases

Three test phases were proposed and performed, the first 2 phases having 3 tests each, and phase III having 2 tests.

The tests performed in phases I and II, aimed to evaluate the efficiency of the biological process on each filter media, depending on the ammonium concentration in raw water and depending on the filtration speed.

The tests performed in phase III aimed to increase the efficiency of the biological process in reducing the ammonium concentration in raw water by evaluating the influence of external sources of nutrients when added to water.

The following table shows the tests proposed in the 3 phases.

Table 3.1 Experimental phases.

Faza	Q _{raw water} [l/h]	Q _{raw water/filter} [l/h]	C _{ammonium} [mg/l]	Remarks
I	60	20	≈2	No phosphoric acid
	60	20	≈5	
	60	20	≈10	
II	105	35	≈2	
	105	35	≈5	
	105	35	≈10	
III	60	20	≈5	No phosphoric acid
	60	20	≈5	With the addition of phosphoric acid

The names used for ammonium concentrations in this research report are

- low concentrations: 0.5-4 mg/l;
- average concentrations: 4-8 mg/l;
- high concentrations: 8-12 mg/l.

3.2 Quality parameters, laboratory equipment and reagents

To determine the analyzed parameters of raw water and biologically filtered water, the following laboratory equipment was used:

- HACH spectrophotometer – DR3900;
- HACH digital laboratory multimeter with two-channel - HQ440D;
- HACH dry heat thermostat with 2 blocks – LT200;
- Marvel WTW PH-meter– pH526.

The following table shows the analysis methods for the analyzed parameters.

Table 3.2 Analysis methods of the analyzed parameters.

Nr.	Analyzed quality parameter	Method used	Lab equipment
1	Ammonium	HACH – USEPA ^a Nessler Method ^b	HACH spectrophotometer – DR3900
2	Nitrates	HACH - Cadmium Reduction Method	

Nr.	Analyzed quality parameter	Method used	Lab equipment
3	Nitrites	HACH - USEPA Diazotization Method ^c	
4	Phosphorus	HACH - LCK349 Fosfor total / Fosfat orto	HACH spectrophotometer – DR3900 HACH dry heat thermostat with 2 blocks – LT200
5	pH	SR EN ISO 10523:2012	HACH digital laboratory multimeter with two-channel - HQ440D Marvel WTW PH-meter– pH526
6	Conductivity	SR EN 27888:1997	HACH digital laboratory multimeter with two-channel - HQ440D
7	Dissolved oxygen	SR EN 25813:2000/C91:2009	
8	Temperature	-	
9	Iron	HACH – USEPA ^d FerroVer Method ^e	HACH spectrophotometer – DR3900
10	Alcalinity	SR EN ISO 9963-1:2002	-
11	COD	SR EN ISO 8467/2001	-

^a - USEPA accepted for wastewater analysis (distillation required), Method 350.2;

^b - adapted from Standard Methods for the Examination of Water and Wastewater, 4500-NH₃ B & C, 15th Edition;

^c - USEPA approved for wastewater analysis, Federal Register, 44(85), 25505 (May 1, 1979);

^d - USEPA approved for reporting wastewater analysis, Federal Register, June 27, 1980; 45 (126: 43459);

^e - adapted from Standard Methods for the Examination of Water and Wastewater.

An Intellical LDO101 field oxygen sensor, luminescent/optical, was used to determine the dissolved oxygen concentration.

The oxygen sensor and the chemical reagents used to determine the ammonium, nitrate, nitrite and phosphorus water quality parameters are part of a grant received from HACH LANGE S.R.L.

3.3 Working mode of experimental tests

Experimental tests were performed during the weekend. In the corresponding week of each test, raw water with a flow rate and with an ammonium concentration approximately equal to those in the test at the end of the week, was introduced in the installation.

In order to realised the experimental tests, from the start of the installation, taking water samples and determining the water quality parameters, several steps were followed:

- Before the beginning of each filtration cycle, the raw water flow introduced in the biofilter installation and the ammonium concentration in raw water are established;
- A sample of water is taken from the raw water tank for which the ammonium concentration is determined;
- Depending on the concentration of ammonium in raw water tank and depending on the desired concentration to be introduced into the installation, the necessary dose of ammonium chloride to be added to water is calculated;

- For raw water prepared with ammonium chloride, the water quality parameters established at the beginning of the experimental tests will be determined: ammonium, phosphorus, nitrates, nitrites, pH, conductivity and dissolved oxygen;
- The installation starts;
- In the second half of the filtration cycle, water samples are taken from the sand and ceramic biofilters in the lower and middle layers;
- At the end of the filtration cycle, samples of biologically filtered water are taken from each biofilter.
- For the water samples taken from the filter layers and from the outlet of the biofilters, the quality parameters established at the beginning of the experimental tests are determined;
- The installation is prepared for the next filtration cycle by pumping water from the biologically filtered water tank into the raw water tank.
- After preparing the installation for the next filtration cycle, follow the steps mentioned above.

It is mentioned that the above working method is valid only for the days when the experimental tests were performed.

Throughout the experimental tests, the biofilters water supply was stopped for a maximum of 1 hour/day, in order to prepare the synthetic raw water, otherwise the installation worked continuously, by recirculation.

4 Results of experimental tests in phases I and II

4.1 Efficiency of reducing the ammonium concentration in raw water

The main purpose of the experimental tests was to determine the efficiency of the nitrification process on the three support media used: sand, ceramic granules and granular activated carbon.

The biofilters performance was monitored by measurements of factors influencing the biological process, such as temperature, pH and dissolved oxygen.

The nitrification process takes place at temperatures between 4 and 45°C, with an optimal temperature of 35°C for *Nitrosomonas* and an optimal temperature of 35-42°C for *Nitrobacter*.

For an optimal functioning of the nitrification process, it is recommended that the minimum level of dissolved oxygen concentration be 2 mg/l.

For the operation of the nitrification process, it is recommended that the pH be maintained in the range of 6.5-8, with an optimal pH of 7.2.

4.1.1 Efficiency of reducing the ammonium concentration in raw water in phase I

In the first phase, in each biofilter was introduced raw water with a flow rate of 20 l/h and 3 different concentrations of ammonium. The variation of the raw water concentration was achieved by adding ammonium chloride to the raw water.

The following table shows the results of the experimental tests obtained for biologically filtered water on the three biofilters in phase I.

Table 4.1 Raw water and biologically filtered water quality parameters – phase I.

Item	Water sample	NH ₄ ⁺ [mg/l]	Efficiency [%]	P [mg/l]	NO ₃ ⁻ [mg/l]	NO ₂ ⁻ [mg/l]	PH	Cond. [μS/cm]	DO [mg/l]	T [°C]
C_{1-NH₄⁺} = 1.76 mg/l										
1	SRW	1.76	-	0.032	91.8	0.08	6.71	945	7.31	23.3
2	BFWS	0.38	78%	0.029	95.3	0.049	7.68	933	5.11	24.3
3	BFWCG	0.24	86%	0.028	96.1	0.05	7.51	871	5.12	24.1
4	BFWAC	0.59	66%	0.028	95.1	0.044	7.56	965	4.81	24.3
C_{2-NH₄⁺} = 4.68 mg/l										
5	SRW	4.68	-	0.032	163.3	0.204	7.82	1004	6.88	22.8
6	BFWS	0.69	85%	0.028	173.9	0.41	7.21	936	4.74	23.4
7	BFWCG	0.51	89%	0.026	175.0	0.522	7.46	937	4.74	23.3
8	BFWAC	0.95	80%	0.027	174.3	0.486	7.27	1004	4.64	23.2
C_{3-NH₄⁺} = 10.69 mg/l										
9	SRW	10.69	-	0.03	230.1	0.575	8.24	1232	7.00	22.1
10	BFWS	3.79	65%	0.022	251.5	0.581	8.25	1158	5.14	22.4
11	BFWCG	0.56	95%	0.024	262.7	0.586	8.06	1168	4.95	22.5
12	BFWAC	2.9	73%	0.025	255.1	0.583	8.06	1186	4.70	22.4

As can be seen in the table above, the biofilters performance was not affected by temperature, pH and dissolved oxygen, as the differences in the results obtained for these parameters are relatively small.

It can also be seen that the concentration of phosphorus in the prepared raw water is very low and decreases insignificantly below 0.01 mg/l, after biological filtration.

The water conductivity is not affected by the biological process, it remains approximately constant, having a slight decrease in the biologically filtered water.

The following figure shows the efficiencies obtained on each biofilter in order to reduce the ammonium in water, depending on the biofilters support media and depending on the ammonium concentration in water introduced in biofilters.

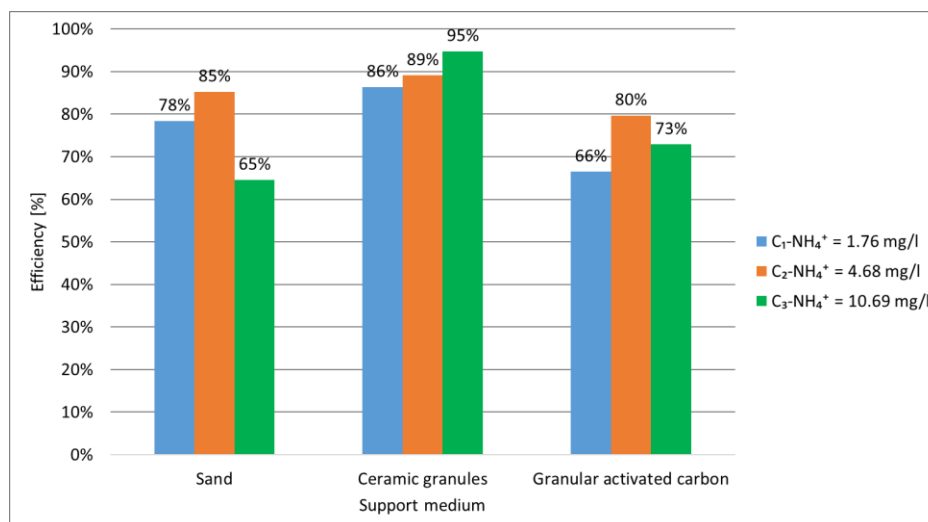


Figure 4.1. Efficiency of reducing the ammonium concentration depending on the support media used and on the ammonium concentration in raw water introduced in biofilters.

