Comparison of nitrification process using biofilm formed on intelligent hydrogel microcarriers and the conventional activated sludge technology

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Abstract
In this study nitrification process was investigated using conventional activated sludge technology and biofilm formed on hydrogel micro-carriers in two laboratory-scale SBR systems. Measurements were conducted to investigate the capacity of these two systems. Nitrogen fractions and the quantity of biomass were monitored throughout the experiments. The activity of *Nitrosomonas* and *Nitrobacter* genera was in the same magnitude, it was more balanced in the case of micro-carriers. According to the results the amount of biomass was higher on the gels than in the activated sludge reactor. The inorganic part of biomass was less in the case of micro-carriers. Experiments were carried out to examine the capacity of ammonium adsorption on the hydrogel as well. About 10-15 % of influent ammonium load was removed by adsorption. To compare the settling properties of the two systems extreme operation conditions were applied: dissolved oxygen and substrate concentration were set to be out of the optimal conditions. The settling parameters of the activated sludge and the modified activated sludge were examined using the conventional Mohlmann index. The results show that hydrogel micro-carriers have favourable settling properties in case of even under extreme environmental conditions.

Keywords
Adsorption; biofilm; hydrogel micro-carriers; nitrification; settling; wastewater treatment

INTRODUCTION

In the last two decades significant efforts have been directed to intensify the removal of nutrients at wastewater treatment plants to control eutrophication processes in surface waters. In case of nitrogen removal usually additional biological reactors (aerated for nitrification and non-aerated for denitrification) have been built to fulfil the stringent effluent requirements. Nitrification is a critical step in nitrogen removal, requiring large aerated reactor volume and long sludge age. Nitrifying bacteria are very sensitive to a large number of substances that can adversely affect their growth. Besides this the growth rate of nitrifers is lower than the growth of heterotrophic bacteria, thus their regeneration time is longer. Temperature tolerance of nitrifying bacteria is low; therefore nitrification efficiency can decrease significantly in the case of lower temperatures (Henze et al., 1995). Industrial components can cause a significant and often fluctuating nitrogen load increase of communal wastewater treatment plants. These conditions often hinder the efficient ammonium removal. After nitrification wastewater goes to the secondary clarifier and denitrification can occur because of anoxic conditions. Nitrogen gas arising in the course of denitrification often cause secondary settling problems (Jenkins et al., 2004).

In order to reduce the above problems nitrification activity and settling characteristics of biofilm formed on intelligent hydrogel micro-carriers was tested. The operation of conventional activated sludge technology and biofilm system using micro-carriers was compared in laboratory-scale experiments to estimate the efficiency of the activated sludge flocs modified by intelligent hydrogel micro-carriers.

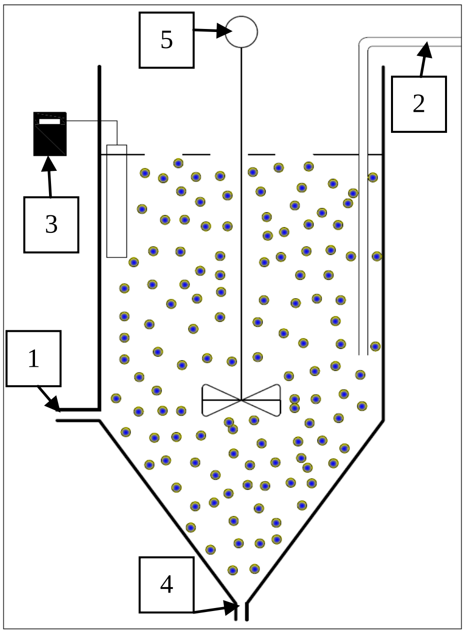
MATERIAL AND METHODS

Hydrogel micro-carrier

Special micro-carriers consisting of PVA–PAS hydrogel were developed in the IASON (Intelligent Activated Sludge Operated by Nanotechnology) project led by the Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics (Fleit et al., 2008). Hydrogel pearls have a diameter of 100-150 μm and water content of 97-98 %. The regulation of the porosity (inner structure) of hydrogel pearls was achieved by the addition of fine starch suspension into the gelifying liquor hence embedding easily biodegradable substrate into the inner structure of the gels. The starch content of the gels was partially removed by a simple method (heat and chemical treatment). Removal of near-to-surface embedded starch granules from the polymer matrix provided surface roughness and micro-pores for the wastewater bacteria for initial adherence.

Laboratory scale experimental system

The outline of the laboratory experimental system is depicted on Figure 1.



Hydraulic reactor volume	5-7 l
Cycle time	4 h
Aeration period (IASON)	3.5 h
Aeration period (Activated sludge)	3.4 h
Volume of the PVA-PAA gels (in the IASON reactor)	500 ml
Settling (IASON)	25 min
Settling (Activated sludge)	30 min
Hydraulic load	0.5-0.7 l/cycle
Ammonium load	175-420 mg/cycle

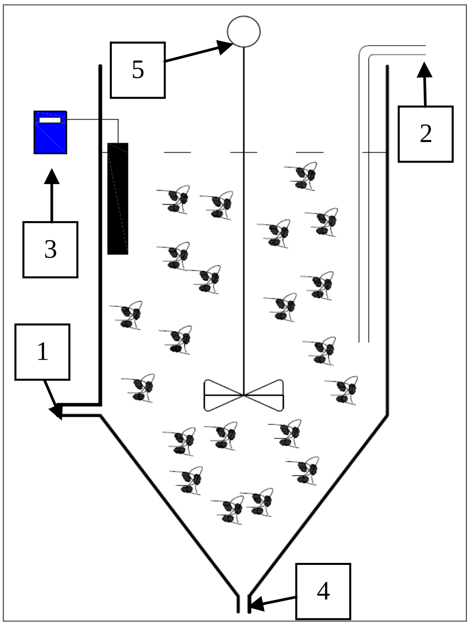


Figure 1. The laboratory-scale experiment system: (1) feed water (2) effluent, (3) DO probe, (4) aeration, (5) stirrer.

