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PILOT SCALE STUDY ON AMMONIUM REMOVAL IN PHAP VAN WATER PLANT, HANOI CITY

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ABSTRACT

The first pilot water plant for ammonium removal in the ground water was built and tried in Hanoi city. Three stages of nitrification - denitrification - post aeration were conducted using three submerged biofiltration columns. The nitrification efficiency could be achieved with the level at the first stage and denitrification can be reached to more than 80% when biodegradable substrates added. The investigation on head loss were carried out and showed the distribution of biomass along the height of biomass material was different in aerated and non-aerated columns. Ammonium and nitrate concentrations after three treatment stages almost reach the Vietnamese standards. Three stages of nitrification-denitrification and post nitrification can be used for removal of high ammonium levels of 20-25 mg $\text{NH}_4\text{-N/L}$ in the ground water for supply water.

INTRODUCTION

Drinking water quality is a serious concern of Vietnamese water supply industry generally, and of Hanoi Water Works Co. particularly. Hanoi is now using exclusively ground water for all purposes. The emerged problem of Hanoi drinking water quality is N-ammonium contamination.

By the end of 2000, there are nine main water treatment plants in the urban area of Hanoi. There are also some tens of smaller water supplies in the city area with capacities ranging from 1,000 to 5,000 m^3/d . A number of them are managed by HWWs and the others are operated by hotels, schools, or industrial enterprises etc. There are also thousands of private wells, continuously abstracting water from the shallow aquifer, and hundreds of wells have already been abandoned. The capacity of those managed by HWWs is estimated at 400,000 m^3/d , and the others are at 80,000 - 100,000 m^3/d , changing through the year. Total capacity of the Hanoi well fields is estimated to be 700,000 m^3/d , closed to the demand of Hanoi City by 2010. Major ground water sources in Hanoi have good quality and satisfy the requirements for domestic usage except problem of Fe, NH_4^+ , Mn, As, and organics etc. in some places.

Water plants in the South of Hanoi, such as Phap Van, Ha Dinh, Tuong Mai and some other smaller stations are facing with particularly high ammonium concentration ranging from 10 mgN/L to 20 mgN/L .

Almost all water treatment plants in Hanoi are following "standard" technology introduced since French colonial time of early 19 century. The existing treatment process consists of 4 main steps: Aeration - Contact settling - Filtration - Chlorination.

Advantage of this ecology is relatively good for iron removal, and if manganese oxide coated sand filter is applied it can also remove well Mn(II); simple in construction and operation; minimum requirement in chemical (just small dose of chlorine), therefore it is very cheap in both construction and operation-maintenance (OM) cost.

One of the drawbacks of this technology is it cannot remove ammonia, which makes chlorination less effective for disinfection.

Ammonium removal in groundwater water, especially with the ammonium concentration range from 10 to 20 mg/L or higher is a new object not only in Hanoi but also in the whole Vietnam. Before 2002, Vietnamese standards of ammonium in supplying water were ≤ 3 mg/L, but since 2002 this was down to 1.5 mg/L (Ministry of Health's Degree 1329/2002) as the same with WHO guideline. This is the reason which promotes many researches on ammonium removal in groundwater in Vietnam, especially for improving the existing water plants with the highest feasibility and minimum retrofitting costs.

Nowadays there are many technologies, which can be applied for ammonium removal such as physicochemical, biological processes and etc. But among them the biological submerged filtration is one of the most suitable selecting techniques for ammonium removal.

Biological ammonium removal consists of two processes of nitrification and denitrification by microorganism activities in submerged biofiltration columns.

The aims of this paper are to report the results of the half year of N-ammonium removal pilot plant at Phap Van water plant. Herein, achieved results will be used for remediation of existing water plants or designing new water plant toward iron and ammonium removal capacity as well as establishment of operation procedure of future N removal plants.