As can be seen in the figure above, in phase I, at any ammonium concentrations in raw water introduced into the biofilters, the highest efficiencies obtained in reducing ammonium were obtained for the biofilter which has ceramic granules as support media. For this biofilter, it is observed that if ammonium concentration in raw water is higher, the efficiency of the biofilter in reducing ammonium increases.

The biofilter used sand as support media has higher efficiencies in reducing ammonia at low (1.76 mg/l) and medium (4.68 mg/l) concentrations compared to the granular activated carbon biofilter, and at high concentrations (10.69 mg/l), granular activated carbon biofilter is more efficient than sand biofilter.

For both, sand biofilter and granular activated carbon biofilter, the best efficiency is obtained at average ammonium concentrations in raw water.

According to the above graphs and according to the previous table, in phase I the biological nitrification process worked, resulting in a decrease in the ammonium concentration and an increase in the nitrates concentration in water.

4.1.2 Efficiency of reducing the ammonium concentration in raw water in phase II

In the second phase, in each biofilter was introduced raw water with a flow rate of 35 l/h and 3 different ammonium concentrations. The variation of the raw water concentration was achieved by adding ammonium chloride to the raw water.

The following table shows the results of the experimental tests obtained for biologically filtered water on the three biofilters in phase II.

Table 4.2 Raw water and biologically filtered water quality parameters – phase II.

Item	Water sample	NH ₄ ⁺ [mg/l]	Efficiency [%]	P [mg/l]	NO ₃ ⁻ [mg/l]	NO ₂ ⁻ [mg/l]	PH	Cond. [μS/cm]	DO [mg/l]	T [°C]
C₁-NH₄⁺=2.81 mg/l										
1	SRW	2.81		0.035	145.2	0.04	7.76	1321	7.70	22.1
2	BFWS	1.39	51%	0.027	149.3	0.18	7.95	1196	5.45	22.1
3	BFWCG	0.62	78%	0.029	150.7	0.08	8.09	1137	5.35	22.2
4	BFWAC	0.77	73%	0.028	149.9	0.038	8.04	1139	5.40	22.1
C₂-NH₄⁺=5.15 mg/l										
5	SRW	5.15		0.032	99.6	0.261	8.08	890	7.23	23.7
6	BFWS	3.41	34%	0.028	104.4	0.374	8.11	845	4.83	23.5
7	BFWCG	1.83	64%	0.026	108.2	0.555	8.15	815	5.00	23.7
8	BFWAC	1.87	64%	0.027	109.0	0.144	8.19	879	4.56	23.9
C₃-NH₄⁺=11.03 mg/l										
9	SRW	11.03		0.029	148.4	0.551	8.11	845	7.16	24.6
10	BFWS	6.59	40%	0.027	161.5	0.58	8.05	851	4.86	24.7
11	BFWCG	1.94	82%	0.027	176.7	0.586	7.7	858	4.76	24.6
12	BFWAC	4.97	55%	0.03	167.2	0.582	7.98	861	4.58	24.9

As can be seen in the above table, the biofilters performance was not affected by temperature, pH and dissolved oxygen, as the differences in the results obtained for these parameters are relatively small.

It can also be seen that the concentration of phosphorus in the prepared raw water is very low and decreases insignificantly, below 0.01 mg/l, after biological filtration.

The water conductivity is not affected by the biological process, it remains approximately constant, having a slight decrease in the biologically filtered water.

The following figure shows the efficiencies obtained on each biofilter in order to reduce the ammonium in water, depending on the biofilters support media and depending on the ammonium concentration in water introduced in biofilters.

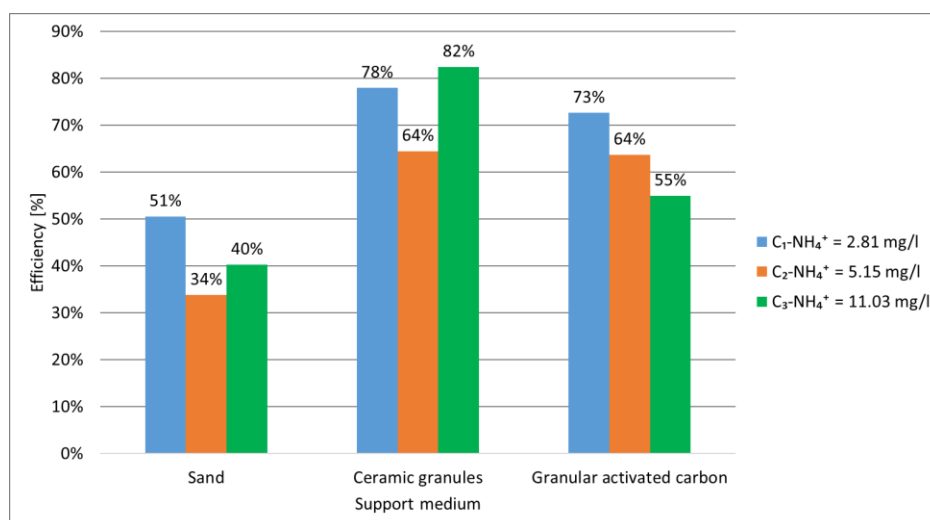


Figure 4.2. Efficiency of reducing the ammonium concentration depending on the support media used and on the ammonium concentration in raw water introduced in biofilters.

As can be seen in the above figure, in phase II, at any ammonium concentrations in raw water introduced into the biofilters, the highest efficiencies in reducing ammonium were obtained for the biofilter which has ceramic granules as support media, followed by the biofilter with granular activated carbon and biofilter with sand. For this biofilter with ceramic granules, it is observed that in the case of high ammonium concentrations (11.03 mg/l), the best efficiency in reducing ammonia in water was obtained, followed by the efficiency for low concentrations (2.81 mg/l) and the efficiency for average concentrations (5.15 mg/l).

The biofilter that uses sand as a support media has the lowest efficiencies in reducing ammonia compared to biofilters with ceramic granules and granular activated carbon and it is observed that as the concentration increases, the efficiency of this biofilter decreases.

In the case of biofilters with granular activated carbon as support media, it is observed that as the ammonium concentration in raw water is higher, the efficiency of the biofilter in reducing ammonium decreases.

According to the above graph and according to the previous table, in phase II the biological nitrification process worked, resulting in a decrease in the ammonium concentration and an increase in the nitrates concentration in water.

Comparing the efficiencies obtained in phase I with those obtained in phase II, there is a decrease in the efficiency of reducing ammonium in water in phase II, when raw water is introduced into the installation with a higher flow. The most affected biofilter by the flow increase in order to reduce ammonium is represented by the sand biofilter.

4.2 Variation of ammonium concentration in filter layer

The variation of the ammonium concentration in filter layer depending on the ammonium concentration in raw water and on the raw water flow introduced in installation was determined for biological filters with sand and ceramic granules.

4.2.1 Variation of ammonium concentration in filter layer in the biofilter with sand

4.2.1.1 Variation of ammonium concentration in filter layer depending on the ammonium concentration in raw water

To determine the variation of ammonium concentration in filter layer, water samples were taken from 4 points, filter inlet, lower layer (H = 0.3 m), upper layer (H = 0.7 m) and from outlet (H = 1 m). For water samples, the water quality parameters analyzed in these experimental tests were determined.

The following table shows the results of the experimental tests for the sand biofilter, in phase I.

Table 4.3 Quality parameters of raw water and biologically filtered water on the sand biofilter in phase I – $Q_{\text{raw water}}=20 \text{ l/h}$.

Item	Water sample	NH_4^+ [mg/l]	P [mg/l]	NO_3^- [mg/l]	NO_2^- [mg/l]	PH	Cond. [$\mu\text{S/cm}$]	DO [mg/l]	T [°C]
$C_{1-\text{NH}_4^+}=1.76$									
1	SRW	1.76	0.032	91.8	0.08	6.71	945	7.31	23.3
2	BFWS	0.38	0.029	95.3	0.049	7.68	933	5.11	24.3
3	BFWS UL	0.57	-	95.2	0.065	7.34	935	5.04	23.7
4	BFWS LL	0.82	-	94.2	0.07	6.95	940	4.85	23.7

Item	Water sample	NH ₄ ⁺ [mg/l]	P [mg/l]	NO ₃ ⁻ [mg/l]	NO ₂ ⁻ [mg/l]	PH	Cond. [μS/cm]	DO [mg/l]	T [°C]
C₂-NH₄⁺=4.68									
5	SRW	4.68	0.036	163.3	0.204	7.82	1004	6.88	22.8
6	BFWS	0.69	0.028	173.9	0.41	7.21	936	4.74	23.4
7	BFWS UL	1.3	-	172.8	0.375	7.35	945	4.85	22.9
8	BFWS LL	2.87	-	167.5	0.312	7.56	975	4.89	22.7
C₃-NH₄⁺=10.69									
9	SRW	10.69	0.03	230.1	0.575	8.24	1232	7.00	22.1
10	BFWS	3.79	0.022	251.5	0.581	8.25	1158	5.14	22.4
11	BFWS UL	4.54	-	249.9	0.583	8.02	1183	4.63	22.1
2	BFWS LL	6.65	-	242.1	0.58	8.05	1183	4.72	22.1

In the previous table it can be seen that the ammonium concentration in biologically filtered water reaches below the maximum allowable limit of 0.5 mg/l according to Law 458/2002, if the water introduced in the filter has an ammonium concentration of 1.76 mg/l. At an ammonium concentration of 4.68 mg/l in raw water, in the biologically filtered water the ammonium concentration is close to the maximum allowable limit, at less than 0.2 mg/l.

The following figures show the variation of the ammonium concentration in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 20 l/h is introduced into the biofilter.