Wastewater composition and origin

During the whole experimental period (3 months) wastewater of the effluent of secondary clarifiers from the South Budapest Wastewater Treatment Plant was utilized as inflow. Ammonium concentration was increased to be around 60 mg/l (by dosing NH_4Cl solution), and pH was set and maintained by dosing 0.5 g/l $NaHCO_3$ to provide the necessary buffering capacity to influent wastewater. Influent wastewater composition in experimental system is given in Table 1.

Table 1. Composition of the influent wastewater used in biofilm maturation and nitrogen removal experiments

Parameter	Average	Minimum	Maximum
pH	7.76	7.45	8.14
o-PO_4-P mg/l	1.8	0.3	3.4
NH_4-N mg/l	45	39	58
NO_2-N mg/l	0.42	0.1	0.31
NO_3-N mg/l	3.12	0	15
Kjeldahl N mg/l	46.2	39.4	60
org N mg/l	1.2	0.4	2
Total N mg/l	49.7	39.5	75.3
SS mg/l	35	<20	45
COD mg/l	65	36	121

Colonization process

IASON reactor. Biofilm establishment on micro-carrier surfaces was achieved by simple ad- and later absorption processes by using the natural attachment processes of the suspended bacteria into solid surfaces, i.e., hydrogel carriers (Figure 2.). Inoculation of the initial 500 ml gel material per reactor was conducted by using wastewater bacterial consortia from the same plant from where the influent originated. It should be noted that seeding material originated from a plant where biofilm reactors are backwashed regularly to activated sludge system. Initial biomass concentration was measured as SS was in the range of 5-10 mg/l. Biomass development was followed by microscopic investigations, SS measurement, and dry matter determination of gels and the attached biomass.

Colonization of PVA-PAA gels required more than 21 days in case of nitrifyers (autotrophic bacteria). Initially the proto-biofilm patches were formed (3 days) that was followed by the slow appearance of single and multiple cell higher organisms (14-21 days). Upon the completion of the formation of the well-textured, solid biofilm surface technological and environmental stress experiments were started. Figure 2. shows the developed biofilm structure on the surface of PVA-PAA hydrogel.

Activated sludge reactor. The seeding biomass for the activated sludge reactor originated from the backwashed water of nitrifying biofilm system from the South-Pest WWTP. In the backwash water the biomass consisted of biofilm pieces. After four weeks feeding and mixing this biomass in a SBR system the conventional activated sludge flocs developed (see Figure 2.).

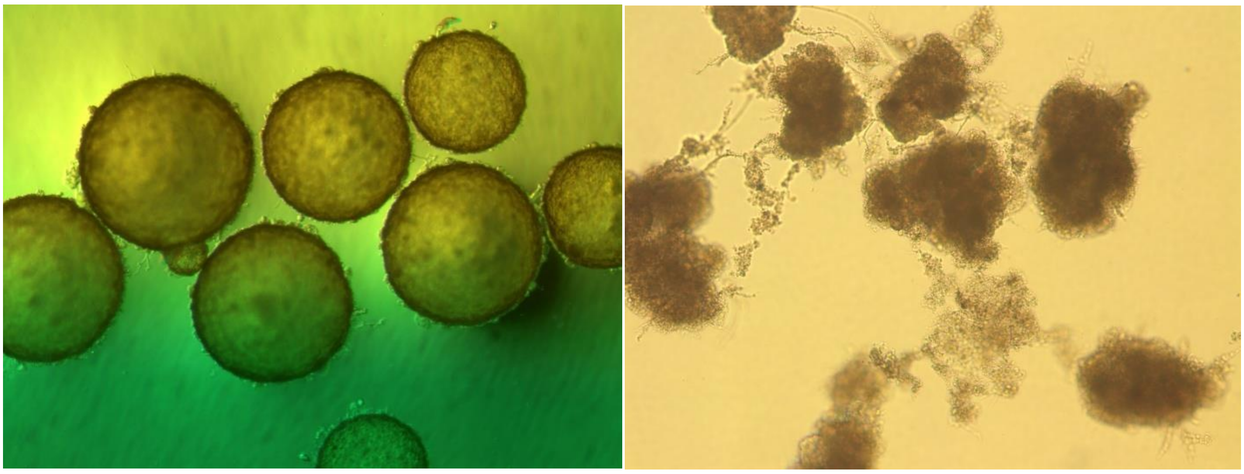


Figure 2. Fully developed biofilm on the surface of PVA-PAA hydrogels and activated sludge flocs.

RESULTS AND DISCUSSION

Ammonium adsorption

To investigate the ammonium adsorption capacity of PVA-PAA hydrogels experiments were carried out with uncolonized (pure) hydrogels. In the course of experiments ammonium solution were added using different dilution, gel concentration and exposition times. The ammonium solution was prepared using NH_4Cl and distilled water. Table 2. shows the exposure times, and concentration of different solution. Figure 3. shows the results of the experiment.