EXPERIMENTS

This project was constructed and implemented on a pilot scale (mini-plant with water flow rate of $5\text{m}^3/\text{h}$) at Phap Van Water Plant ($30,000\text{ m}^3/\text{d}$).

The pilot consists of 6 units: 1. Aeration device, 2. Iron removal, 3. Denitrification module (one submerged biofilter, and one agitated up-flow reactor); 4. Nitrification, 5. Rapid sand filter (one with quartz sand monolayer and the other with dual filtering layer); 6. Chlorination chamber.

The pilot was constructed by such a flexible way that all planned experiments such as Fe, Mn, As and NH_4^+ removal can be conducted parallel or separately. To meet this requirement, the following stages (see figures 1) are as follows:

1. Fe or Mn (if available) removal: it includes 2 units: aeration for DO saturation and contact filter for Fe or Mn precipitates removal.
2. N-ammonium removal: it was constructed such as way that experiments can try either by option A or option B.

Option A includes the units (followed the water flow direction): 1. Nitrification, 2. Denitrification, 3. Post-aeration (see the bold lines flow in the figure 1).

Option B includes the units (followed the water flow direction): 1. Mixing column (for recycling water and organic carbon addition); 2. Denitrification; 3. Nitrification. 4. Intermediate tank and recycling pump; 3. Conventional treatment: Filtration and Chlorination (see the thinner lines flow in the figure 1).

Supporting facilities include: 1. Air blower to provide compressed air for washing and running nitrification and post-aeration units; 2. Washing pump; 3. Chemical dosing pumps for P, organics supplying to nitrification, denitrification and post-aeration units. They also supply

filtering aid if needed to enhance microbe filtration efficiency of the last filtration unit and chlorine for disinfection step.

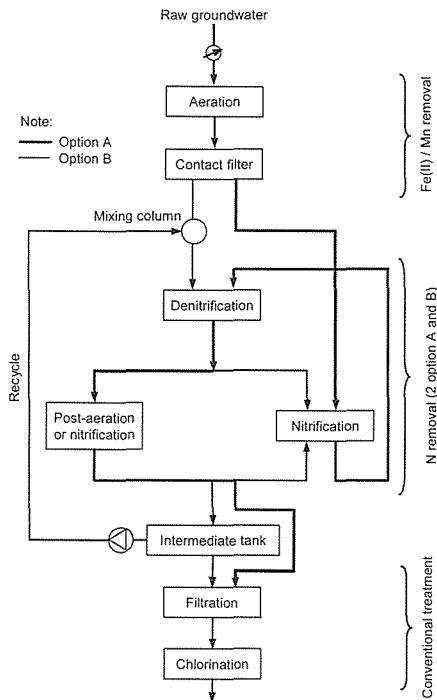
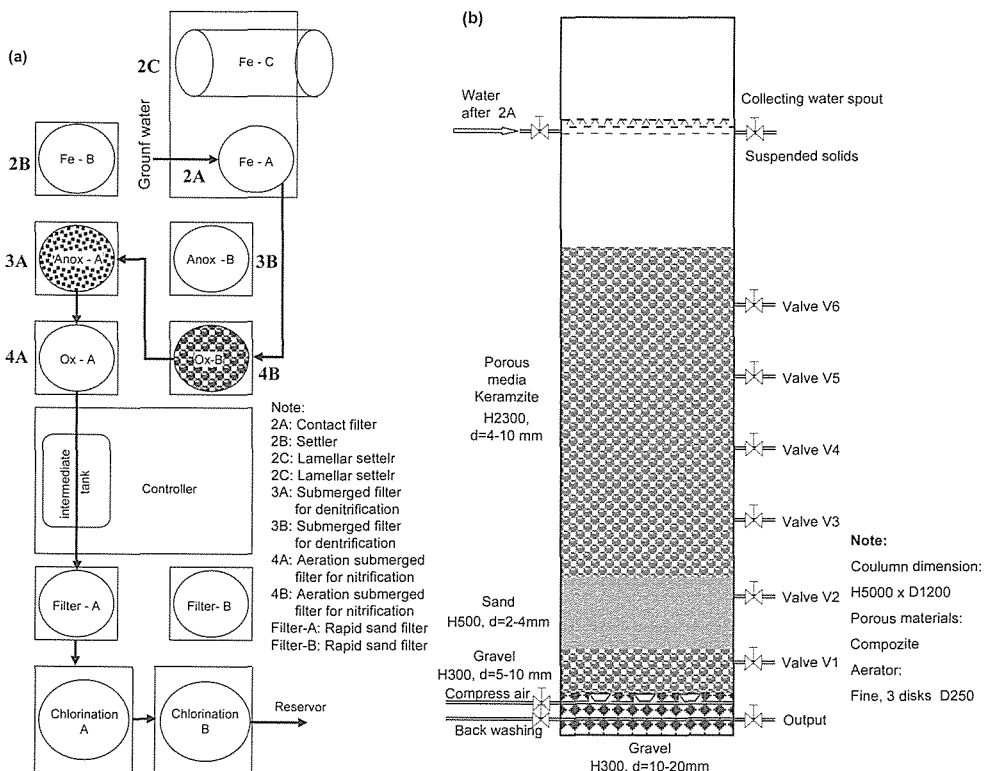