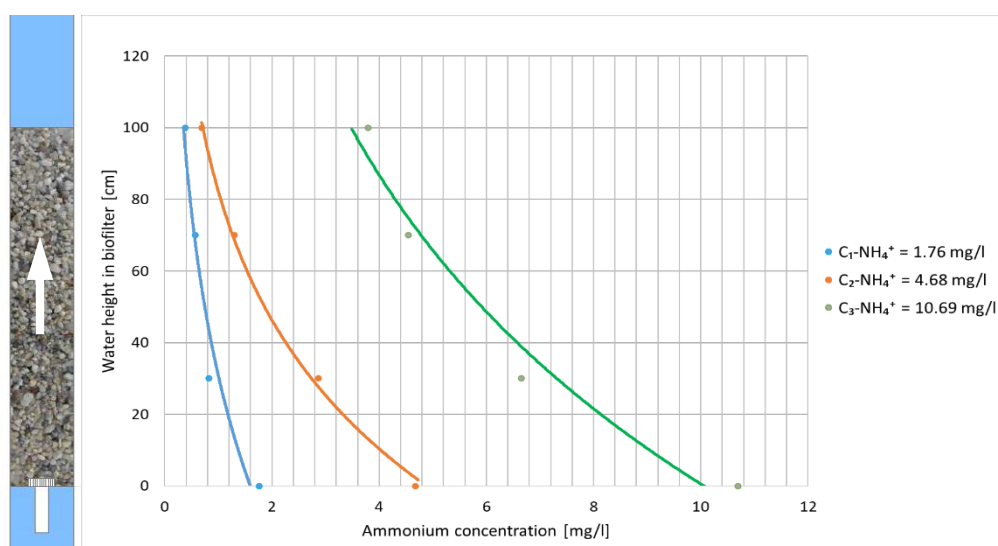


Figure 4.3. Variation of ammonium concentration in the filter layer – $Q_{\text{raw water}} = 20 \text{ l/h}$.

As can be seen in the figure above, for all 3 ammonium concentrations in the raw water introduced into the biofilter, the ammonium concentration in water decreases more in the lower layer, followed by the middle layer and the upper layer, resulting that the most active bacteria are in the lower layer. It can be observed that in the case of concentrations of 1.76 mg/l and 4.68 mg/l the ammonium is reduced to or near the minimum allowable limit according to law 458/2002, and at a concentration of 10.69 mg/l, the ammonium is reduced to 3.79 mg/l.

Another aspect that demonstrates that the attached biomass from the lower layer is the most active, is represented by the efficiency variation of reducing the ammonium concentration in the filter layer, presented in the following table.

Table 4.4 Efficiency of reducing the ammonium concentration in filter layer in the sand biofilter – $Q_{\text{raw water}}=20$ l/h.

Item	Filter layer	NH_4^+ reduced in filter layer [mg/l]	Efficiency [%]
$C_{1-\text{NH}_4^+}=1.76 \text{ mg/l}$			
1	upper	0.19	14%
2	middle	0.25	18%
3	lower	0.94	68%
$C_{2-\text{NH}_4^+}=4.68 \text{ mg/l}$			
4	upper	0.61	15%
5	middle	1.57	39%
6	lower	1.81	45%
$C_{3-\text{NH}_4^+}=10.69 \text{ mg/l}$			
7	upper	0.75	11%
8	middle	2.11	31%
9	lower	4.04	59%

It is observed that the nitrification process works because ammonium is reduced, and another aspect that demonstrates the biological process functioning is represented by the increase of nitrites and nitrates concentrations in biologically filtered water.

The following figures show the variations of nitrites and nitrates in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 20 l/h is introduced into the biofilter.

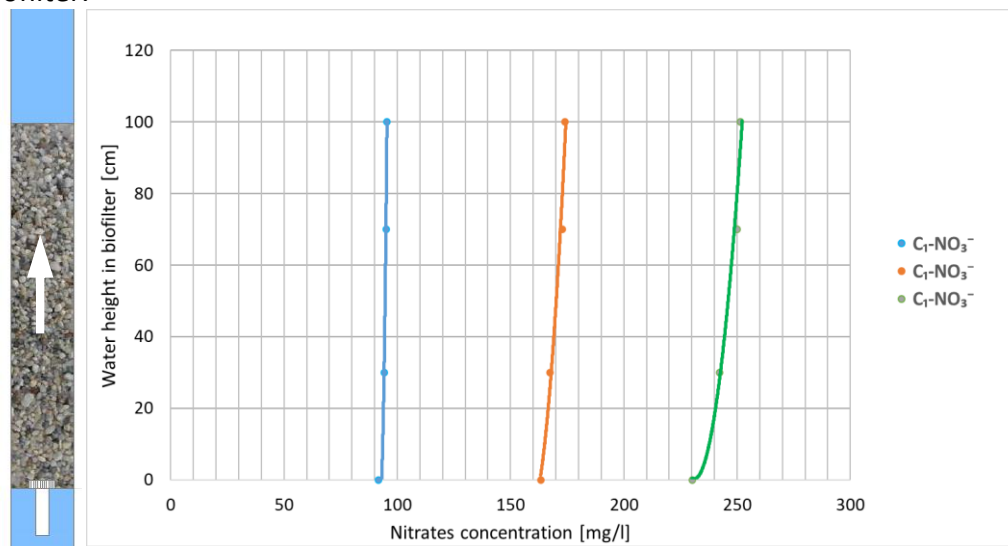


Figure 4.4. Variation of nitrates concentration in the filter layer– $Q_{\text{raw water}} = 20$ l/h.

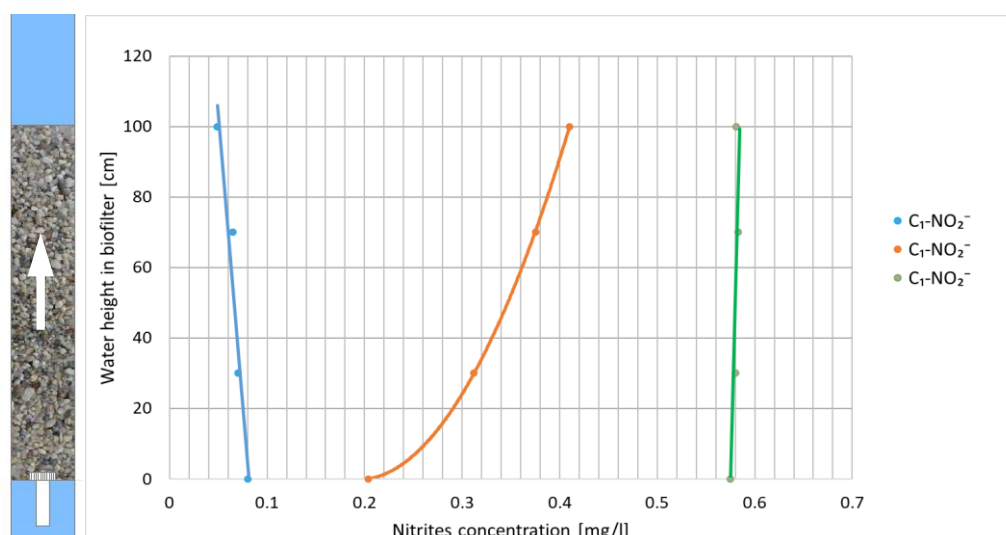


Figure 4.5. Variation of nitrites concentration in the filter layer– $Q_{\text{raw water}} = 20 \text{ l/h}$.

As can be seen in the above figures, the concentrations of nitrates increase, resulting that the biological process working, ammonium being reduced to nitrate. In the case of nitrites, it is observed that their concentrations increase, except for the first curve, where it is observed that their concentrations decrease. In this case, there may be measurement errors because the concentration differences are below 0.05 mg/l .

The following table shows the results of the experimental tests for the sand biofilter for phase II.

Table 4.5 Quality parameters of raw water and biologically filtered water on the sand biofilter in phase II – $Q_{\text{AB}}=35 \text{ l/h}$.

Item	Water sample	NH_4^+ [mg/l]	P [mg/l]	NO_3^- [mg/l]	NO_2^- [mg/l]	PH	Cond. [$\mu\text{S/cm}$]	DO [mg/l]	T [°C]
$C_{1-\text{NH}_4^+}=2.81 \text{ mg/l}$									
1	SRW	2.81	0.035	145.2	0.04	7.76	1321	7.70	22.1
2	BFWS	1.39	0.027	149.3	0.18	7.95	1196	5.45	22.1
3	BFWS UL	1.83		147.9	0.189	7.96	1270	5.71	22
4	BFWS LL	1.92		147.0	0.142	7.97	1285	5.81	21.9
$C_{2-\text{NH}_4^+}=5.15 \text{ mg/l}$									
5	SRW	5.15	0.032	99.6	0.261	8.08	890	7.23	23.7
6	BFWS	3.41	0.028	104.4	0.374	8.11	845	4.83	23.7
7	BFWS UL	3.51		102.9	0.423	8.13	884	5.05	23.9
8	BFWS LL	3.76		102.7	0.346	8.1	890	5.16	23.7
$C_{3-\text{NH}_4^+}=11.03 \text{ mg/l}$									
9	SRW	11.03	0.029	148.4	0.551	8.11	845	7.16	24.6
10	BFWS	6.59	0.027	161.5	0.58	8.05	851	4.86	24.7
11	BFWS UL	7.83		156.9	0.577	8.08	854	5.02	24.9
12	BFWS LL	9.31		153.3	0.582	8.01	854	4.91	24.7

The following figure shows the variation of the ammonium concentration in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 35 l/h is introduced into the biofilter.