Table 2. The concentration of gels, exposition time and NH4-N concentrations.

Ratio (gel volume/ solution volume)	The concentration of gels [g/l]	The concentration of gels [l/l]	Exposition time (min)	NH_4-N (mg/l) (initial)
1:10	2	0.1	2	56.5
1:5	4	0.2	10	67.3
			30	76.2
				87.2

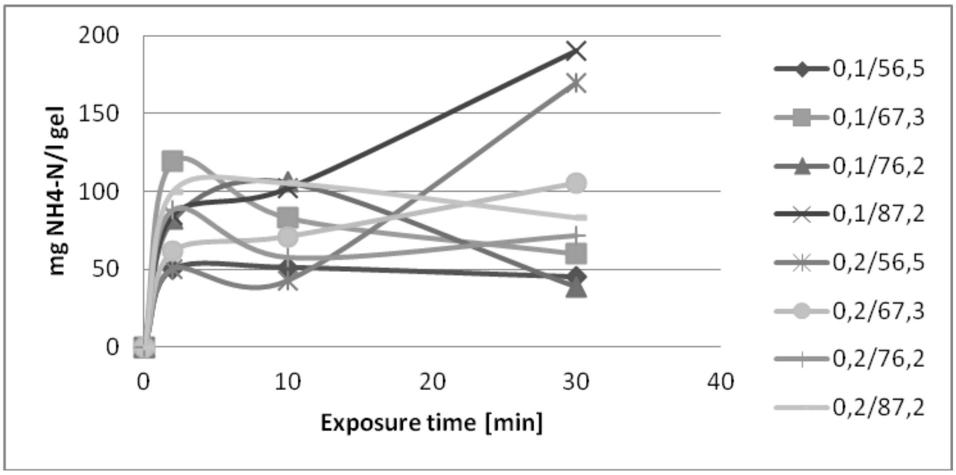


Figure 3. The ammonium adsorption capacity of the PVA-PAA gels. (The legend shows the concentration of gels and the initial ammonium concentration)

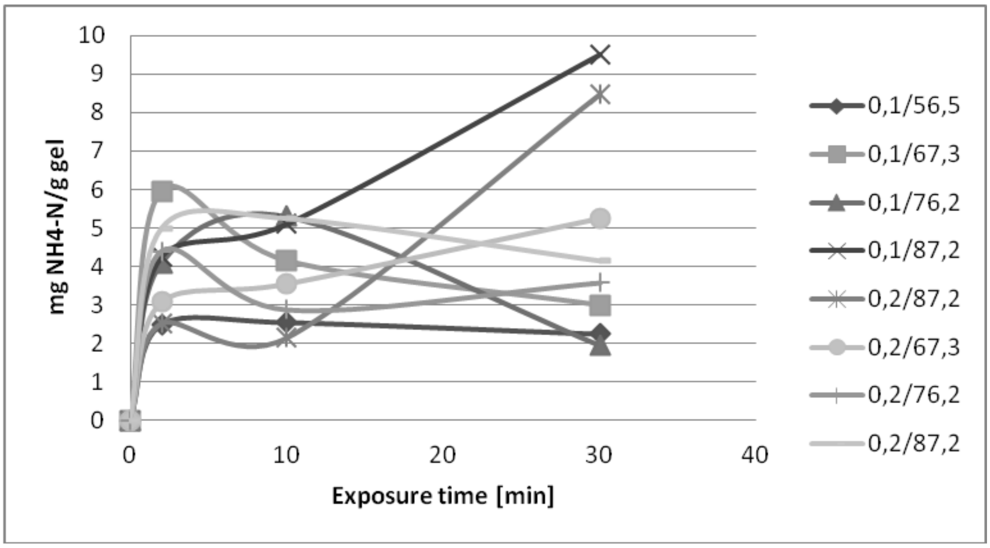


Figure 4. The ammonium adsorption capacity of the PVA-PAA gels.
(The legend shows the concentration of gels and the initial ammonium concentration)

According to the results adsorption was higher using higher exposure times, reduction of ammonium was between 8 and 31 %. Reduction rate was higher when initial ammonium concentration was higher. Because of industrial wastewater and water consumption the influent load of ammonium can be higher occasionally. This scale of adsorption can reduce significantly the peak-load of ammonium in the effluent water.

Comparison of nitrification activity

After the colonization process nitrification activity was tested under different conditions in both reactors. The same feed water was used in both reactors, where initial ammonium load was 250 mg/cycle. Inorganic nitrogen forms, biomass concentration, dry matter content, pH, conductivity and DO were measured during the experiments. Figure 4. shows a typical nitrogen profile. During the experiments DO level was above 2.0 mg/l, temperature was around 20 C°, thus nitrification was not inhibited by these environmental conditions.