Fig. 1. Flow scheme of pilot plant for explanation of option A and B.

Actual distribution of all units and description of nitrification unit was outlined in the figure 2.

All treatment units were designed as a cylindrical column (d1200mm x h5000mm) and made of fiber reinforced polyester. Under drain was made of perforated PVC pipes. Gravels were used as supporting layers. Biological treatment units (Denitrification 3A, Post-aeration nitrification 4A and Nitrification 4B) had the same physical structure. The main feature of these units is biomass attaching layer of 2.3 - 2.5 m high. It is special porous artificial mineral which has about 50% void volume can serve as a good housing for microorganisms. Besides, conventional under drain system 4A and 4B had also air diffusers in the form of porous ceramic ditches.



**Fig. 2. a. Top view schemes of distribution of treatment units of Phap Van pilot plant and
b. submerged filtration units 4B, 3A and 4A**

Inlet water has the same contents of the inlet of Phap Van water plant: pH in the range 6.8 - 7.2, $\text{NH}_4\text{-N}$ from 20 - 25 mg/L, alkalinity of 200-300 mg/L. The high alkalinity is enough for nitrification of this ammonium concentration.

RESULTS AND DISCUSSION

Starting up of 4B (aerated submerged biofilter -ASBF)

Nitrifier biomass was prepared as described in the literature [1]. 700 L of biomass which has COD of 600 mg/L was added for starting 4B. Then water was circulated with support of a pump. COD of outlet water (filtrate) was determined to estimate how much biomass is attached (or filtrated). When this value became stable the nitrifying reactor was switched on the continuous mode of operation. Duration of attachment procedure was about 3 days. Right after biomass attachment process the biomass acclimation began. The water after unit 2A “iron free” input into the reactor 4B. The starting up period with flow rate $Q=2\text{m}^3/\text{h}$ was investigated (as the run 1). The similar procedure was applied for starting up of 3A and 4B.

At the moment of this report results of 2, 3 and 4 m^3/h were achieved. During the starting up some questions must be answered are as follows:

- How long does the acclimation period last?
- What is the influence of P, organics addition, type and amount of organics (especially the denitrification unit)?