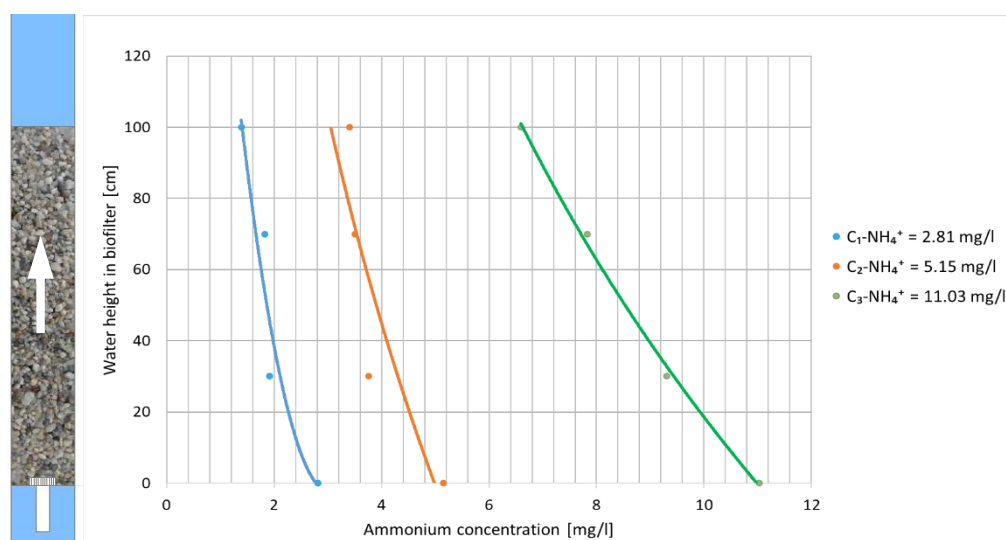


Figure 4.6. Variation of ammonium concentration in the filter layer – $Q_{\text{raw water}} = 35 \text{ l/h}$.

As can be seen in the above figure, the variation of the ammonium concentration in the filter is different for the 3 types of raw water introduced in the biofilter.

In the case of the low ammonium concentration in raw water introduced into the biofilter, the ammonium is more reduced in the lower filter layer, followed by the upper layer and the middle layer.

In the case of the average ammonium concentration in raw water introduced in the biofilter, the ammonia is reduced in the lower layer, after which it remains approximately constant until the filter outlet, being insignificantly reduced in the middle and upper layers.

In the case of the high ammonium concentration in raw water introduced into the biofilter, the ammonia is reduced approximately constantly over the entire height of the filter, very little being reduced better in the lower layer.

Another aspect that demonstrates that the attached biomass from the lower layer is the most active, is represented by the efficiency variation of reducing the ammonium concentration in the filter layer, presented in the following table.

Table 4.6 Efficiency of reducing the ammonium concentration in filter layer in the sand biofilter – $Q_{\text{raw water}} = 35 \text{ l/h}$.

Item	Filter layer	NH_4^+ reduced in filter layer [mg/l]	Efficiency [%]
$C_{1-\text{NH}_4^+} = 2.81 \text{ mg/l}$			
1	upper	0.44	31%
2	middle	0.09	6%
3	lower	0.89	63%
$C_{2-\text{NH}_4^+} = 5.15 \text{ mg/l}$			
4	upper	0.1	6%
5	middle	0.25	14%
6	lower	1.39	80%
$C_{3-\text{NH}_4^+} = 11.03 \text{ mg/l}$			
7	upper	1.24	28%
8	middle	1.48	33%
9	lower	1.72	39%

It is observed that the nitrification process works in phase II, ammonium being reduced to nitrates, but comparing the results obtained in phase I with those obtained in phase II, it can be stated that the sand biofilter is very affected by the increase of the filtration speed, and a reduction of ammonium below the maximum admissible limit according to law 458/2002 cannot be obtained not even in the case of a reduced concentration of 2.81 mg/l.

The following figures show the variations of nitrites and nitrates in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 35 l/h is introduced into the biofilter.

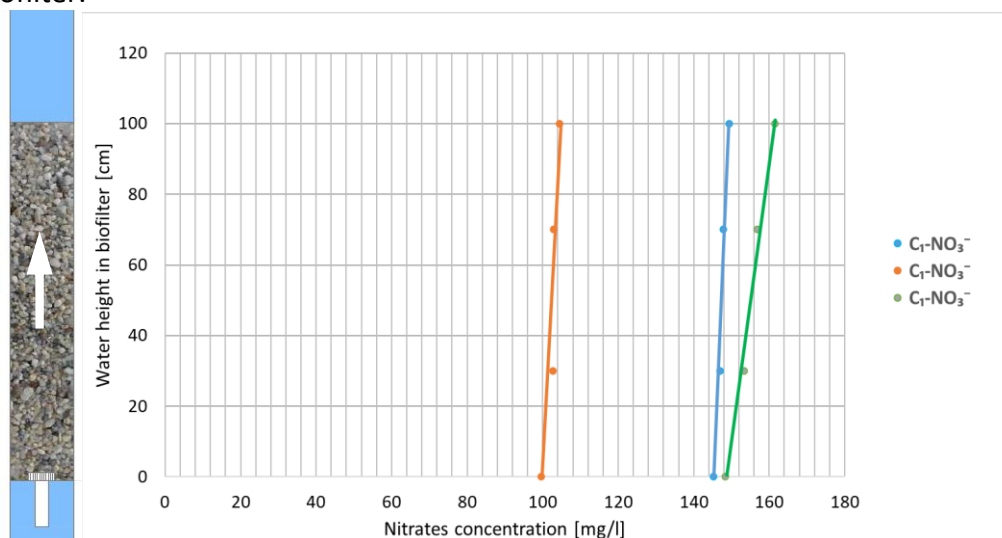


Figure 4.7. Variation of nitrates concentration in the filter layer– $Q_{\text{raw water}} = 35 \text{ l/h}$.

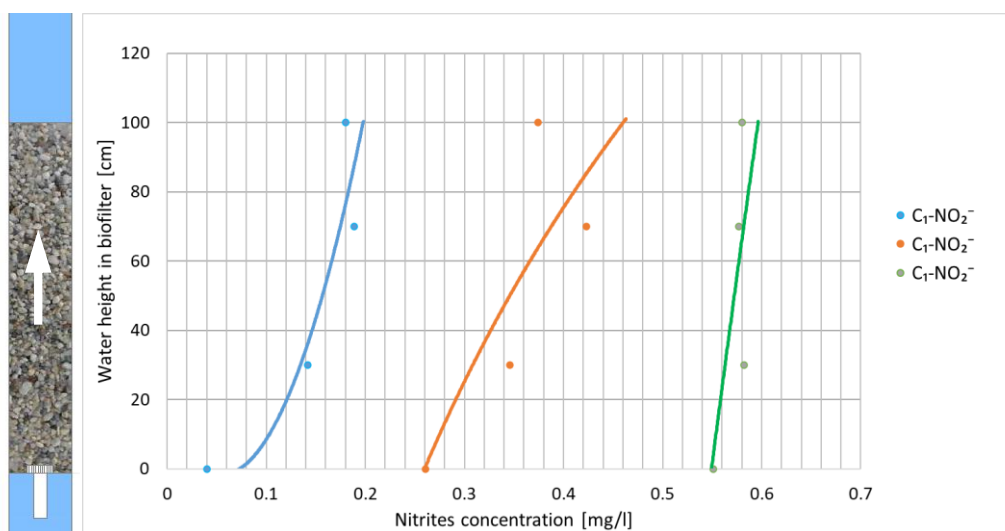


Figure 4.8. Variation of nitrites concentration in the filter layer– $Q_{\text{raw water}} = 35 \text{ l/h}$.

As can be seen in the above figures, the concentrations of nitrites and nitrates increase, resulting that the biological process working, and ammonium is reduced to nitrite and then to nitrate.

4.2.1.2 Variation of ammonium concentration in filter layer depending on the raw water flow introduced in the installation

The following figures show the variation of the ammonium concentration in the filter layer, depending on the raw water flow introduced in the biofilter.

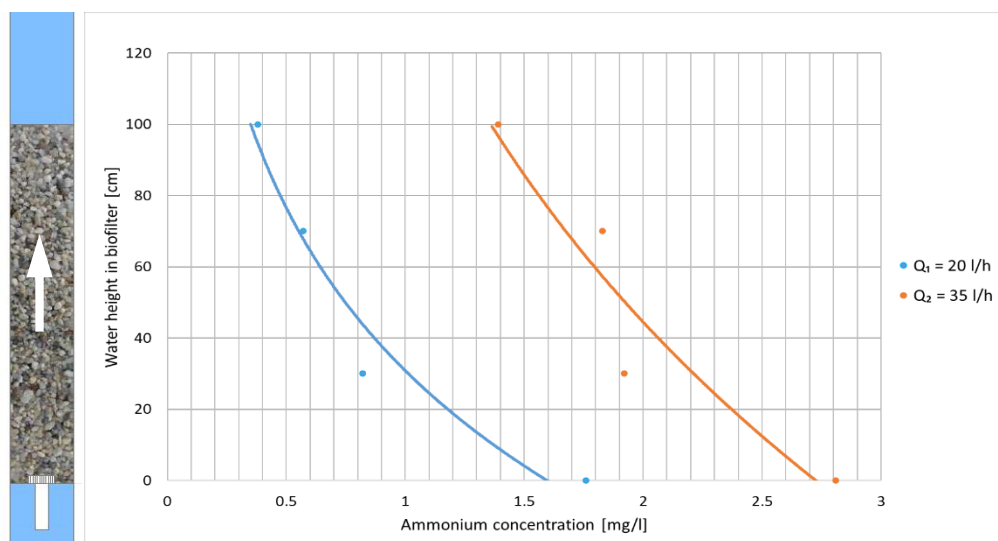


Figure 4.9. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – low ammonium concentrations (1.76 si 2.81 mg/l) in raw water.

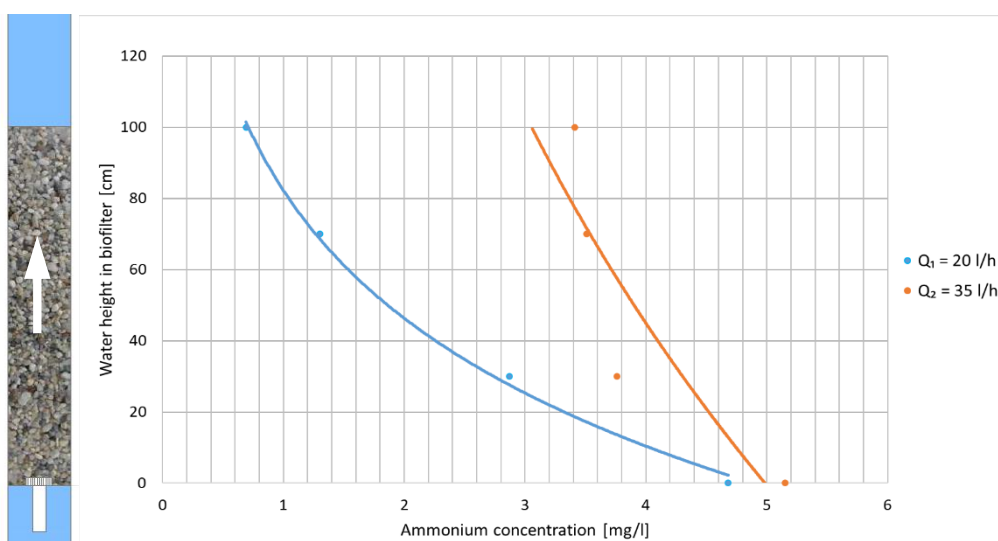


Figure 4.10. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – average ammonium concentrations (4.68 si 5.15 mg/l) in raw water.