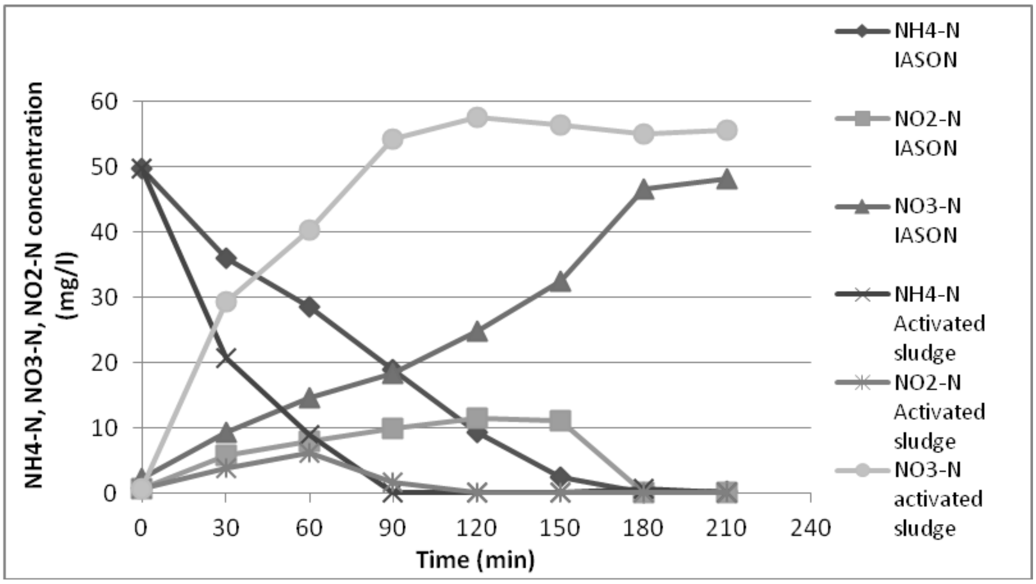


Figure 5. Ammonium, nitrate and nitrite profile in the IASON and the activated sludge reactor (77 days after the start of colonization, when the biofilm was fully developed).

It can be seen on Figure 5. that reduction of ammonium is slower in the case of IASON, however nitrate concentration in the effluent is less than in the activated sludge reactor. This indicates that denitrification occurs in the inner part of the hydrogel. Biomass concentration was higher in the IASON reactor. Most likely significant part of the biomass consisted of bacteria other than nitrifyers, because of the oxygen gradients within the gels.

During the colonization process and experiments VSS and dry matter content were monitored. The results of the measurements show that the amount of the biomass was in the same range in both reactors. Besides this the inert part of the biomass was higher in the case of conventional activated sludge as Figure 7 shows.

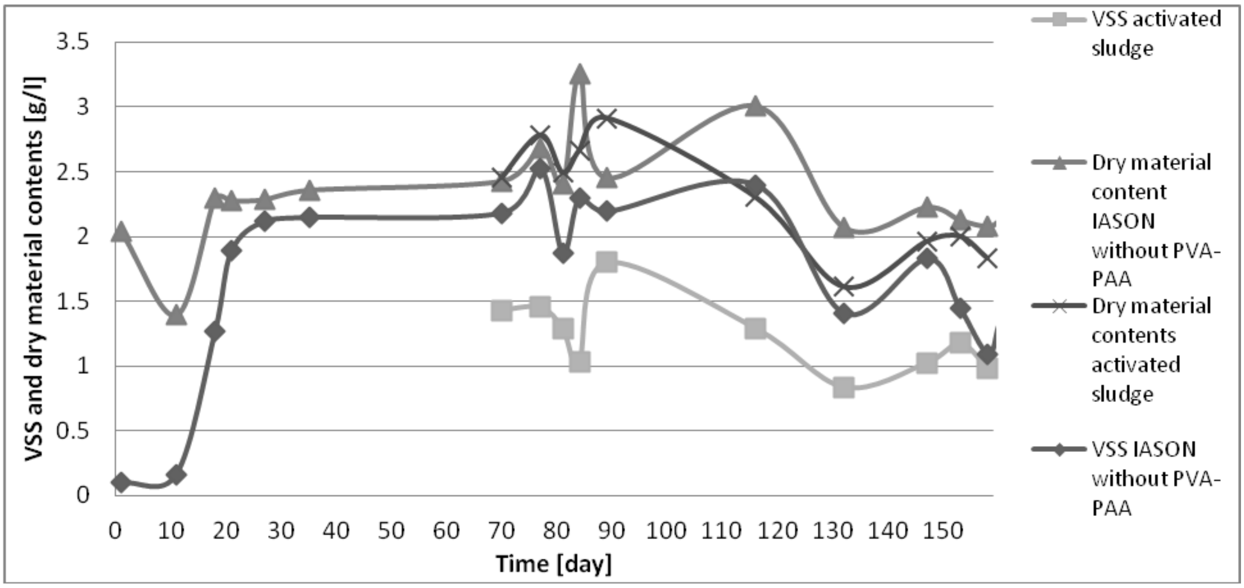


Figure 6. VSS and dry matter content of the activated sludge and IASON micro-carriers.

