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Effects of Hydrogen Peroxide, Chloramine-T and Guaiacol on Nitrification Efficiency in Small-Scale Recirculating Systems

by

Lilik Teguh Pambudi

Department of Fisheries Biology

The Graduate School

Pukyong National University

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소형순환여과시스템의 질산화효율에 미치는 과산화수소 크로라민-T 및 목초액의 영향

Advisor : Jae-Yoon Jo

by
Lilik Teguh Pambudi

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Effects of Hydrogen Peroxide, Chloramine-T and Guaiacol on Nitrification Efficiency in Small-Scale Recirculating Systems

A dissertation

By

Lilik Teguh Pambudi

Approved as to style and content by:

(Chairman) Dr. Jong-Myoung Kim

(Member) Dr. Min Do Huh

(Member) Dr. Chang-Hoon Kim

(Member) Dr. Sung-Yong Oh

(Member) Dr. Jae-Yoon Jo

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Lilik Teguh Pambudi

Department of Fisheries Biology, Graduate School
Pukyong National University

Abstract

The present experiments were conducted to evaluate the effects of different levels of hydrogen peroxide, chloramine-T and guaiacol on nitrification efficiency of biofilters in small scale freshwater and seawater recirculating systems at three different water temperatures. The impairment of nitrification efficiency of biofilters by each of these chemotherapeutants was evaluated at 25, 20 and 15°C in freshwater, 25 and 20°C in seawater recirculating systems over short (24 h) and long periods (stabilized period). Each recirculating system consisted of a circular tank containing 200 L of water, a biofilter cylinder with polystyrene microbead, a pump and a water temperature controller. In each experiment, synthetic wastewater was supplied to the circular tank of each of eight systems to give the ammonia loading rate of 25 g m^{-3} d^{-1}. At the beginning of the experiment the water in each of the eight circular tanks was treated to contain one of four concentrations (0, 50, 100 or 150 ppm for hydrogen peroxide; 0, 10, 20 or 30 ppm for chloramine-T and 10, 30 or 50 ppm for guaiacol) of the chemotherapeutant under experiment in duplicates. The exposure time of the chemoterapeutants was 1 hour and nitrification efficiency of each biofilter was measured at 15 min, 30 min, 1, 3, 6, 9, 12, 18 and 24 h within first day and once a day for the next 25 days. The 50, 100 and 150 ppm of hydrogen peroxide showed impairment on nitrification efficiency of the biofilters significantly by the range of 12 − 27, 34 − 49 and 47 − 74%, respectively. The 10 ppm of chloramine-T had no significant effect to nitrification efficiency of the biofilters, whereas the 20 and 30 ppm of chloramine-T impaired nitrification efficiency of the biofilters by 21 − 37 and 38 − 41%, respectively. Furthermore, the 10 ppm of guaiacol had no significant effect to nitrification efficiency of the biofilters, while the 30 and 50 ppm of guaiacol showed impairment on nitrification efficiency of the biofilters by 27 − 43 and 50 − 75%, respectively. These effects occurred because the chemotherapeutants inhibit nitrifying bacteria which caused decreasing of nitrification efficiency.

Keywords: recirculation, chemotherapeutant, nitrification, biofilter

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I. General Introduction

1.1. Recirculating aquaculture system and biofilter

Aquaculture industries play important role to fulfil fisheries consumption demand due to declining of capture fisheries production in many areas (FAO, 2003; Guiterrez-Wing and Malone, 2006). Furthermore, FAO (2003) mentioned that production from capture fisheries showed around 1.2% of annual increase, while the aquaculture showed the rate at 9.1% increase. Supporting these data, fish consumption per capita also increased 24% from 1970 to 1998, according to report by USDA/ERS (1999). Therefore, more intensive practises in aquaculture industries needed, together with recirculating aquaculture system.

Recirculating systems have been identified as one of the emerging technology to increase world aquaculture production. This technology has been used to reduce water demands and discharges, better food conversions ratio, more intensive practises and minimize environmental impacts (Goldburg et al., 2001; Losordo et al., 1998). The main component of recirculating aquaculture system is the presence of biofilter, which has important function to maintain water quality by removing ammonia rather than discharge contaminated water (Guiterrez-Wing and Malone, 2006).

Ammonia is well-known as major by-product of protein deamination in aquaculture feeds and is released primarily through fish's gills. It also can be released from decaying feed and faeces (Spotte, 1979) and might be very toxic to aquatic organisms (Wood, 1993). Nitrifying bacteria oxidize ammonia in biofilter in a two-step process. According to Hargreaves (1998) and Keck and Blanc (2002), in the first step, ammonia-oxidizing bacteria oxidize ammonia to nitrite and converted to nitrate by nitrite-oxidizing bacteria in the second step. Nitrate is relatively harmless to fish and can be maintained at safe levels with regular water changes (Hargreaves, 1998). Pennel and McLean (1996) and Keck and Blanc (2002) stated that ammonia and nitrite concentrations are important limiting factors in aquaculture systems, due to the necessity of simultaneous management of equilibrated fish and bacterial populations. Several genera of autotrophic bacteria such as *Nitrosomonas*, *Nitrosospira*, *Nitrospira*, *Nitrosococcus*, *Nitrobacter* and *Pseudomonas* play role on nitrification process (Ivanova et al., 2000; Leonard et al., 2000).

There are many researches tried to find out an ideal biofilter for intensive aquaculture systems. The ideal one would be able to remove 100% of the inlet ammonia concentration, produce no nitrite, require a relatively small footprint, use inexpensive media, require no water pressure or maintenance to operate, and would not capture solids (Timmons et al., 2001). Several types of biofilters have been studied for use in the aquaculture industry, each with its own design and operational characteristics (Hall, 1999). Specific surface area (SSA), cost, availability, size, shape and weight per unit volume are usually considered for biofilter media selection (Lekang and Kleppe, 2000). Biofilter must have high homogenous water flow to avoid dead zone and channeling effect which can decrease nitrification performance (Harwanto, 2009). Heterotroph microorganisms are also living on the biofilter and have ability to metabolize TAN and organic material (Chen et al., 2006; Harwanto, 2009). Those microorganisms grow biologically on the surface of media and oxidize ammonia with the nitrification process (Summerfelt and Sharrer, 2004). The types of biofilters commonly used in intensive recirculating aquaculture systems are submerged biofilters, trickling biofilters, rotating biological contactors (RBC), floating bead biofilters, dynamic bead biofilters and fluidized-bed biofilters (Timmons et al., 2001).

Trickling biofilter was studied in aquaculture by several researchers. Liao and Mayo (1974) tried to apply trickling biofilter for recirculating system in salmonid hatcheries and hence providing the basis knowledge for modern recirculation technology in aquaculture (Eding et al., 2006). Advantages of trickling biofilters as compared to other biofilter are: (1) high process stability due to constant high oxygen levels; (2) CO_2 removal by degassing; (3) water cooling in summer-time; and (4) simplicity of design, construction, operation and management (Eding et al., 2006).