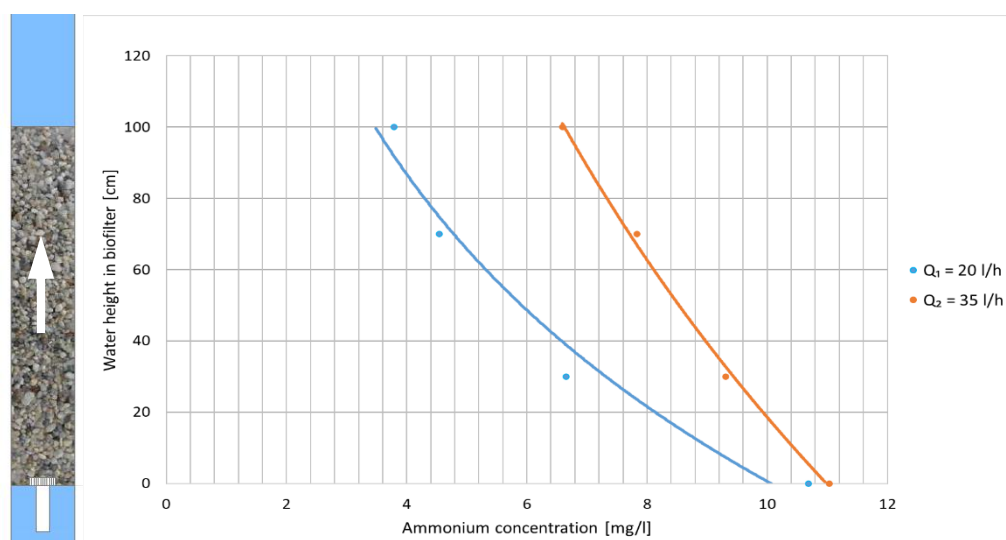


Figure 4.11. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – high ammonium concentrations (10.69 si 11.03 mg/l) in raw water.

As can be seen in the above figures, as the raw water flow increases, the filtration rate increases and the biofilter performance decreases, largely due to the reduced contact time between water and attached biomass. It can be seen that the lower layer is less affected by the reduction of the contact time between water and attached biomass compared to the middle and upper layers.

4.2.2 Variation of ammonium concentration in filter layer in the biofilter with ceramic granules

4.2.2.1 Variation of ammonium concentration in filter layer depending on the ammonium concentration in raw water

To determine the variation of ammonium concentration in filter layer, water samples were taken from 4 points, filter inlet, lower layer ($H = 0.3 \text{ m}$), upper layer ($H = 0.7 \text{ m}$) and from filter outlet ($H = 1 \text{ m}$). For water samples, the water quality parameters analyzed in these experimental tests were determined.

The following table shows the results of the experimental tests for the biofilter with ceramic granules, in phase I.

Table 4.7 Quality parameters of raw water and biologically filtered water on the ceramic granules biofilter in phase I – $Q_{\text{raw water}} = 20 \text{ l/h}$.

Item	Water sample	NH_4^+ [mg/l]	P [mg/l]	NO_3^- [mg/l]	NO_2^- [mg/l]	PH	Cond. [$\mu\text{S}/\text{cm}$]	DO [mg/l]	T [$^{\circ}\text{C}$]
$C_{1-\text{NH}_4^+} = 1.76 \text{ mg/l}$									
1	SRW	1.76	0.032	91.8	0.08	6.71	945	7.31	23.3
2	BFWS	0.24	0.028	96.1	0.05	7.51	871	5.12	24.1
3	BFWCG UL	0.46	-	95.1	0.067	7.61	890	5.05	23.8
4	BFWCG LL	0.78	-	94.4	0.075	7.55	915	4.97	23.8
$C_{2-\text{NH}_4^+} = 4.68 \text{ mg/l}$									
5	SRW	4.68	0.036	163.3	0.204	7.82	1004	6.88	22.8
6	BFWS	0.51	0.03	175.0	0.522	7.46	937	4.74	23.3
7	BFWCG UL	1.3	-	171.9	0.512	7.55	941	4.61	22.5
8	BFWCG LL	3.42	-	166.8	0.437	7.56	975	4.72	22.5

Item	Water sample	NH ₄ ⁺ [mg/l]	P [mg/l]	NO ₃ ⁻ [mg/l]	NO ₂ ⁻ [mg/l]	PH	Cond. [μS/cm]	DO [mg/l]	T [°C]
C₃-NH₄⁺=10.69 mg/l									
9	SRW	10.69	0.03	230.1	0.575	8.24	1232	7.00	22.1
10	BFWS	0.56	0.024	262.7	0.586	8.06	1168	4.95	22.5
11	BFWCG UL	1.42	-	258.9	0.585	8	1177	4.94	22.4
12	BFWCG LL	4.41	-	250.7	0.584	8	1184	4.91	22.4

In the previous table it can be seen that the ammonium concentration in biologically filtered water on the biofilter with ceramic granules reaches the maximum allowable limit of 0.5 mg/l according to the Law 458/2002, at low concentrations (1.76 mg/l), and at medium concentrations (4.68 mg/l) and high concentrations (10.69 mg/l) approaching the limit at less than 0.1 mg/l.

The following figure shows the variation of the ammonium concentration in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 20 l/h is introduced into the biofilter.

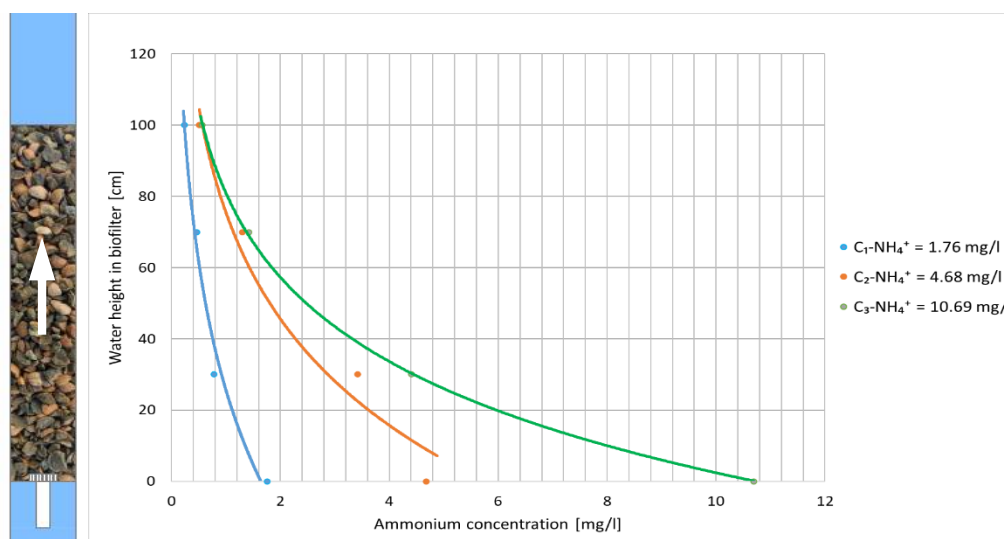


Figure 4.12. Variation of ammonium concentration in the filter layer – $Q_{\text{raw water}} = 20 \text{ l/h}$.

As can be seen in the above figure, for all 3 ammonium concentrations in raw water introduced into the biofilter, the ammonium concentration in water decreases more in the lower layer, followed by the middle layer and the upper layer, resulting that the most active bacteria are in the lower layer.

Another aspect that demonstrates that the attached biomass from the lower layer is the most active, is represented by the efficiency variation of reducing the ammonium concentration in the filter layer, presented in the following table.

Table 4.8 Efficiency of reducing the ammonium concentration in filter layer in the ceramic granules biofilter – $Q_{\text{raw water}} = 20 \text{ l/h}$.

Item	Filter layer	NH ₄ ⁺ reduced in filter layer [mg/l]	Efficiency [%]
C₁-NH₄⁺=1.76 mg/l			
1	upper	0.22	14%
2	middle	0.32	21%
3	lower	0.98	64%

Item	Filter layer	NH_4^+ reduced in filter layer [mg/l]	Efficiency [%]
$C_{2-\text{NH}_4^+}=4.68 \text{ mg/l}$			
4	upper	0.79	19%
5	middle	2.12	51%
6	lower	1.26	30%
$C_{3-\text{NH}_4^+}=10.69 \text{ mg/l}$			
7	upper	0.86	8%
8	middle	2.99	30%
9	lower	6.28	62%

With one exception it is observed that at concentrations of 4.68 mg/l, the most active area is the middle layer area.

It is observed that the nitrification process works because the ammonium is reduced, and another aspect that demonstrates the functioning of the biological process is represented by the increase of nitrites and nitrates concentrations in biologically filtered water.

The following figures show the variations of nitrites and nitrates in the filter layer, when raw water with three different concentrations of ammonium and a constant flow of 20 l/h is introduced into the biofilter.