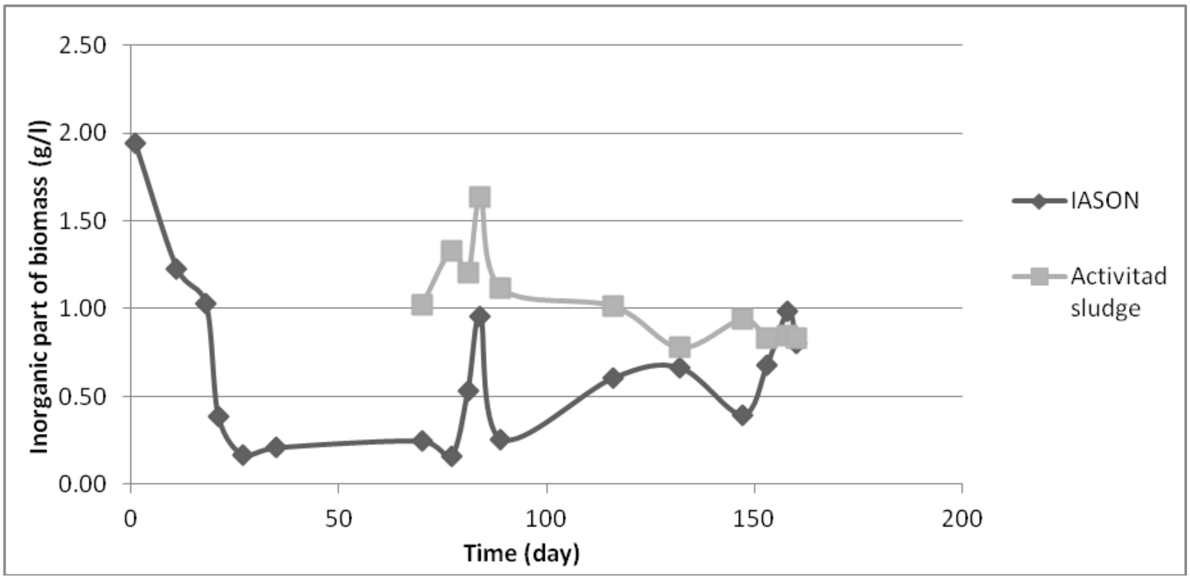


Figure 7. Inorganic part of biomass in the IASON micro-carriers and in the activated sludge

Experiments were carried out to investigate the activity of nitrification under extreme conditions. Changing ammonium load and low DO level were used in both reactors. The typical profile about the change of the inorganic nitrogen compounds can be seen on Figure 8. Due to the low DO level the rate of nitrification reduced significantly. There were not significant differences between the two reactors.

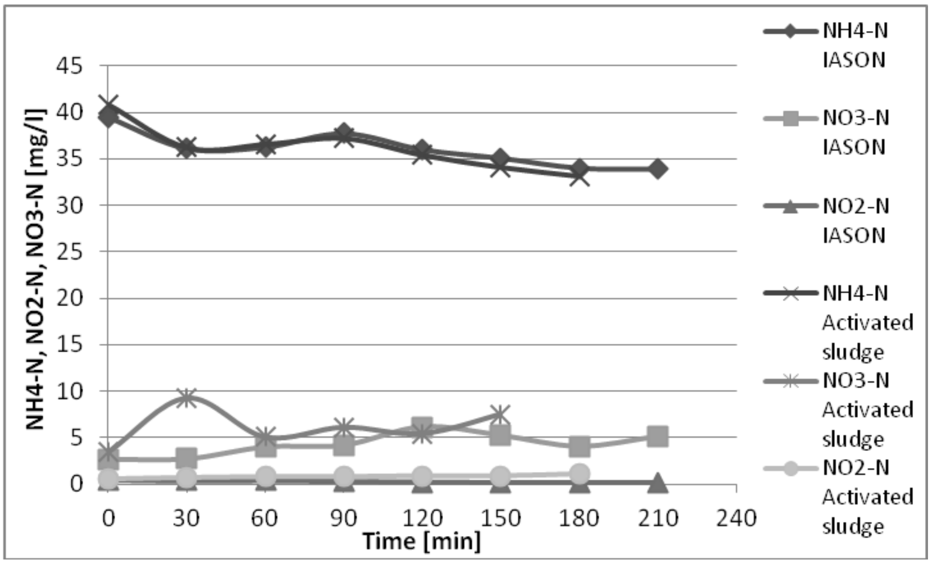


Figure 8. Ammonium, nitrate and nitrite profile in the IASON and the activated sludge reactor (153 day after the start of colonization, when the biofilm was fully developed).

The activity of *Nitrosomonas* and *Nitrobacter* was calculated in every 30 minutes in both reactors. The activity of the *Nitrosomonas* was higher in the activated sludge. The reason probably can be that dissolved oxygen could be present within the internal part of the smaller sludge flocs. However the activity became zero after around 150 minutes in both reactors in most cases. Thus the removal of the ammonium was more balanced in the case of the IASON reactor. Between the 120 and 160 days low DO level was used in the reactor.