Among the biofilter media which has been investigated, polystyrene foam beads showed high floating capability (Malone and Beecher, 2000). Greinner and Timmons (1998) classified polystyrene with diameter of 1 – 3 mm as microbead media. Malone and Pfeiffer (2006) and Harwanto (2009) also mentioned that this biofilter media has high SSA, light, good for solid removal and relatively inexpensive as compared to those of sand and Kaldnes filter media.

1.2. Disinfection management

Disinfection management in recirculating unit is difficult due to intensive practises and certain characteristic of the biofilter system allowing the growth of organism causing diseases. Moller et al. (2009) explained that formalin is currently one of the most commonly used therapeutic agents because of its high treatment efficiency and substantial knowledge on the dose-response effect. Formalin was also mentioned that does not appear to be harmful for fish or biofilters in recirculating aquaculture systems (RAS) in the doses relevant for treatment (Pedersen et al., 2007). On the other hand, excess amount of formaldehyde on water bodies imposes an ecological problem and caused growing concerns on environemnt (Moller et al., 2009; Pedersen et al., 2007) as well as worker safety issues (IARC, 2004). According to these circumstances, alternative chemotherapeutants are needed.

Hydrogen peroxide (HP) has advantages such as the end-products proved to be non-toxic substances (Block, 1991; Moller et al., 2009) and showed good capability on the treatment of parasites and fungus on fish and fish eggs (Heinecke and Buchmann, 2009). This chemotherapeutant also decomposes relatively fast in the aquaculture system to be sufficiently eliminated before discharge and complies with discharge regulations (Schmidt et al., 2006). Hydrogen peroxide has been mostly used on flow-through aquaculture systems to study for parasites treatment efficiency and the tolerance of different fish species to HP in bath treatments. Those treatments usually consist of a high dose of HP (50 – 100 mg L^{-1}) for fish and up to 1000 mg L^{-1} for eggs from 15 min to 2 hours (Montgomery-Brock et al., 2001; Moller et al., 2006). Hydrogen peroxide also had been applied to eradicate sea lice *Lepeophtherius salmonis* on farmed Atlantic salmon *Salmon salar* on static bath treatment (Treasurer et al., 2000; Treasurer and Grant, 1997; McAndrew et al., 1998), and for treating saprolegniasis on cultured Nile tilapia (El-Atta., 2008).

A few studies tried to figure out the effect of HP on the nitrification process in biofilter of recirculating aquaculture system. Schwartz et al. (2000) stated that 100 mg L^{-1} of HP concentration inhibited significantly on TAN removal while tested on static bath treatment. Sortjkaer et al. (2008) also investigated the effect of multiple doses of HP on the nitrification performance in RAS biofilter. They concluded that biofilter performance was unaffected by HP application at the concentration below 30 mg L^{-1}, but continuously giving HP dosage showed nitrite accumulation. Moller et al. (2009) also tested the effect of HP in a small-scale recirculating system biofilter (BIO-BLOK) but this although experiment did not use fully normal operated recirculating aquaculture system.

Chloramine-T (Chl-T) is an external disinfectant whose therapeutic use to reduce mortalities associated with external bacterial infections of freshwater fish in U.S. aquaculture is presently under review by the US Food and Drug Administration (Gaikowski et al., 2008). It is also well-known as chemotherapeutant used in aquaculture industries to eradicate parasites, bacteria, fungus and other pathogens (Altinok, 2004). Chloramine-T effectively controlled external columnaris disease on walleye *Sander vitreum* when administrated at 10 mg L^{-1} and on goldfish *Carassius auratus* intentionally infected with

Flavobacterium columnare when administered at 15 mg L^{-1}. Chloramine-T was investigated to control amoebic gill disease in Atlantic salmon (Leef et al., 2007; Powell and Clark, 2004) and also for disinfection treatment in rainbow trout *Oncorhynchus mykiss* (Powell and Perry, 1997; Powell et al., 1998).

Guaiacol (o-methoxyphenols) is one of the active components isolated from higher plants. It can acts as an inhibitor of calcium flow (Toyoda et al., 1993). According to this capability, it is suggested that guaiacol affects calcium metabolism either directly or indirectly. Furthermore, guaiacol has significant antibacterial activities (He et al., 2006). Guaiacol has been used traditionally on aquaculture activities by fish farmer on some areas and also by ornamental fish hobbyist. National Fisheries Research and Development Institute of Republic of Korea (NFRDI) posted guaiacol, hydrogen peroxide and chloramine-T as chemotherapeutant in the manual book for fish disease treatment (NFRDI, 2010). However, there are few information and almost none of research report about using guaiacol as disinfectant in aquaculture.

1.3. Objectives

Information about treatment efficiency and treatment regime by those chemotherapeutants in RAS is limited, especially potential inhibiting effects on nitrifying process. These experiments are needed to figure out chemotherapeutants application on normal operation in RAS, especially related to fish disease management and three stages of the experiments were carried out as below:

1. Effect of hydrogen peroxide, chloramine-T and guaiacol on nitrifying efficiency in small-scale recirculating systems at 25°C of freshwater and seawater.
2. Effect of hydrogen peroxide, chloramine-T and guaiacol on nitrifying performance in small-scale recirculating systems at 20°C of freshwater and seawater.

3. Effect of hydrogen peroxide, chloramine-T and guaiacol on nitrifying performance in small-scale recirculating system at 15°C of freshwater.

II. Materials and Methods

2.1. System design

The experiments were conducted in four sets of closed small-scale recirculating systems, including control, hydrogen peroxide (HP), chloramine-T (Chl-T), and guaiacol (Gcl) treatment. Each treatment system contains a fiberglass circular tank (80 x 80 x 60 cm), a biofilter cylinder (diameter 19 cm; length 100 cm) and a pump (Fig.1). Water volume in each system was 200 L and water was pumped into the biofilter cylinder (trickling system) and flowed back to the circular tank. Water flow rate on each biofilter was maintained at 24 L min^{-1}. A synthetic wastewater tank (50 L) and a peristaltic pump were installed to distribute synthetic waswater into each system to get desired ammonia loading rate. Submersible heater and air conditioner were used to maintain water temperature at 25, 20 and 15°C.

2.2. Experimental design

Experimental design was conducted by three different chemotherapeutants, a biofilter media, four different chemotherapeutant concentrations, three different water temperature of freshwater and two different water temperature of seawater and also an ammonia loading rate (Table 2.1).

2.3. Biofilter media

Polysterene microbead (MB) was installed on each biofilter system in the filter cylinder with the amount of 7 L in volume. This biofilter media has 1.0 – 1.3 mm of diameter with specific surface area (SSA) of 3,287 $m^2 m^{-3}$ and 23 m^2 L^{-1} of surface area (Harwanto, 2009). All biofilter systems were operated by trickling method.

2.4. Ammonia loading rates

Ammonia loading rate used in this experiment was 25 g m^{-3} d^{-1} based on the previous study (Harwanto, 2009). This ammonia loading rate is equivalent to tilapia biomass of 25 kg m^{-3} of water volume and red sea bream biomass of 42 kg m^{-3} of water volume. The formulation of synthetic wastewater used in this experiment is based on Roger and Klemenston (1985) and is shown in Table 2.2. The wastewater feeding was carried out by peristaltic pump (Cheon Sei, Korea) at the rate of 7 mL min^{-1} to control the system.