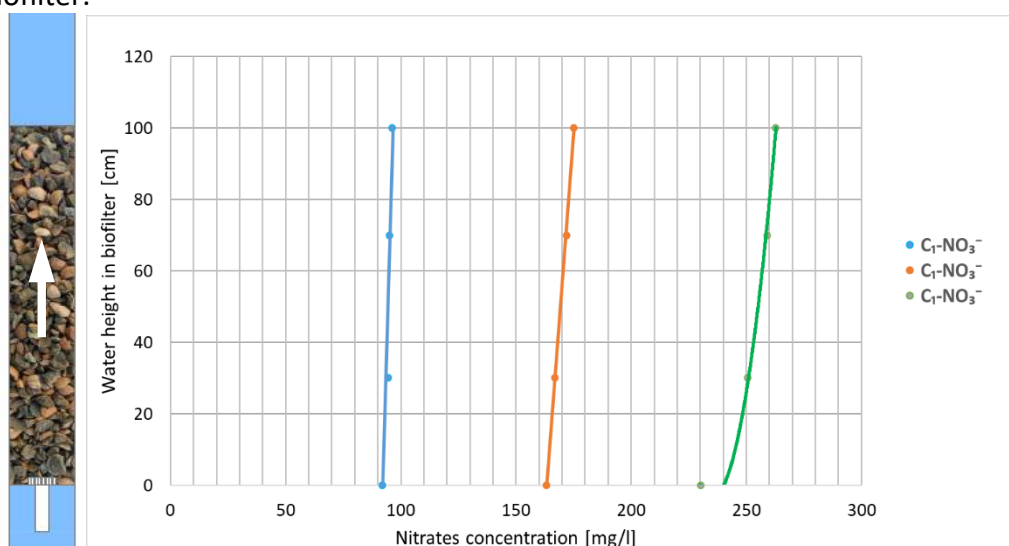


Figure 4.13. Variation of nitrates concentration in the filter layer– $Q_{\text{raw water}} = 20 \text{ l/h}$.

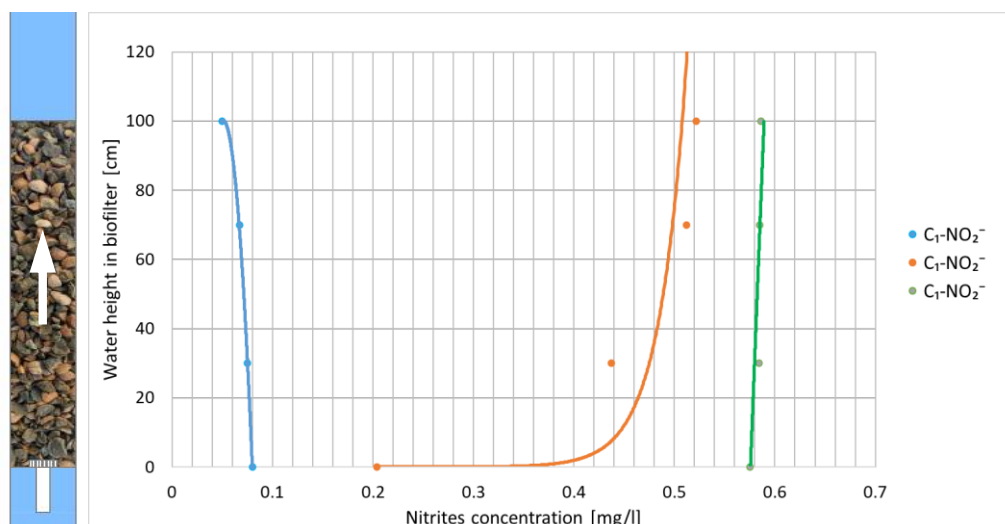


Figure 4.14. Variation of nitrites concentration in the filter layer– $Q_{\text{raw water}} = 20$ l/h.

As can be seen in the above figures, the concentrations of nitrates increase, resulting that the biological process working, ammonium being reduced to nitrate. In the case of nitrites, it is observed that their concentrations increase, except for the first curve, where it is observed that their concentrations decrease. In this case, there may be measurement errors because the concentration differences are below 0.05 mg/l.

The following table shows the results of the experimental tests for the biofilter with ceramic granules, for phase II.

Table 4.9 Quality parameters of raw water and biologically filtered water on the ceramic granules biofilter in phase II – $Q_{\text{raw water}} = 35$ l/h.

Item	Water sample	NH_4^+ [mg/l]	P [mg/l]	NO_3^- [mg/l]	NO_2^- [mg/l]	PH	Cond. [$\mu\text{S}/\text{cm}$]	DO [mg/l]	T [°C]
$C_{1-\text{NH}_4^+} = 2.81$ mg/l									
1	SRW	2.81	0.035	145.2	0.04	7.76	1321	7.70	22.1
2	BFWS	0.62	0.029	150.7	0.08	8.09	1137	5.35	22.2
3	BFWCG UL	0.98	-	149.3	0.06	8.08	1228	5.68	22.2
4	BFWCG LL	1.29	-	148.7	0.137	8.05	1257	5.85	22.1
$C_{2-\text{NH}_4^+} = 5.15$ mg/l									
5	SRW	5.15	0.032	99.6	0.261	8.08	890	7.23	23.7
6	BFWS	1.83	0.026	108.2	0.555	8.15	815	5.00	23.7
7	BFWCG UL	3.02	-	105.5	0.549	8.21	872	5.17	23.6
8	BFWCG LL	3.95	-	102.8	0.482	8.18	884	5.21	23.6
$C_{3-\text{NH}_4^+} = 11.03$ mg/l									
9	SRW	11.03	0.029	148.4	0.551	8.11	845	7.16	24.6
10	BFWS	1.94	0.027	176.7	0.586	7.7	858	4.76	24.6
11	BFWCG UL	4.2	-	169.9	0.583	7.92	847	4.71	24.8
12	BFWCG LL	6.09	-	164.3	0.583	7.9	860	4.27	24.9

The following figure shows the variation of the ammonium concentration in the filter layer, when the raw water is introduced into the biofilter with three different ammonium concentrations and a constant flow of 35 l/h.

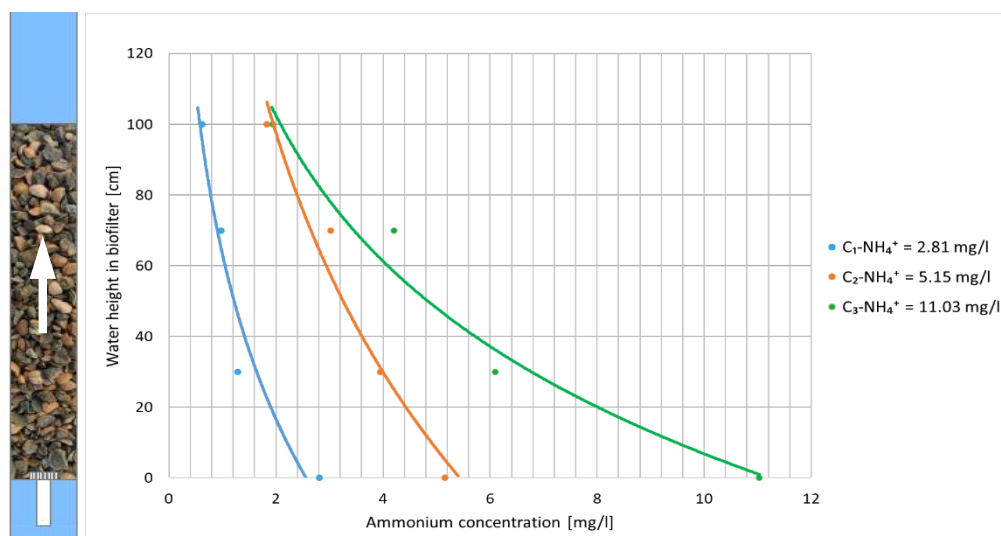


Figure 4.15. Variation of ammonium concentration in the filter layer – $Q_{\text{raw water}} = 35 \text{ l/h}$.

As can be seen in the above figure, for all 3 ammonium concentrations in raw water introduced into the biofilter, the ammonium concentration in water decreases more in the lower layer, followed by the upper layer and the middle layer, resulting that the most active bacteria are in the lower layer. It can be seen that depending on the ammonium concentration in raw water, it is reduced in larger quantities to higher concentrations. It can be observed that ammonium is reduced almost (at a difference of less than 0.15 mg/l) from the maximum permissible limit according to law 458/2002, in case of concentrations of 2.81 mg/l , and in case of concentrations of 5.15 and 11.03 mg/l , ammonium is reduced to below 2 mg/l .

Another aspect that demonstrates that the attached biomass from the lower layer is the most active, is represented by the efficiency variation of reducing the ammonium concentration in the filter layer, presented in the following table.

Table 4.10 Efficiency of reducing the ammonium concentration in filter layer in the ceramic granules biofilter – $Q_{\text{raw water}} = 35 \text{ l/h}$.

Item	Filter layer	NH_4^+ reduced in filter layer [mg/l]	Efficiency [%]
$C_1\text{-NH}_4^+ = 2.81 \text{ mg/l}$			
1	upper	0.36	16%
2	middle	0.31	14%
3	lower	1.52	69%
$C_2\text{-NH}_4^+ = 5.15 \text{ mg/l}$			
4	upper	1.19	36%
5	middle	0.93	28%
6	lower	1.2	36%
$C_3\text{-NH}_4^+ = 11.03 \text{ mg/l}$			
7	upper	2.26	25%
8	middle	1.89	21%
9	lower	4.94	54%

The following figures show the variations of nitrites and nitrates in the filter layer, when raw water with three different ammonium concentrations and a constant flow of 35 l/h is introduced into the biofilter.

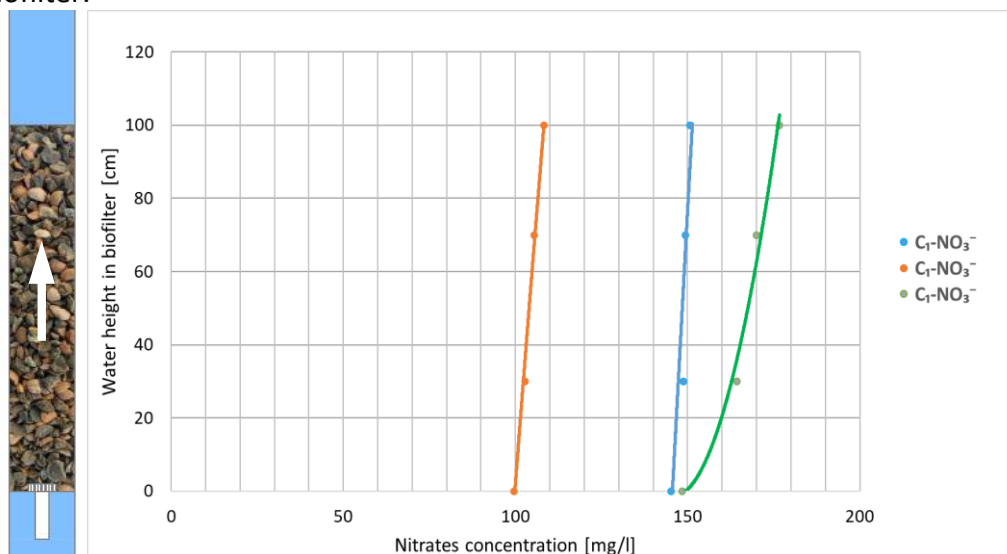


Figure 4.16. Variation of nitrates concentration in the filter layer– $Q_{\text{raw water}} = 35 \text{ l/h}$.