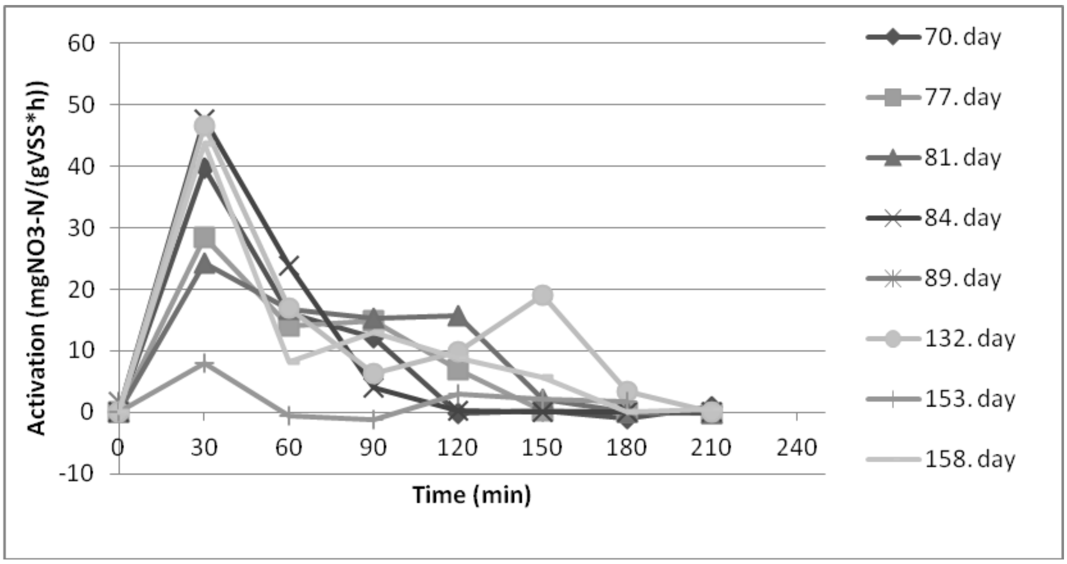


Figure 9. Activated sludge *Nitrosomonas* activity.

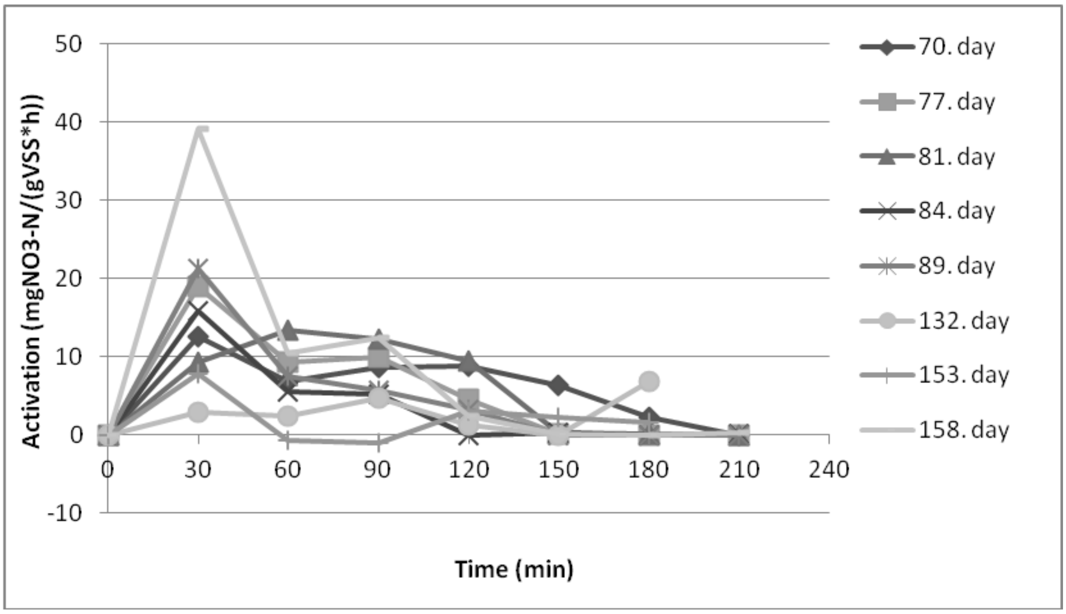


Figure 10. IASON *Nitrosomonas* activity.

The activity of *Nitrobacter* was calculated as well. In the case of the activated sludge the activity was higher in the first 60 minutes and then it is continually decreased. The activity was balanced in the case of IASON reactor in comparison with the activated sludge reactor.