Nitrification performance of unit 4B

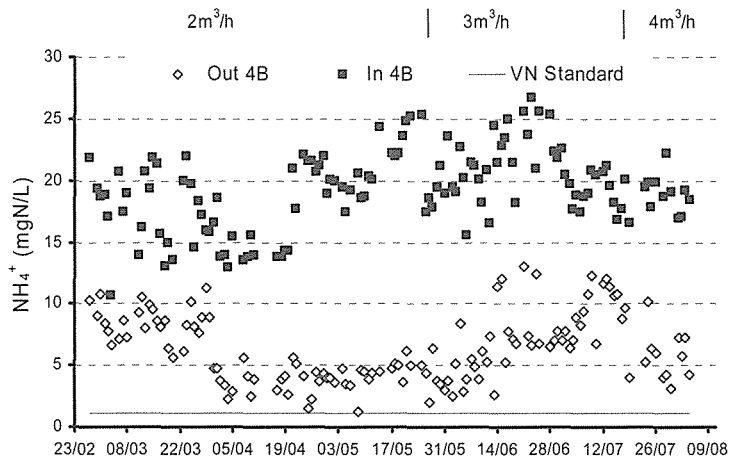


Fig. 3. Input and output ammonium concentrations of nitrification column 4B

Ammonium concentration inlet into 4B was fluctuated from 14 to maximum 25 mgN/l and generally from 15 to 25 mgN/L. Outlet of 4B ammonium was as high as from 7 to 10 mg/l in the period from January to April 6. After that period ammonium in the output was down from 2 to 6 mg/L until May 26 before switched into the $Q=3\text{m}^3/\text{h}$. In this period the nitrification process was not so effective. In the run 2 with $Q=3\text{m}^3/\text{h}$ (from May 27 to July 10) and run 3 ($Q=4\text{m}^3/\text{h}$) outlet ammonium increased and variable from 3 to 10mg/L. From data the figure 3 it can be realized that biomass needed 1 month for acclimation and it also was the “starting

up”(from February 25 to April 6) since the system started by activated sludge attachment on porous media. So after the “starting up” period the nitrification unit was working with the most effectivity in the run 2 with $Q=2\text{m}^3/\text{h}$.

Figure 4 shows that nitrification efficiencies were in the range from 40 - 90 % in the whole experiments under 3 runs. Nitrification efficiency increased in the “starting up” period and reached the highest average value of 76% in the run 1 with $Q=2\text{m}^3/\text{h}$ and then decreased in the run 2 ($Q=3\text{m}^3/\text{h}$) and run 3 ($Q=4\text{m}^3/\text{h}$) with the average values of 68 and 61%, respectively. The run 3 is still going on so it needs some more data to average the whole run 3 with $Q = 4 \text{ m}^3/\text{h}$. However, unit 4B still will be operated in the run 4 with $Q=5\text{m}^3/\text{h}$ for further investigation. The movement of ammonium concentration and nitrification efficiencies can be explained by the increasing input loading and decreasing hydraulic retention time due to increasing inlet flow rates.

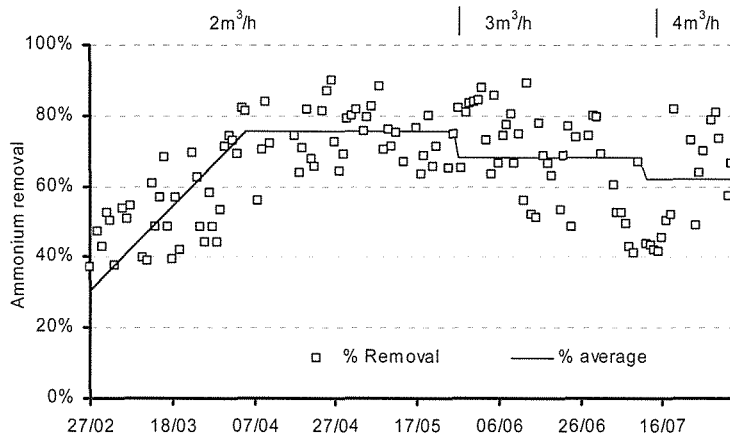


Fig. 4. Nitrification efficiencies of 4B in 3 runs with inlet flow rates (Q) of 2, 3 and 4 m^3/h