2.5. Biofilter conditioning and operation

Biofilters were conditioned with inoculated sludge from old biofilters into the experimental systems and cultured nitrifying bacteria by feeding synthetic wastewater at the rate of 10 mg L^{-1} d^{-1} of TAN for the 7 days and at 50 mg L^{-1} d^{-1} of TAN for the next 7 days. After nitrification processes of the experimental systems were stabilized, the water on each system was changed with new water and the experiment was started.

The experiment was carried out with three different chemotherapeutants (hydrogen peroxide, chloramine-T, guaiacol) and three different water temperatures (25, 20, 15°C). The acclimation for all experimental systems was started at the same time. Ammonia loading rate and certain water temperature were maintained at the points during the experiment period based on research design. Acclimation process was finished after TAN concentration in each biofilter system was stabilized. Predetermined concentration of chemotherapeutant was given in the certain system including the control (0 ppm) and then replacing 10% of water volume after one hour treatment. While short period observation was carried out within 24 hour, for the long period experiment was carried out until all system reached to stabilization. When the experiment was finished, water in all systems was changed with the new water and continued to the next treatment. The 10 L of synthetic wastewater were added continuously into each biofilter system by peristaltic pump for 24 hours with the removal of 10 L excess water from each system daily.

The experiment evaluated nitrification efficiency of the biofilter system treated with chemotherapeutants for the short period and long period. The short period consists 24 hours and duration of the long period depends on stabilized period of nitrification efficiency of the biofilters.

2.6. Water sampling

Water samples were taken from inlet and outlet of biofilter system to find out of the concentration difference between two sampling points. Concentration of total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2-N) and nitrate-nitrogen (NO_3-N) were determined to figure out the nitrification efficiency. Water temperature, dissolved oxygen, pH and salinity were measured in each system daily.

The water sampling for short period dynamic of nitrification process was carried out at 15 min, 30 min, 1 h, 3 h, 6 h, 9 h, 12 h, 18 h and 24 h. Water sampling was carried out every day to evaluate long period of nitrification efficiency.

2.7. Water quality measurements

Total ammonia nitrogen was measured by HACH DR 2000 (freshwater) and Orion 720A (seawater), nitrate and nitrite concentrations were measured by HACH DR 2000. Water temperature and dissolved oxygen were measured by Oxyguard and pH was monitored by Ecomet pH meter Type P25. Salinity was measured by Atago Handy Salinometer.

Following equations were used to determine nitrification performance of biofilter:

Volumetric removal rates (VTR, $g\ m^{-3}\ d^{-1}$) = $1.44 \times (TAN_{in}-TAN_{out}).Q.V^{-1}$

Areal removal rates (ATR, $g\ m^{-2}\ d^{-1}$) = $1.44 \times (TAN_{in}-TAN_{out}).Q.V^{-1}.S^{-1}$

Removal efficiency (TRE, %) = $\{(TAN_{in}-TAN_{out})\ TAN_{in}^{-1}\} \times 100$

Where TAN_{in} is concentration of total ammonia nitrogen in inlet of biofilter (mg L^{-1}), TAN_{out} is concentration of total ammonia nitrogen in outlet of biofilter (mg L^{-1}), Q is total water flow through biofilter ($m^3\ d^{-1}$), V is volume of filter bed (m^3) and S is SSA of media ($m^2\ m^{-3}$).

2.8. Statistical analysis

Minitab Statistical Software Ver. 16 was used for statistical analysis. The mean concentration of nutrient (TAN, nitrite and nitrate) and nutrient removal or production in each biofilter were statistically analysed using one-way ANOVA. The Tukey's-HSD Tests were used to analyze differences of nutrient concentration and nutrient removal to find out significant difference ($p < 0.05$).

Table 2.1. Experimental design

Chemo.	Biofilter Media	Chemo.Conc. (ppm)	Temperature (^{o}C)	Type of Water	Ammonia Loading Rate (gm^{-3}d^{-1})
HP	MB	0, 50, 100, 150	25	FW, SW	25
		0, 50, 100, 150	20	FW, SW	
		0, 50, 100, 150	15	FW	
Chl-T	MB	0, 10, 20, 30	25	FW, SW	25
		0, 10, 20, 30	20	FW, SW	
		0, 10, 20, 30	15	FW	
Gcl	MB	0, 10, 30, 50	25	FW,SW	25
		0, 10, 30, 50	20	FW, SW	
		0, 10, 30, 50	15	FW	

FW: freshwater; SW: seawater

Table 2.2. Composition and amount of chemicals used for making 50 L of synthetic wastewater

Composition	Amount of chemical (g)
$(NH_4)_2SO_4$	120.28
$NaHCO_3$	154.44
Na_2HPO4	39.01
Glucose	32.88
$MnSO_4$	2.11

Roger and Klementson (1985) and Harwanto (2009)

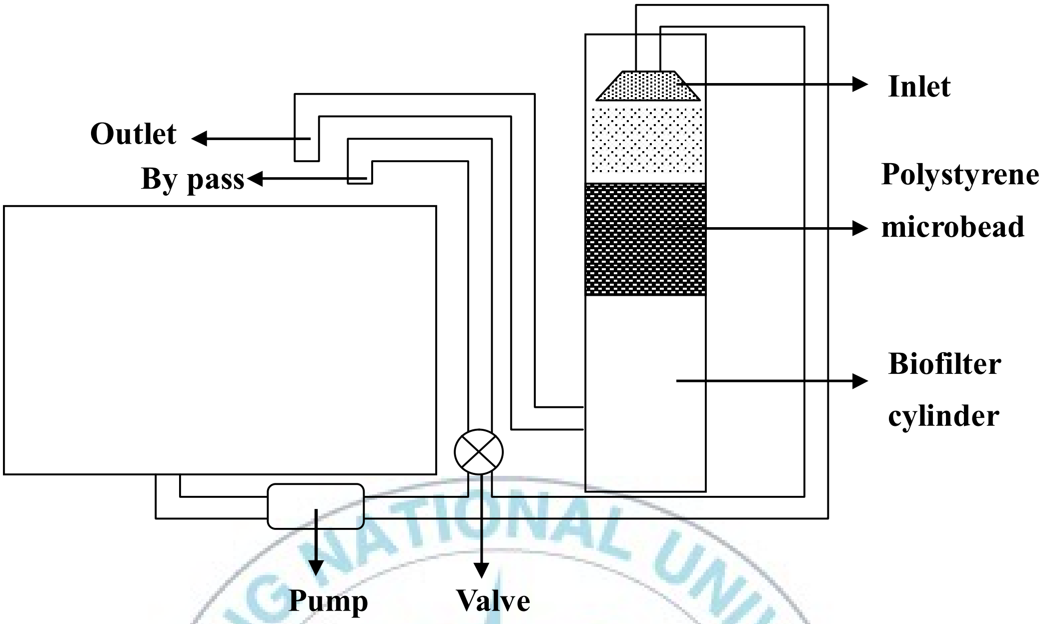

Figure 2.1. Schematic diagram of biofilter system

III. Results

3.1. Nitrification efficiency in freshwater

3.1.1. Nitrification efficiency at 25°C

The water temperature and dissolved oxygen (DO) were maintained at 24.6 – 25.2°C and 7.3 -8.9 mg L^{-1}, respectively. The pH of the water ranged between 6.9 and 7.8 in the entire biofilter systems.