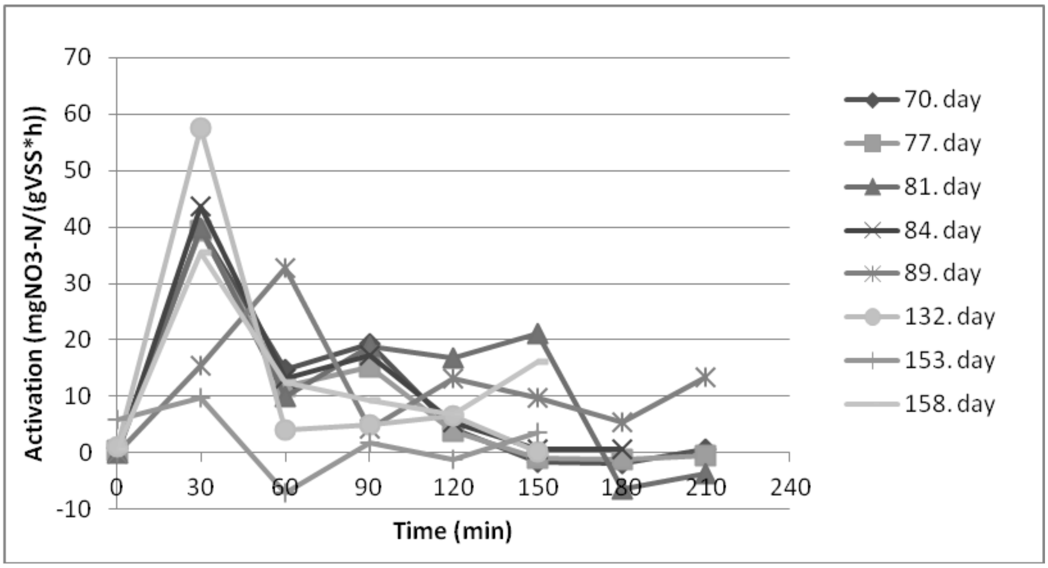


Figure 11. Activated sludge *Nitrobacter* activity

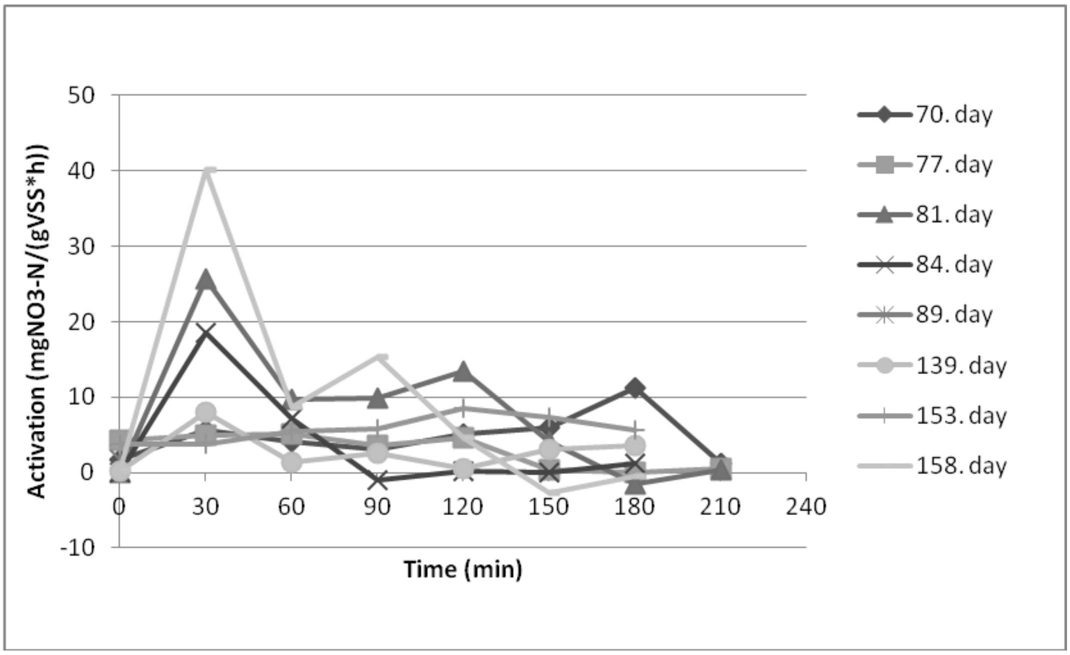


Figure 12. IASON *Nitrobacter* activity

Investigation of settling properties

The characteristic of settling was examined during the experiments in both reactors. Sludge Volume Index (SVI) was calculated (Ekama et. al, 1998), however SVI was calculated not only in the 30th minute but in earlier as well. The conventional Mohlmann columns were used for the settling experiments. The change of concentration of dry matter content and VSS were monitored, the samples were taken from the 500 ml height of the column. At first the operational conditions were ideal (high DO, permanent load). The results can be seen on Figure 13.

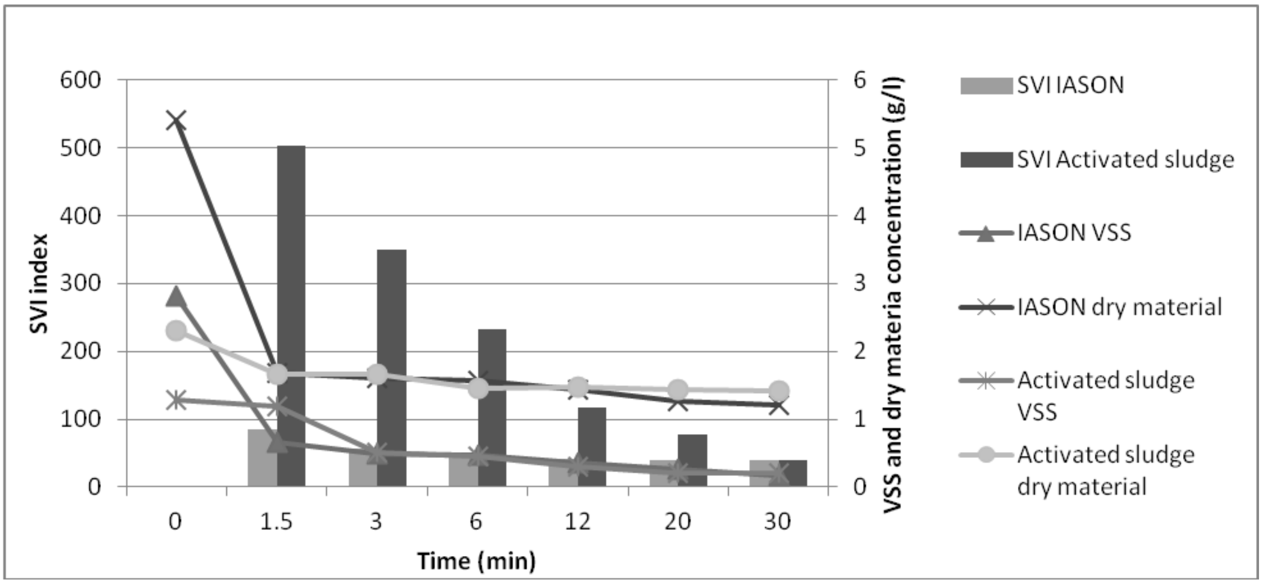


Figure 13. The results of the settling experiments (after 116 day the start of colonization, when the biofilm was fully developed)

It can be seen that settling of the hydrogel was much faster; after 1.5 min most of the gels were under 500 ml. Settling of activated sludge was rather fast comparing with earlier studies (Ekama et. al, 1998). However it has to be considered that the activated sludge consisted mainly nitrifiers, therefore the structure of the flocs were very thick as Figure 14. shows.