When nitrification reached relatively stable level of conversion the treatment capacity (TC) of the reactor at the given flow rate (or hydraulic or substrate loading) was calculated. Then, the system was investigated the run 2, 3 with the flow rates of 3, 4 and 5 m^3/h . In each run TC was calculated as the equation follows:

$$TC = \frac{Q \cdot 24 \cdot \Delta C_N}{V_{bc}} \quad [\text{gN}/\text{m}^3 \cdot \text{d}]$$

Where: TS: treatment capacity of ASBF; Q : flow rate, m^3/h ; V : volume of biomass carrier - material; ΔC_N : oxidized ammonium concentration, gN/m^3

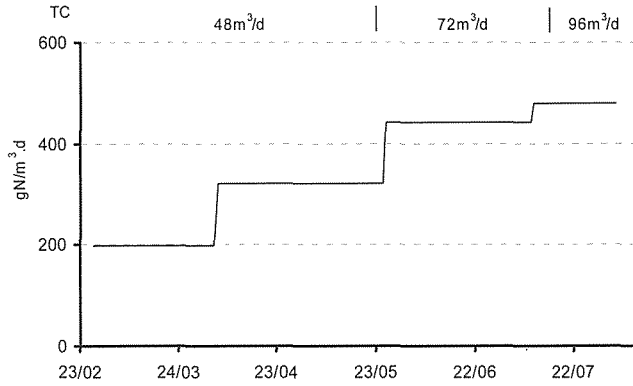


Fig. 5. Treatment capacity of unit 4B in “starting period, run 1, 2 and 3..

Calculated TCs described in the figure 5 showed that TC is increasing via 3 runs while nitrification efficiency reached the highest value in the run 2 with $Q=2\text{m}^3/\text{h}$. This can be explained that the biomass is still acclimating with the media and inlet water. The highest TC of $480\text{ gN}/\text{m}^3\cdot\text{day}$ in the run 3 is just one fourth in comparison lab experimental maximum value of $2\text{ kgN}/\text{m}^3\cdot\text{day}$ in the literature [2].

Head loss on the column 4B

Head loss of the column at each position for evaluation of the impediment for water flow caused by filtration materials. This would contribute the data for system designing.

Head loss is defined as the difference between water level in the column and water level at each position along the column which measured by piezometer. The head loss of each position was increased linear (see figure 6) so it could be seen that the filtration media and microorganisms were distributed equally in the nitrification column. The end of linear curve is the total head loss of the column. The highest head loss is the end point of run 2 with the value of 78 mm then run 3 and run 1 are 43 and 36 mm, respectively. The highest total head loss ($\Delta P = 78\text{ mm}$) was very small in comparison with the height of biomass media layer ($h = 3.4\text{ m}$). So head loss caused by the biomass in this column is small and not made the impediment for water flow. Some literatures cited the acceptable head loss of 3 m.

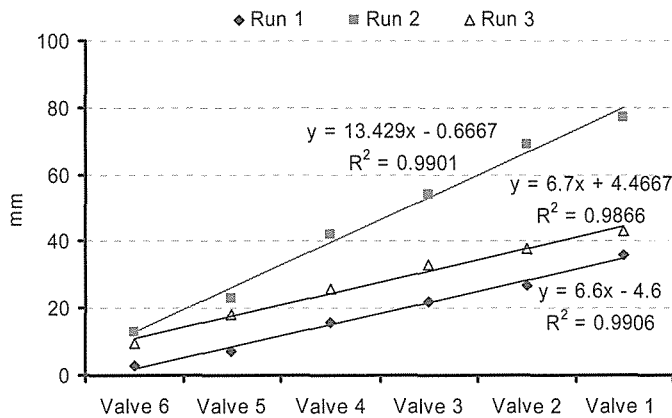


Fig. 6. Head loss values at different position of the column 4B.

The different slopes in each curve due to the impediment by biomass on media. The run 2 had the highest slop actually the unit 4B got clogging sometimes in this experiment.