Short period observation

In the short period observation (24 h) of the hydrogen peroxide (HP) treatment, the lowest total ammonia nitrogen (TAN) concentration was found in the control, followed by 50, 100 and 150 ppm. This is caused by the control which has higher volumetric removal rate was 291.84 g m^{-3} d^{-1} than other HP treatment with removal rates of 50, 100 and 150 ppm were 230.40, 153.60 and 92.16 g m^{-3} d^{-1}, respectively. Similar results were also found in the areal removal rate and removal efficiency. The treatment of chloramine-T (Chl-T), the highest TAN concentration (5.76 mg L^{-1}) was found in the treatment of 30 ppm, and then lower concentration was followed by 20, 10 ppm and control, which were 4.87, 2.75 and 2.41 mg L^{-1}, respectively. The result indicates that higher concentration of Chl-T caused lower volumetric removal rate, areal removal rate and removal efficiency. Higher concentration of guaiacol (Gcl) resulted in the higher of TAN concentration. The control showed the highest volumetric removal rate of 307.20 g m^{-3} d^{-1}, followed by 10, 30 and 50 ppm which were 261.12, 199.68 and 92.16 g m^{-3} d^{-1}, respectively (Table 3.1).

The lowest volumetric removal rate of NO_2-N was produced by treatment of 150 ppm of HP which was 46.08 g NO_2-N m^{-3} d^{-1}. The values were subsequently increased in the treatment of 100, 50 ppm and control which were 0.31 and 0.40 g NO_2-N m^{-3} d^{-1}, respectively. Furthermore, in the Chl-T treatment, the highest volumetric removal rate was found in the control which was 125.95 g m^{-3} d^{-1}, followed by treatment of 10, 20 and 30 ppm which were 116.74, 67.58 and 58.37 g m^{-3} d^{-1}, respectively. This trend also occurred in the areal removal rate and removal efficiency as well. While the 50 ppm treatment of Gcl showed the lowest volumetric removal rate of 0.016 g m^{-3} d^{-1}, the rates were subsequently increased in the treatment of 30, 10 ppm and control which were 0.023, 0.037 and 0.038 g m^{-3} d^{-1}, respectively (Table 3.2).

The significant differences of NO_3-N concentration in the treatment of HP occurred between all treatments, in which the control showed the highest mean concentration compared to the 50 ppm, followed by 100 and 150 ppm. This tendency was also shown on the volumetric removal rate, areal removal rate and production efficiency as well. Production efficiency in the control was 5.12%, and subsequently decreased in the 50, 100 and 150 ppm which were 3.63%, 2.23% and 1.25%, respectively. In the treatment of Chl-T, the highest mean volumetric removal rate was found in the control which was 1,136.64 g NO_3-N m^{-3} d^{-1}, followed by 10, 20 and 30 ppm which were 890.88, 491.52 and 337.92 g NO_3-N m^{-3} d^{-1}, respectively. In the treatment of Gcl, the lowest production efficiency was found in the treatment of 50 ppm and subsequently increased in the 30, 10 ppm and control. This trend was also found in the volumetric production rate and areal production rate, whereas for the volumetric production rate, treatment of 50 ppm showed 307.20 g NO_3-N m^{-3} d^{-1} followed by 30 ppm, 100 ppm and control which were 552.96, 860.16 and 1167.36 g NO_3-N m^{-3} d^{-1}, respectively (Table 3.3).

In general, it can be stated that only treatment of 10 ppm of Chl-T and Gcl showed no significant impact on the nitrification efficiency of the biofilters.

Long period observation

Long period observation was carried out to evaluate the difference of nutrient concentration during the stabilization period of nitrification efficiency in all treatments. Based on the results, HP treatment showed increase in TAN concentration. In the control, the highest TAN concentration (7 mg L^{-1}) was achieved at 5th day, and in the 50 ppm occurred at 4th day which was about 18 mg L^{-1}. In the 100 and 150 ppm occurred at 4th and 5th day with the concentrations of 26.8 and 34.5 mg L^{-1}, respectively. While the stabilized period was started at 7th day in the control, while in the 50, 100 and 150 ppm occurred at 12th, 15th and 21st day, respectively. The mean of TAN concentration in the control was the lowest concentration of 2.39 mg L^{-1}, followed by 50, 100 and 150 ppm which were 5.21, 9.91 and 16.65 mg L^{-1}, respectively (Figure 3.1 and Table 3.4). The concentration of NO_2-N in the control and all other treatments on the first day was 0.78 mg L^{-1} and began to increase from the next day. In the control, the highest concentration was reached at day 4th with the concentration of 1.18 mg L^{-1}, whereas the 50, 100 and 150 ppm reached at day 9th with the concentration of 1.62 mg L^{-1}, at day 7th with a concentration of 1.96 mg L^{-1} and at day 5th with the concentration of 2.84 mg L^{-1}, respectively. Then the concentration of NO_2-N tended to decline until the stabilized period occurred (Figure 3.1 and Table 3.5). Furthermore, NO_3-N concentration in the control and all treatments was 2.1 mg L^{-1} at the first day and then increased gradually. At the end of the experiment, concentration of NO_3-N in the control, 50, 100 and 150 ppm of HP were 190.25, 75.50, 48.61 and 29.82 mg L^{-1}, respectively (Figure 3.1 and Table 3.6).

In the treatment of Chl-T, the control showed highest concentration of TAN (8.3 mg L^{-1}) at 5th day. The 10 ppm showed 9.5 mg L^{-1} at 5th day, whereas in the 20 ppm occurred at 4th day (15.5 mg L^{-1}), then in the 30 ppm occurred at 4th day (17.2 mg L^{-1}). Furthermore, stabilized period in the control occurred at 7th day, followed by 10, 20 and 30 ppm which began at day 9th, 13th and 15th, respectively (Figure 3.2 and Table 3.4). The highest concentrations of NO_2-N were achieved in the control, 10, 20 and 30 ppm were 1.48, 1.63, 2.35 and 2.578 mg L^{-1}, respectively. At the end of the experiment, those concentrations were

0.72, 0.67, 0.86 and 0.9 mg L^{-1}, respectively (Figure 3.2 and Table 3.5). Furthermore, the NO_3-N concentration showed increase from the first day, where the rate of increase in the higher concentration of Chl-T indicated slower process. At the end of the experiment, the concentrations in the control, 10, 20 and 30 ppm were 160.5, 146.5, 97.25 and 92.75 mg L^{-1}, respectively (Figure 3.2 and Table 3.6).

Upon Gcl treatment, the highest TAN concentrations were found in the control, 10, 30 and 50 ppm were 11.4, 15.6, 20.5, and 29.5 mg L^{-1} that appeared at 4th day for the control and the rest were at 5th day. After that period, the concentration began to decline until stabilized period where for the control, 10, 30 and 50 ppm were occurred at day 8th, 10th, 14th and 19th (Figure 3.3 and Table 3.4).