To investigate the effect of extreme operational conditions the ammonium load and DO level was changed. After two weeks filamentous bacteria started to growth in both reactors (see Figure 14.). The settling was examined; the results can be seen on the Figure 15.

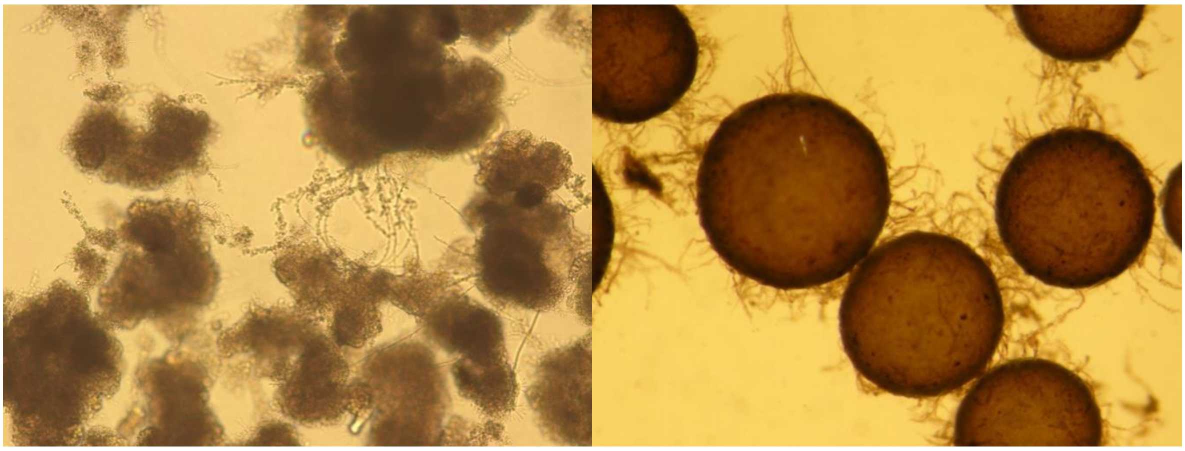


Figure 14. The filamentous bacteria appeared in the activated sludge and hydrogels.

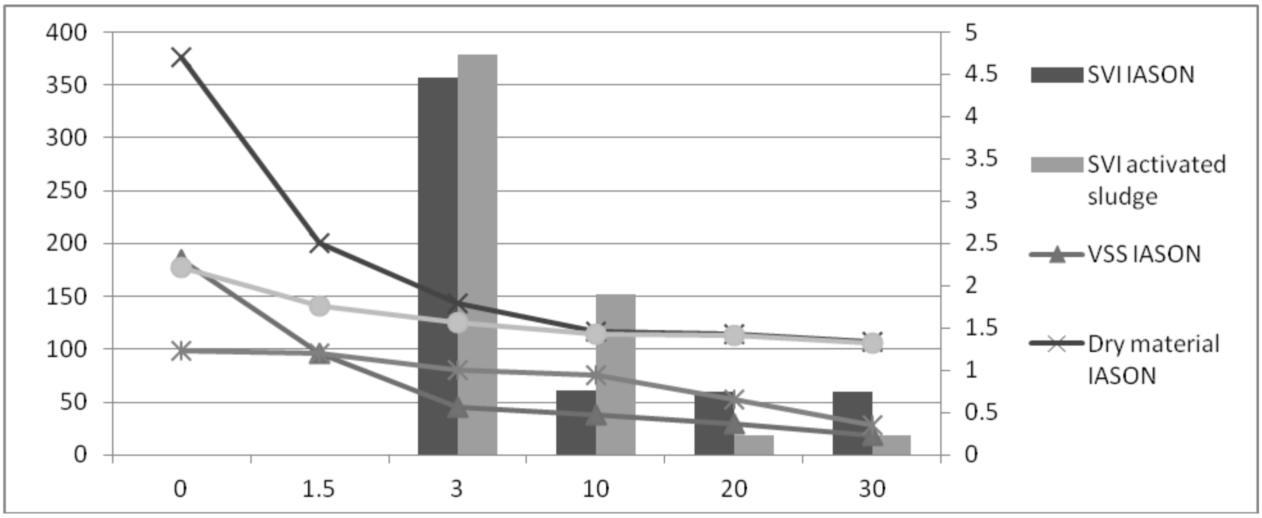


Figure 15. The results of the settling experiments on Day 158.

It can be stated that the settling was faster in the case of hydrogels, however after 30 minutes the activated sludge settled as well.

CONCLUSIONS

According to the results the PVA-PAA hydrogels can adsorp the significant part of ammonium load (8-30%). The VSS concentration was similar range in both reactor; however the inert part of biomass was higher in the case of activated sludge. The activity of *Nitrosomonas* and *Nitrobacter* was in the same range, the initial value of activity was higher in activated sludge, whereas the activity was more balanced in the IASON reactor. The activity of biomass was similar in the case of extreme environmental conditions. The settling velocity was higher in the case of IASON gels, after 3 minutes most of the gels were settled, while the conventional activated sludge required much longer settling time. Despite of the extreme environmental conditions the settling was efficient in the IASON reactor.

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