Denitrification performance in module 3A:

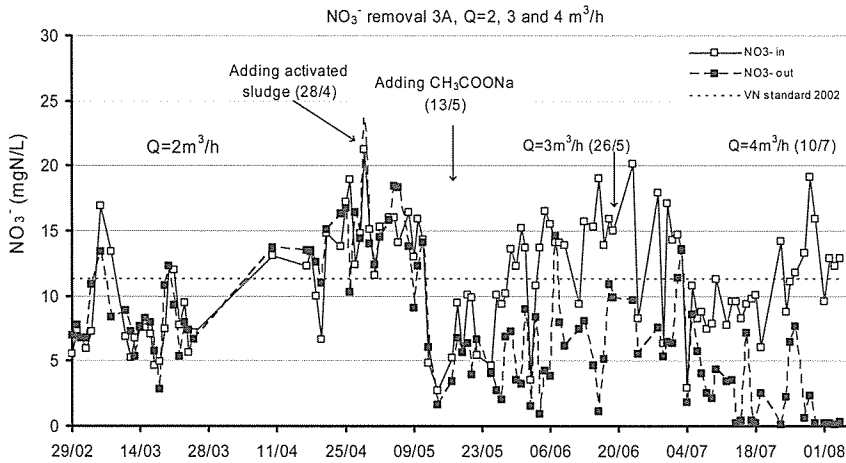


Fig. 7. Input and output nitrate concentrations of denitrification column 3A

The first months there was no microorganisms in the column 3A so the denitrification was not active and nitrate seem had no change. 300 L of activated sludge with COD of 10 mg/L was added on April 28 into the column 3A as microorganisms for denitrification but there was no significant change of nitrate concentration between input and output. But since May 13 sodium acetate was added (7.6 mg/L) nitrate concentration in output of 3A decreased strongly because denitrifiers had enough carbon sources for the denitrification process. Nitrate in output was down to less than 8 mg/l and some times to 0.5 mg/L (see figure 7).

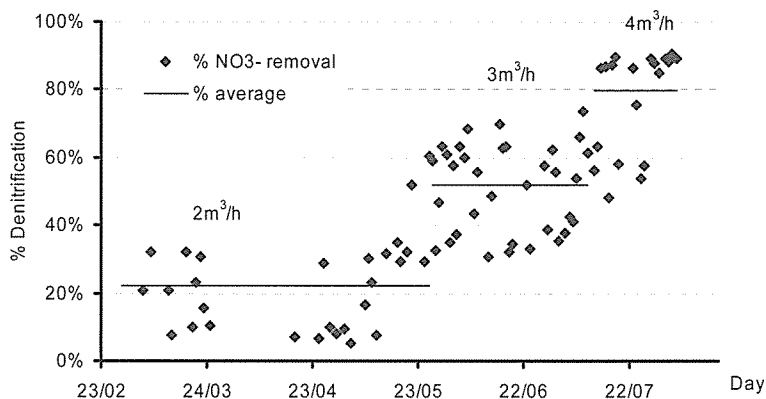


Fig. 8. Denitrification efficiencies of nitrification module 3A at Q=2, 3, 4 m³/h

Summary of denitrification under 3 runs with Q of 2, 3 and 4 m³/h showed the denitrification efficiency increased parallel with inlet flow rate. In the run 1 (Q= 2 m³/h) denitrification efficiencies were variable at low average value of 22% because of the denitrifiers need a period for adaptation and the lack of organic needed for denitrification process. The denitrification approached the average value of 43% in run 2 (Q=3m³/h) and highest value in the run 3 (Q = 4 m³/h). Addition of sodium acetate could improve significantly denitrification

efficiency. From this results organic carbon source addition is an important factor for the denitrification.