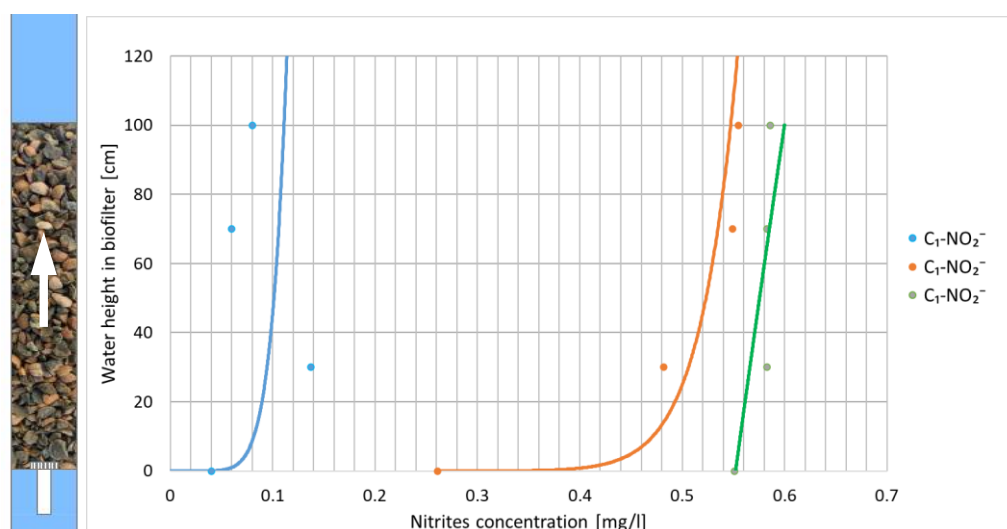


Figure 4.17. Variation of nitrites concentration in the filter layer– $Q_{\text{raw water}} = 35 \text{ l/h}$.

As can be seen in the figures above, the concentrations of nitrites and nitrates increase, resulting in the biological process working.

4.2.2.2 Variation of ammonium concentration in filter layer depending on the raw water flow introduced in the installation

The following figures show the variation of the ammonium concentration in the filter layer, depending on the raw water flow introduced in the biofilter.

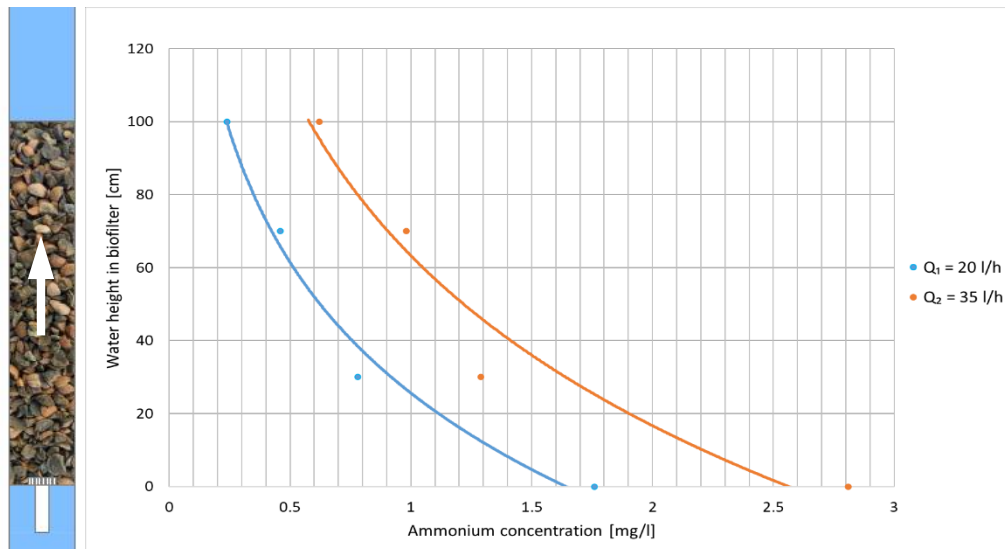


Figure 4.18. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – low ammonium concentrations (1.76 si 2.81 mg/l) in raw water.

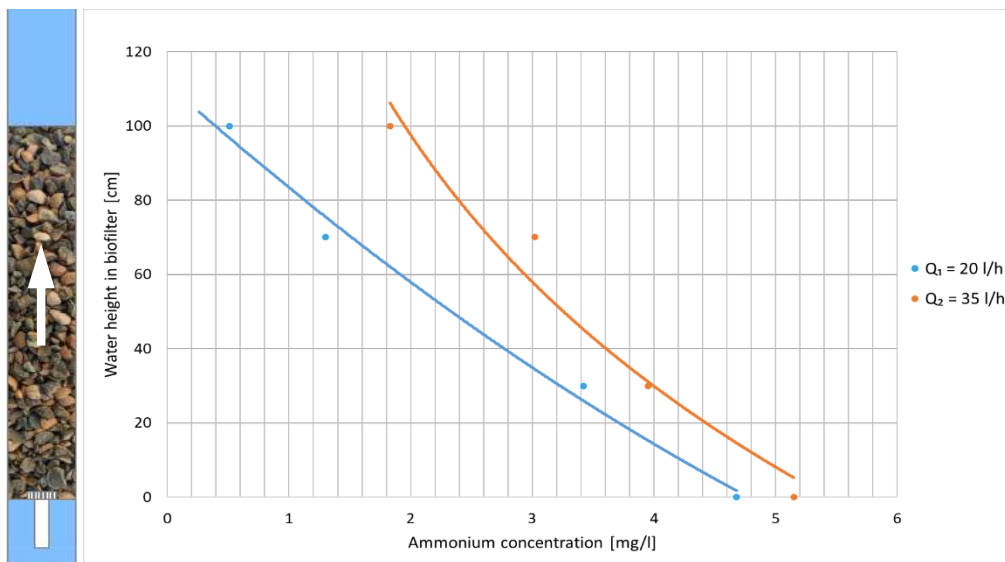


Figure 4.19. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – average ammonium concentrations (4.68 si 5.15 mg/l) in raw water.

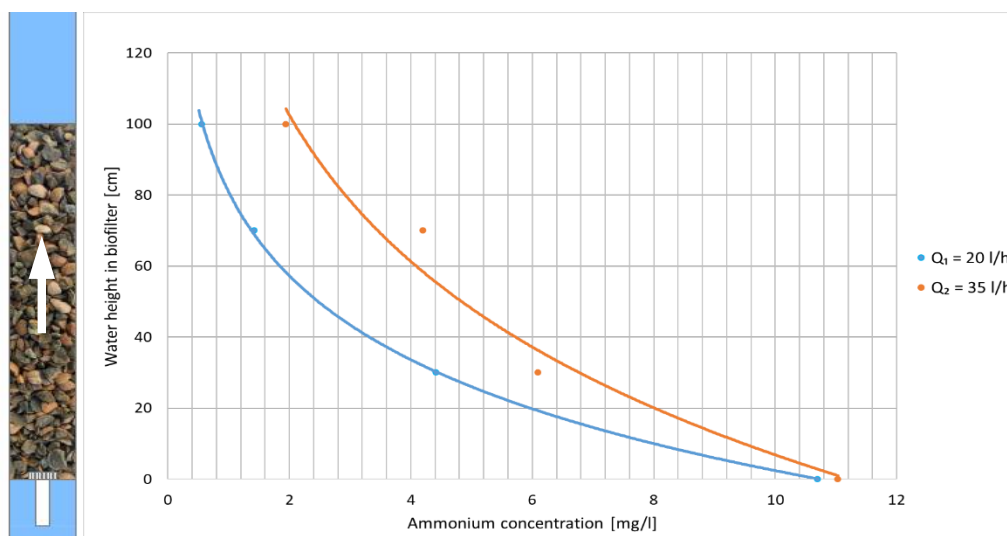


Figure 4.20. Variation of ammonium concentration in filter layer depending on the raw water flow introduced in biofilter – high ammonium concentrations (10.69 si 11.03 mg/l) in raw water.

As can be seen in the above figures, an increase of raw water flow increases the filtration speed, and the performance of the biofilter decreases, which is largely due to the reduction of the contact time between water and attached biomass. It can be seen that the lower layer is less affected by the reduction of the contact time between water and attached biomass compared to the middle and upper layers. Compared to sand biofilters, ceramic granule biofilters are less affected by the reduced contact time between water and the attached biomass. Comparing the results obtained in phase II for the sand biofilter with the results obtained for the ceramic granules biofilter, it can be said that the ceramic granules biofilter is less affected by the reduced contact time between water and attached biomass as opposed to the sand biofilter.

5 Experimental test results in phase III

In the tests performed in phases I and II, approximately 95% efficiencies were obtained in the reduction of ammonium concentration for the biological filter with ceramic granules, but for any ammonium concentration in the raw water, after biological filtration, the ammonium concentration does not fall below the minimum value of 0.24 mg/l.

In the first phases it was also observed that the concentration of phosphorus in water is very low, phosphorus being a necessary nutrient in the nitrification process and for this reason, in this phase, a new test was performed, with the addition of phosphoric acid (0.26 mg/l) to check if a better efficiency in reducing ammonium is obtained.

After biological filtration process, it has been observed that the alkalinity decreases and the chemical oxygen demand increases.