In the control, the highest concentrations of NO_2-N was reached to 1.21 mg L^{-1}, while in the 10, 30 and 50 ppm was reached to 1.57, 1.73, 1.89 mg L^{-1} that occurred at day 4th, 7th, 8th and 10th, respectively (Figure 3.3 and Table 3.5). At the first day, the concentration of NO_3-N in the control, 10, 30 and 50 ppm were 2.3, 2.2, 2.3, and 2.3 mg L^{-1}, respectively. Then began to increase gradually where the concentrations at the end of the experiment were 160.5, 124.25, 101.5 and 58.5 mg L^{-1}, respectively (Figure 3.3 and Table 3.6).

Table 3.1. Short period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.35^{a}	4.5^{b}	9.29^{c}	16.11^{d}	2.41^{a}	2.75^{a}	4.87^{b}	5.76^{b}	2.55^{a}	3.57^{a}	7.40^{b}	13.53^{c}
TAN outlet (mg L^{-1})	2.24^{a}	4.41^{b}	9.33^{c}	16.08^{d}	2.31^{a}	2.66^{a}	4.80^{b}	5.70^{b}	2.43^{a}	3.47^{a}	7.33^{b}	13.5^{c}
Removal per pass (mg L^{-1})	0.105^{a}	0.083^{b}	0.055^{c}	0.033^{d}	0.100^{a}	0.094^{a}	0.072^{b}	0.061^{b}	0.111^{a}	0.094^{a}	0.072^{b}	0.033^{c}
Vol. removal rate (g m^{-3} d^{-1})	291.84^{a}	230.40^{b}	153.60^{c}	92.16^{d}	276.48^{a}	261.12^{a}	199.68^{b}	168.96^{b}	307.20^{a}	261.12^{a}	199.68^{b}	92.16^{c}
Areal removal rate (mg m^{-2} d^{-1})	88.79^{a}	70.09^{b}	467.30^{c}	28.04^{d}	84.11^{a}	79.44^{a}	60.75^{b}	51.40^{b}	93.46^{a}	79.44^{a}	60.75^{b}	28.04^{c}
Removal efficiency (%)	4.46^{a}	1.17^{b}	0.38^{c}	0.20^{d}	4.15^{a}	3.41^{a}	1.48^{b}	1.06^{b}	4.31^{a}	2.63^{a}	0.97^{b}	0.24^{c}

Values in same treatment and same row with different letters are significantly different (p<0.05)

Table 3.2. Short period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_2-N inlet (mg L^{-1})	0.71^{a}	0.85^{b}	1.05^{c}	1.30^{d}	0.82^{a}	0.86^{a}	1.12^{b}	1.18^{b}	0.86^{a}	0.88^{a}	1.07^{b}	1.34^{c}
NO_2-N outlet (mg L^{-1})	0.67^{a}	0.82^{b}	1.03^{c}	1.28^{d}	0.78^{a}	0.82^{a}	1.10^{b}	1.16^{b}	0.82^{a}	0.84^{a}	1.04^{b}	1.32^{c}
Removal per pass (mg L^{-1})	0.040^{a}	0.031^{b}	0.023^{c}	0.016^{d}	0.045^{a}	0.043^{a}	0.024^{b}	0.021^{b}	0.111^{a}	0.038^{a}	0.023^{b}	0.016^{c}
Vol. removal rate (g m^{-3} d^{-1})	110.59^{a}	86.02^{b}	64.51^{c}	46.08^{d}	125.95^{a}	116.74^{a}	67.58^{b}	58.37^{b}	107.52^{a}	104.45^{a}	64.51^{b}	46.08^{c}
Areal removal rate (mg m^{-2} d^{-1})	14.42^{a}	11.22^{b}	8.41^{c}	6.01^{d}	38.32^{a}	35.51^{a}	20.56^{b}	17.76^{b}	32.71^{a}	31.78^{a}	19.63^{b}	14.02^{c}
Removal efficiency (%)	5.63^{a}	3.63^{b}	2.23^{c}	1.25^{d}	5.44^{a}	4.86^{a}	2.13^{b}	1.80^{b}	5.44^{a}	4.86^{a}	2.13^{b}	1.26^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.3. Short period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	7.77^{a}	4.73^{b}	2.98^{c}	2.36^{d}	6.80^{a}	5.74^{a}	3.56^{b}	2.82^{b}	7.50^{a}	6.60^{a}	4.31^{b}	2.53^{c}
NO_3-N outlet (mg L^{-1})	8.2^{a}	4.97^{b}	3.13^{c}	2.45^{d}	7.21^{a}	6.06^{a}	3.74^{b}	2.94^{b}	7.92^{a}	6.91^{a}	4.51^{b}	2.64^{c}
Production per pass (mg L^{-1})	0.422^{a}	0.244^{b}	0.144^{c}	0.088^{d}	0.0411^{a}	0.322^{a}	0.177^{b}	0.122^{b}	0.422^{a}	0.311^{b}	0.200^{c}	0.111^{d}
Vol. production rate (g m^{-3} d^{-1})	1,167.36^{a}	675.84^{b}	399.36^{c}	245.76^{d}	1,136.64^{a}	890.88^{a}	491.52^{b}	337.92^{b}	1,167.36^{a}	860.16^{b}	552.96^{c}	307.20^{d}
Areal prod. rate (mg m^{-2} d^{-1})	355.14^{a}	205.61^{b}	121.49^{c}	74.76^{d}	345.79^{a}	271.03^{a}	149.53^{b}	102.80^{b}	355.14^{a}	261.68^{b}	168.22^{c}	93.45^{d}
Production efficiency (%)	5.12^{a}	4.82^{a,b}	4.44^{a,b}	3.24^{b}	5.68^{a}	5.31^{a,b}	4.75^{a,b}	4.14^{b}	5.60^{a}	4.69^{a,b}	4.64^{a,b}	4.34^{b}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