Substrate consumption along the denitrification column 3A:

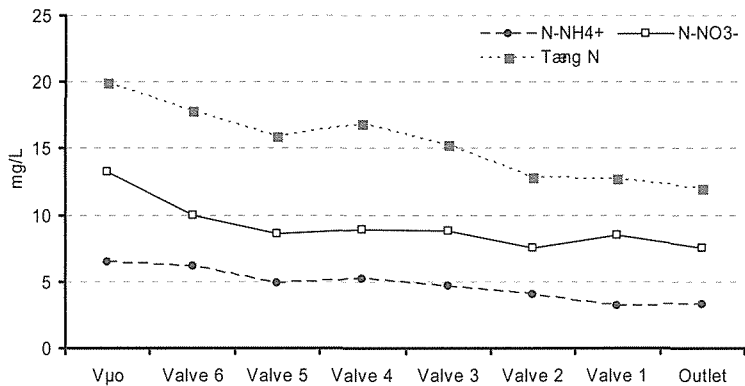


Fig. 9. Nitrate concentration along the denitrification column (3A)

Ammonium concentration decreased slightly from the top of column 3A (6.5 mgN/L) to the end of the column (3.7 mgN/L). It may first due to the nitrification process still continued because the effluent water brought some oxygen from nitrification column (4B) into the top of 3A column. Nitrate concentration decreased from the top (13.6 mgN/L) to the end of the column what is of 7.1 mgN/L. At the same time total nitrogen also decreased from 19.9 to 11.9 mg/l. The nitrification fraction efficiency could be achieved 43%.

COD from the top of denitrification column 3A was relative low (2-5 mg/L). The data showed that without organic carbons addition into the column the denitrification would occur insignificantly or very low. After addition of sodium acetate COD of 3A inlet increased to 25 mg/L then decreased almost linear at lower position (valve 6 - 1). COD decreasing pattern showed that microorganisms utilized COD for the denitrification.

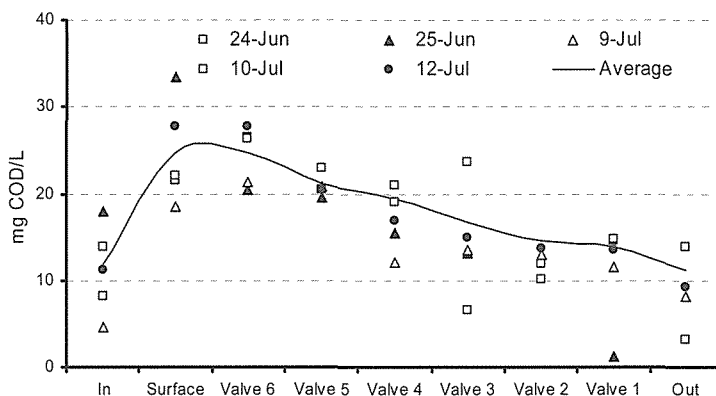


Fig. 10. COD concentration at different position of the denitrification column (3A)

Head loss on the column 3A:

Head loss of each position increased drastically from valve 6 to 5 and then slightly increased from valve 5 to 1 of the denitrification column 3A. This correlation was not linear like that in the 4B (figure 6) because the microorganisms were not distributed equally along the column.

Microorganisms located mainly on the top of this column due to without aeration and nitrogen emission. The head loss from valve 5 to valve 1 ($\Delta P = 13.4$ to 38.8 cm) was rather small for the height of the filtration material of 3.4 m.

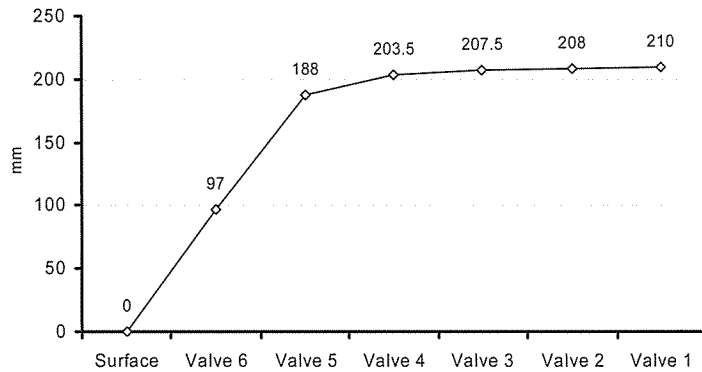


Fig. 11. Head loss values at different position of the column 4B.