In both cases (without phosphoric acid and with the addition of phosphoric acid) the alkalinity decreases by 1.4 mval/l in biologically filtered water on ceramic granules and by 1.2 mval/l for biologically filtered water on sand and granular activated carbon.

Chemical oxygen demand in the case of biological filtration (without phosphoric acid) on granular activated carbon increased by 0.5 mg/l and in the case of biological filtration on sand and ceramic granules increased by 6 mg/l.

The chemical oxygen demand of in the case of biological filtration (with phosphoric acid) on granular activated carbon remained constant and in the case of biological filtration on sand and ceramic granules it increased by approximately 5 mg/l.

Considering the results obtained for the chemical oxygen demand on the filtered water on the ceramic granules and on the filtered water on the sand, it can be stated that the increase of the chemical oxygen demand can indicate the biomass detachment from the 2 support media.

The following figure shows the efficiencies obtained for biological filtration in phase III.

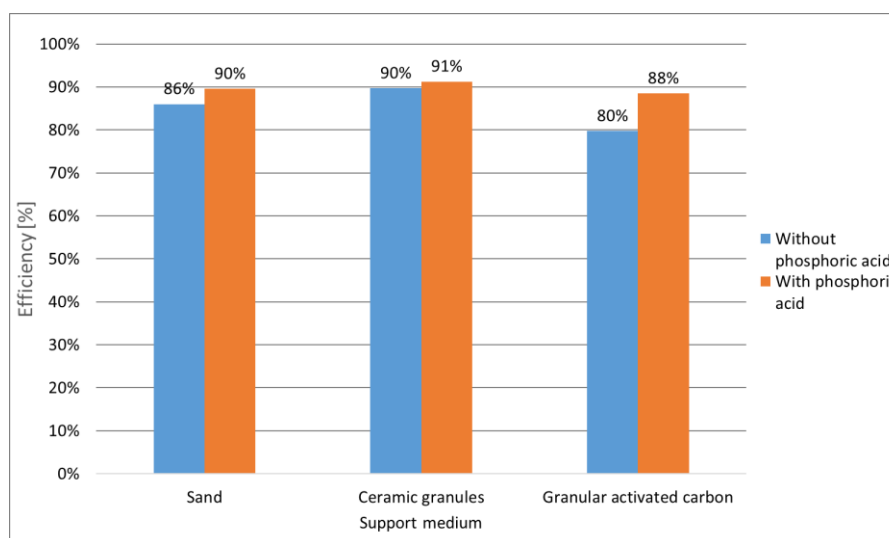


Figure 5.1. Efficiency of reducing the ammonium concentration depending on the support media used - phase III.

Comparing the results obtained on the efficiencies of the biological process in reducing ammonium for normal operation and operation with the addition of phosphoric acid, it is observed that similar efficiencies are obtained in both cases, with one small exception, a small increase in ammonium reduction efficiency for raw water with phosphoric acid.

The following figures show the variation of the ammonium concentration in the filter layer in phase III, when the raw water is introduced into the biofilter with an ammonium concentration of approximately 5 mg/l and a constant flow of 20 / h.

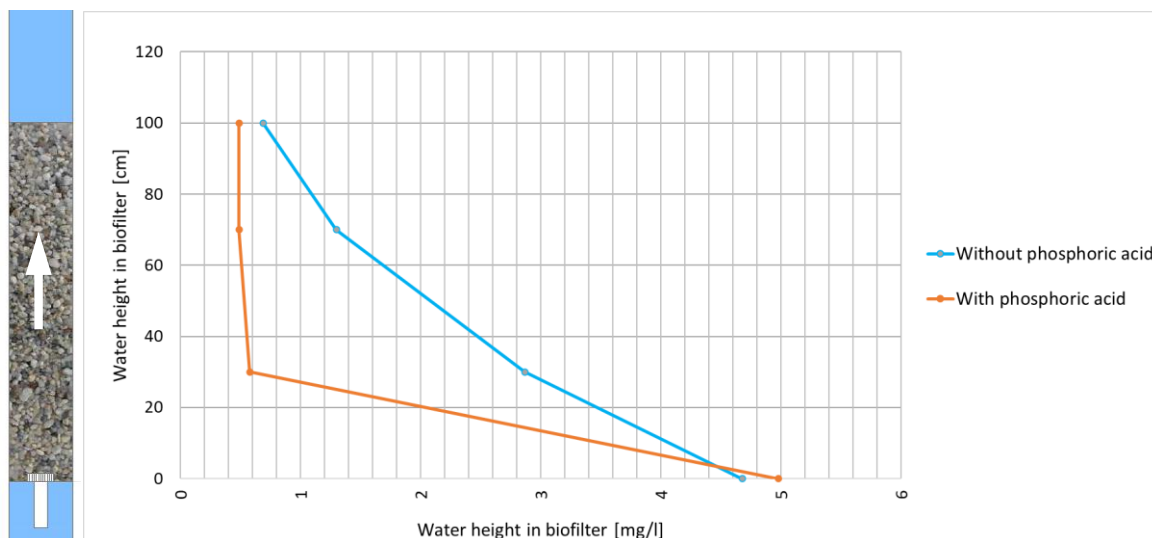


Figure 5.2. Variation of ammonium concentration in biofilter with sand in phase III.

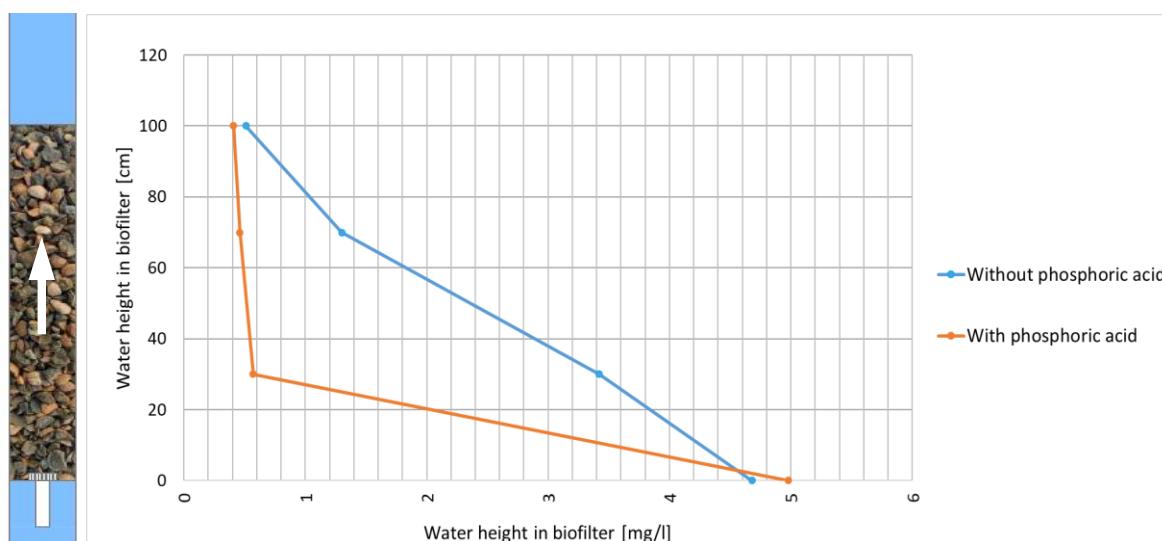


Figure 5.3. Variation of ammonium concentration in biofilter with ceramic granules in phase III.

It can be seen in the previous figures that, in the case of both media used, the ammonium concentration in biofilters varies approximately constantly for raw water without phosphoric acid, but in the case of raw water with phosphoric acid, phosphorus is consumed in the first centimeters of the filter layer (first contact area), the area where the ammonium concentration decreases suddenly, and then remains approximately constant until the biofilter outlet. In the case of fractional introduction of phosphoric acid on the height of filter layer, it is possible that the attached biomass will be better stimulated, which would lead to an even better efficiency of the biofilter in the retention of ammonium.

6 General conclusions

The present research report aimed to determine the biofilters efficiency in reducing the ammonium concentration in raw water depending on the support media used and to determine the variation of ammonium concentration on the height of the filter layer. These are briefly described below.

According to the results obtained from the experimental tests, the following can be stated:

- The biological nitrification process worked during the experimental tests, considering that a reduction of ammonium concentration was obtained simultaneously with an increase of nitrates concentration in treated water;
- In all tests in the three phases, the ammonium concentration is best reduced in the lower layer, resulting that the most active area in the biofilter being the first contact area;
- Biofilters that use ceramic granules as support media have the highest efficiency (over 90%) in reducing ammonium, for all ammonium concentrations in raw water introduced into the biofilter;
- The biological process is affected by the reduction of the contact time between water and attached biomass:
 - For the biofilters with ceramic granules, at flow rates of 20 l/h (when the contact time is longer) and low concentrations (1.76 mg/l), ammonium was reduced below the maximum allowable limit according to Law 458/2002, and at average concentrations (4.68 mg/l) and high (10.69 mg/l) is close to the limit of less than 0.1 mg/l. At flow rates of 35 l/h (when the contact time is longer), the ammonium is reduced almost (at a difference of less than 0.15 mg/l) to the maximum permissible limit according to law 458/2002, in case of concentrations of 2.81 mg/l, and at concentrations of 5.15 and 11.03 mg/l, ammonium is reduced to below 2 mg/l
 - At low flow rates, when the contact time is longer, the biofilters used sand as support media have better efficiencies than granular activated carbon biofilter, but at high flow rates, when the filtration rate increases and the contact time decreases, their efficiencies decrease and are below the efficiencies obtained for granular activated carbon biofilter;
 - At high flow rates, when the contact time is shorter, the biofilters that use granular activated carbon as a support media have better efficiencies than the sand biofilter, but as the ammonium concentration in the water increases, the efficiency decreases.
- The biological process efficiency is not significantly improved by the addition of nutrients, but in the case of the nutrients addition (phosphoric acid), it is observed that ammonium is reduced in the lower layer to near the maximum allowable limit according to law 458/2002, after which it remains approximately constant until the the biofilter outlet. It is possible that the attached biomass will be better stimulated in case of fractional introduction of phosphoric acid at the height of the filter layer, which would lead to an even better biofilter efficiency in retention of ammonium.

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