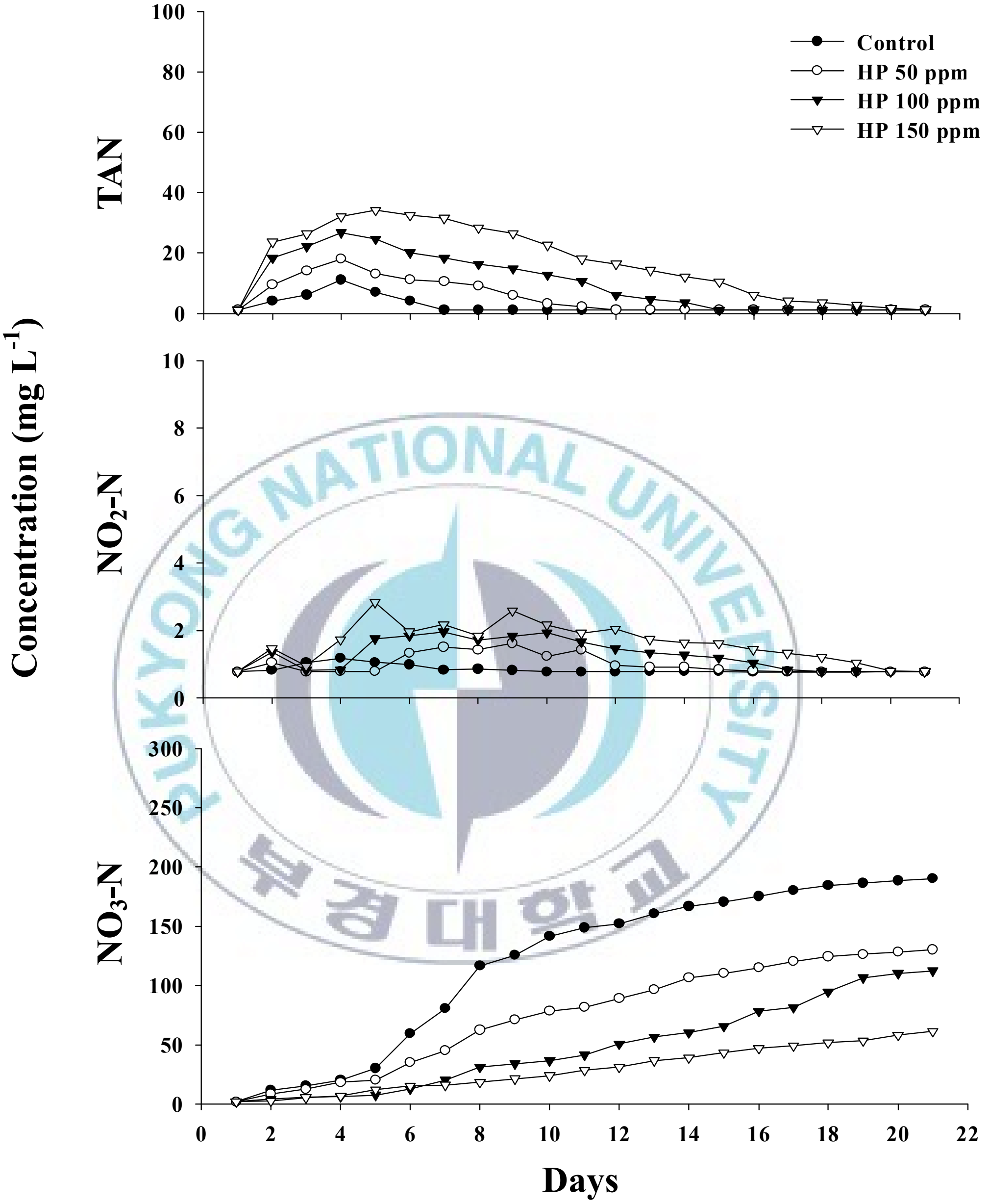

Fig. 3.1. Long period of nitrification rate of biofilter under hydrogen peroxide (HP) treatment at 25 °C in freshwater

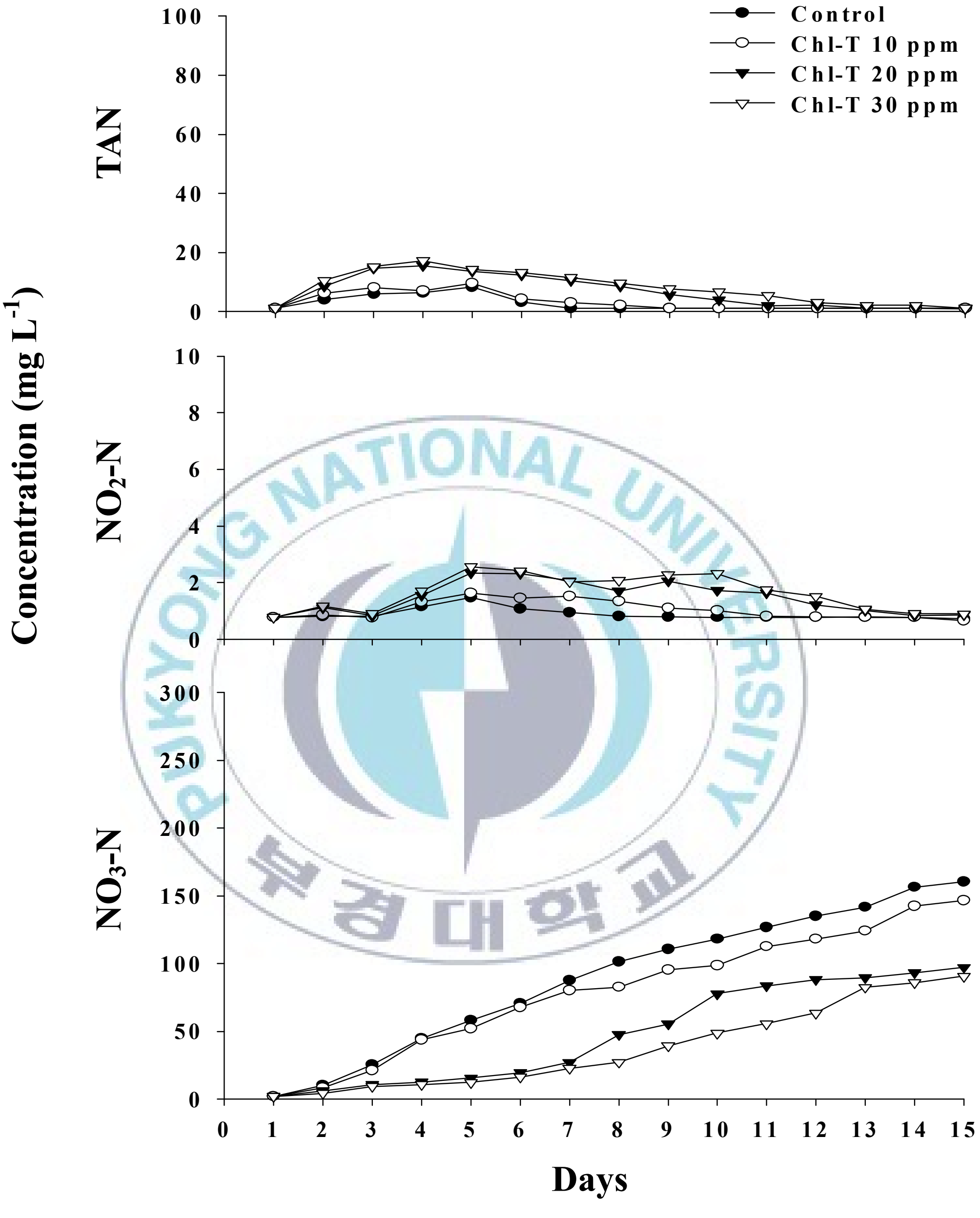

Fig. 3.2. Long period of nitrification rate of biofilter under chloramine-T (Chl-T) treatment at 25 °C in freshwater