Post aeration column 4A:

Actually this column (4A) is an additional nitrification for oxidizing remained ammonium and organic carbons after 3A and also played a role as a polishing stage. The first period from March 27 to May 23 (starting period) the system was operated with only nitrification 4B. In this period the post aeration 4A was not yet started so the ammonium after 4A was as high as $5-9$ mg/L. It is because activated sludge was filled into 3A and 4A on April 28. And after adding sodium acetate in the column 3A, ammonium concentration was decreased significantly with the level from 0 to less than 3 mg/L. Some peaks of ammonium occurred due to pump stuck or clogging and back-washings the column. Nitrate concentration after 4A had the similar pattern with ammonium concentration but in the reverse order.

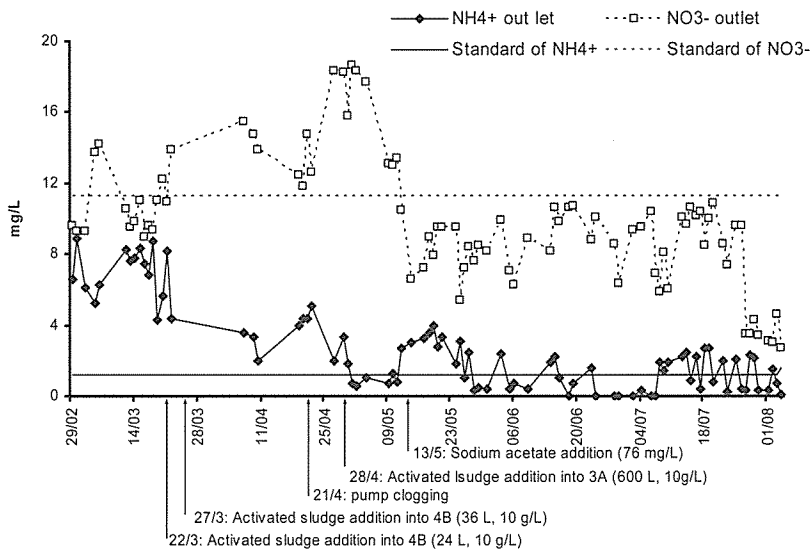


Figure. 11. Ammonium and nitrate concentration after column 4A

Water after the post aeration column reflected the quality of treated water regarding to nitrogenous concentration because the next stages are the filtration and chlorination, where N concentration changes insignificantly (about $1-2$ mg/L is oxidized during filtration).

Ammonium concentration in outlet of 4A was varied around the Vietnamese standard on ammonium in drinking water (1.5 mg/L e.q. 1.17 mgN/L). Nitrate concentration were lower than Vietnamese standard on nitrate in drinking water (50 mg/L e.q. 11.29 mgN/L). Generally, treated water were almost approached the Vietnamese standards regarding to nitrogenous concentration.

CONCLUSION

The pilot system has been starting 6 months ago with the goal of trial of ammonium removal using aerated submerged biofiltration for nitrification and also denitrification. The experiments for finding treatment capacity as well as optimal operation procedure parameters are not yet completed but some preliminary results showed that three stages of nitrification-denitrification - post aeration can be used for removal of high ammonium levels of 20-25 mg NH₄-N/L in the ground water for produce supply water. At the first stage nitrification efficiency could be achieved with the level of 76% and denitrification can be reached to more than 80% with addition of sodium acetate. The remained ammonium as well as organics would be removed in the third stage, then water can meet almost demands of Vietnamese standards (and also WHO standard) fro drinking water. The head loss of each position on column showed different values in nitrification and denitrification units. This can be contributed in the new full scale plant design and construction.

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