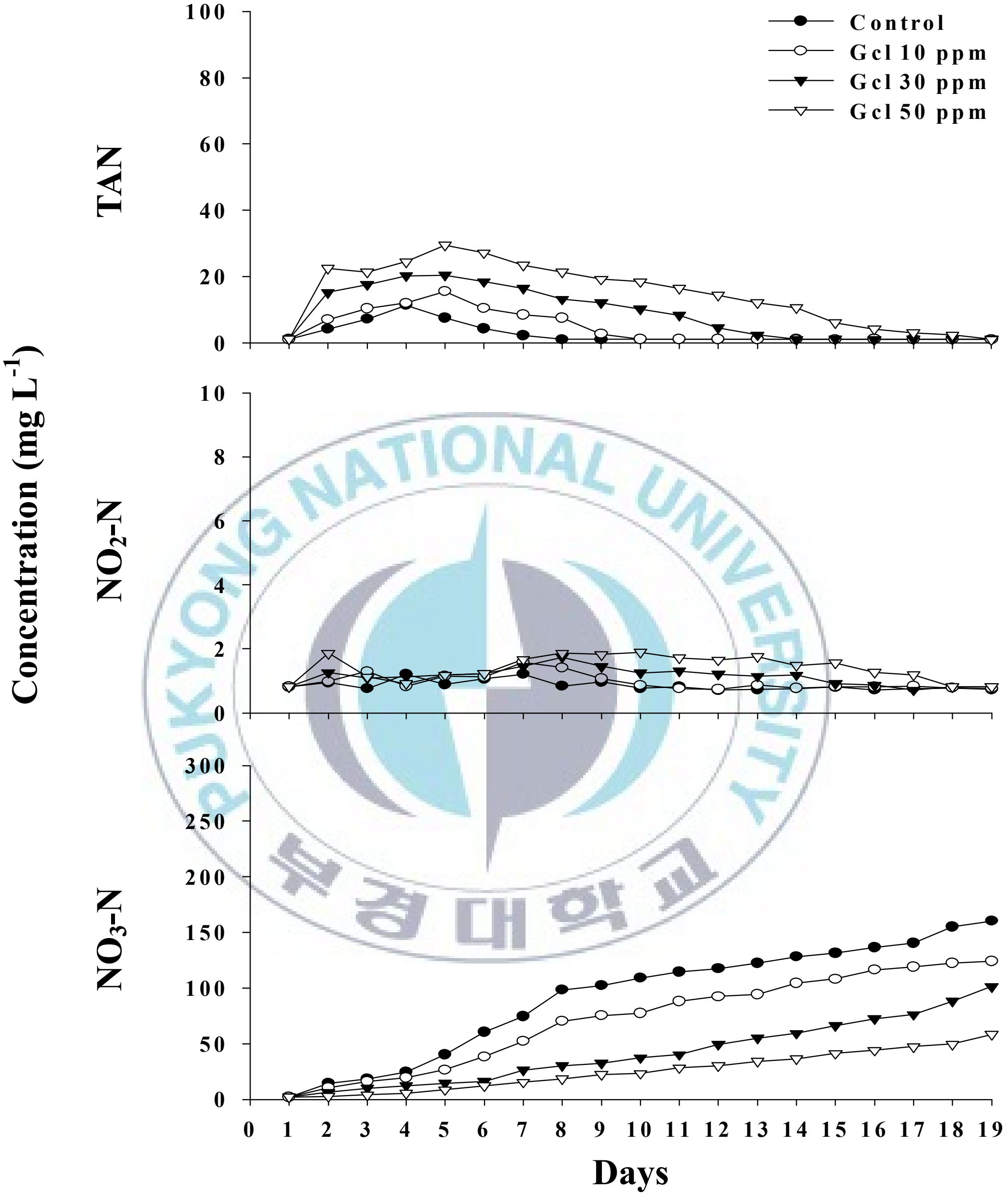

Fig. 3.3. Long period of nitrification rate of biofilter under guaiacol (Gcl) treatment at 25 °C in freshwater

Table 3.4. Long period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25^{o}C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.39^{a}	5.21^{b}	9.91^{c}	16.64^{d}	2.60^{a}	3.29^{a}	6.80^{b}	8.06^{b}	2.72^{a}	4.57^{a}	8.82^{b}	14.72^{c}
TAN outlet (mg L^{-1})	2.28^{a}	5.13^{b}	9.85^{c}	16.60^{d}	2.50^{a}	3.20^{a}	6.72^{b}	7.99^{b}	2.62^{a}	4.48^{a}	8.75^{b}	14.47^{c}
Removal per pass (mg L^{-1})	0.102^{a}	0.083^{b}	0.064^{c}	0.047^{d}	0.100^{a}	0.093^{a}	0.073^{b}	0.063^{b}	0.102^{a}	0.089^{a}	0.068^{b}	0.050^{c}
Vol. removal rate (g m^{-3} d^{-1})	283.06^{a}	230.40^{b}	177.74^{c}	131.66^{d}	276.48^{a}	258.05^{a}	202.75^{b}	175.10^{b}	283.76^{a}	247.38^{a}	189.17^{b}	138.24^{c}
Areal removal rate (mg m^{-2} d^{-1})	86.12^{a}	70.09^{b}	54.07^{c}	40.05^{d}	84.11^{a}	78.51^{a}	61.68^{b}	53.27^{b}	86.33^{a}	75.26^{a}	57.55^{b}	42.06^{c}
Removal efficiency (%)	4.26^{a}	1.53^{b}	0.60^{c}	0.28^{d}	3.84^{a}	2.79^{a}	1.08^{b}	0.79^{b}	3.67^{a}	1.94^{a}	0.77^{b}	0.34^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.5. Long period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.84^a	1.00^b	1.27^c	1.62^d	0.88^a	1.04^a	1.47^b	1.62^b	0.85^a	0.95^a	1.13^b	1.40^c
NO_2-N outlet (mg L^{-1})	0.80^a	0.97^b	1.24^c	1.60^d	0.83^a	0.99^a	1.44^b	1.60^b	0.81^a	0.91^a	1.10^b	1.37^c
Removal per pass (mg L^{-1})	0.043^a	0.034^b	0.027^c	0.022^d	0.049^a	0.047^a	0.028^b	0.024^b	0.042^a	0.040^a	0.029^b	0.024^c
Vol. removal rate (g m^{-3} d^{-1})	119.81^a	96.11^b	76.36^c	61.88^d	136.40^a	130.87^a	77.41^b	68.20^b	116.41^a	112.05^a	81.49^b	66.94^c
Areal removal rate (mg m^{-2} d^{-1})	36.45^a	29.24^b	23.23^c	18.83^d	41.50^a	39.81^a	23.55^b	20.75^b	35.42^a	34.09^a	24.79^b	20.36^c
Removal efficiency (%)	5.10^a	3.40^b	2.16^c	1.38^d	5.56^a	4.27^a	1.37^b	1.06^b	5.10^a	3.40^a	2.16^b	1.74^c

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.6. Long period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_3-N inlet (mg L^{-1})	119.49^{a}	75.50^{b}	48.61^{c}	29.82^{d}	90.03^{a}	79.82^{a}	48.45^{b}	38.15^{b}	92.27^{a}	71.58^{a}	42.05^{b}	25.70^{c}
NO_3-N outlet (mg L^{-1})	119.90^{a}	75.73^{b}	48.78^{c}	29.96^{d}	90.42^{a}	80.14^{a}	48.63^{b}	38.31^{b}	92.67^{a}	71.95^{a}	42.27^{b}	25.84^{c}
Production per pass (mg L^{-1})	0.416^{a}	0.226^{b}	0.167^{c}	0.088^{d}	0.390^{a}	0.320^{a}	0.186^{b}	0.160^{b}	0.402^{a}	0.360^{a}	0.218^{b}	0.139^{c}
Vol. production rate (g m^{-3} d^{-1})	1,152^{a}	625.37^{b}	460.80^{c}	243.56^{d}	1,078.27^{a}	884.73^{a}	516.09^{b}	442.36^{b}	1,113.19^{a}	996.78^{a}	603.89^{b}	385.61^{c}
Areal prod. rate (mg m^{-2} d^{-1})	350.47^{a}	190.25^{b}	140.19^{c}	74.09^{d}	328.04^{a}	269.16^{a}	157.01^{b}	134.58^{b}	338.66^{a}	303.25^{a}	183.72^{b}	117.31^{c}
Production efficiency (%)	0.34^{a}	0.30^{a}	0.27^{a}	0.23^{a}	0.42^{a}	0.40^{a}	0.39^{a}	0.37^{a}	0.43^{a}	0.40^{a}	0.36^{a}	0.32^{a}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

3.1.2. Nitrification efficiency at 20^{o}C

During the experiment was conducted, water temperature was maintained at 19.8 - 20.3 ^{o}C. The pH values ranged between 6.80 and 7.76, and the dissolved oxygen was in the range of 7.7 - 8.6 mg L^{-1}.

Short period observation

During the short period (24 h) observation in the HP treatment, the TAN concentration in the control, 50, 100 and 150 ppm were 2.61, 5.05, 10.83 and 16.71 mg L^{-1}, respectively. The highest volumetric removal rate of TAN in the control was 245.76 g TAN m^{-3} d^{-1}, followed by 50, 100 and 150 ppm which were 215.04, 153.60 and 92.16 g TAN m^{-3} d^{-1}, respectively. In the treatment of Chl-T, the control, 10, 20 and 30 ppm treatment showed the volumetric removal rate of TAN were 261.12, 245.76, 168.06 and 153.60 g TAN m^{-3} d^{-1}, respectively. These removal abilities resulted TAN concentrations in the treatments which were 2.52, 2.88, 5.05 and 6.19 mg L^{-1}, respectively. Furthermore, in the treatment of Gcl, TAN concentration in the control, 10, 30 and 50 ppm were 2.43, 3.57, 7.44 and 12.2 mg L^{-1}, respectively. The volumetric removal rate of TAN in the control, 10, 30 and 50 ppm treatment were 261.12, 230.40, 184.32, 76.80 g TAN m^{-3} d^{-1}, respectively (Table 3.7).

Upon higher concentration of HP treatment, the concentration of NO_2-N was higher due to lower ability in the volumetric removal rate. The NO_2-N concentration in the control, 50, 100 and 150 ppm treatment were 0.76, 0, 89, 1.04 and 1.24 mg L^{-1}, respectively. In the Chl-T treatment, the control showed volumetric removal rate of 116.74 g NO_2-N m^{-3} d^{-1}, whereas the 10, 20 and 30 ppm were 113.66, 64.51 and 55.30 g NO_2-N m^{-3} d^{-1}, respectively. In the Gcl treatment, the 50 ppm resulted lower volumetric removal rate than other treatments and the control, where the rate was 43.01 g NO_2-N m^{-3} d^{-1}, while the values in the control, 10 and 30 ppm were 95.23, 89.09 and 55.30 g NO_2-N m^{-3} d^{-1}, respectively (Table 3.8).

Under the HP treatment, the NO_3-N concentration in the control, 50, 100 and 150 ppm were 6.64, 4.12, 2.72, and 2.25 mg L^{-1}, respectively and the volumetric removal rates were 1.059, 84, 614.4, 368.64 and 215.04 g NO_3-N m^{-3} d^{-1}, respectively. In the Chl-T treatment, the 30 ppm showed the lowest volumetric removal rate and concentration of NO_3-N, and then showed higher following by 20, 10 ppm and control. Furthermore, in the Gcl treatment, the NO_3-N concentration in the control, 10, 30, and 50 ppm treatment were 6.17, 5.61, 3.01 and 2.29 mg L^{-1}, respectively (Table 3.9).

Long period observation

Once the long period observation was carried out, in the treatment of HP, the control showed TAN concentration was 2.75 mg L^{-1} and there were increases in the 50, 100 and 150 ppm treatment which were 6.62, 12.39 and 19.67 mg L^{-1}, respectively. The stabilized period in the control, 50, 100 and 150 ppm were found at 8th, 14th, 17th and 22th day, respectively (Figure 3.4 and Table 3.10). At the beginning of the experiment, the concentration of NO_2-N in all systems was 0.76 mg L^{-1}. The fluctuation was found, the control showed the highest concentration of 1.22 mg L^{-1} at 6th day, whereas the 50 ppm was 1.63 mg L^{-1} at 11th day, the 100 ppm was 1.9 mg L^{-1} at 10th day, and the 150 ppm was 2.31 mg L^{-1} at 6th day. The NO_2-N concentrations in the control, 50, 100 and 150 ppm treatment were 0.87, 1.01, 1.25 and 1.50 mg L^{-1}, respectively (Figure 3.4 and Table 3.11). The NO_3-N concentrations in the control, 50, 100 and 150 ppm treatment were 117.70, 71.32, 44.53 and 27.42 mg L^{-1}, respectively. At the end of the experiment, the concentrations in each treatment were 193.25, 129.5, 110.5 and 57.5 mg L^{-1}, respectively (Figure 3.4 and Table 3.12).

In the Chl-T treatment, the concentration of TAN in all systems was 1.10 mg L^{-1} approximately. Then started to increase where the control showed highest TAN concentration of 8.6 mg L^{-1} at 5th day, the 10 ppm was 9.6 mg L^{-1} at 6th day, the 20 ppm was 17.5 mg L^{-1} at 5th day and the 30 ppm treatment was 19.7 mg L^{-1}

at 5th day (Figure 3.5. and Table 3.10). The NO_2-N concentration in the control, 10, 20 and 30 ppm treatment were 0.84, 0.94, 1.28, and 1.48 mg L^{-1}, respectively. The control showed the volumetric removal rate of NO_2-N of 110.59 g NO_2-N m^{-3} d^{-1} and the 10, 20 and 30 ppm treatment were 77.92, 67.86 and 51.53 g NO_2-N m^{-3} d^{-1}, respectively (Figure 3.5 and Table 3.11). At the beginning of the experiment, the NO_3-N concentration in all treatments was 1.9 mg L^{-1} approximately and then increased gradually. The volumetric production rate in the control, 10, 20 and 30 ppm treatment were 1,081.52, 943.28, 487.90 and 439.15 g of NO_3-N m^{-3} d^{-1}, respectively. At the end of the experiment, the NO_3-N concentrations were 162.5, 152.5, 103.755 and 96.75 mg L^{-1}, respectively (Figure 3.5 and Table 3.12).

In the treatment of Gcl, TAN concentration at the beginning of the experiment was about 1.1 mg L^{-1} in all treatments. In the control, the highest concentration was 12.1 mg L^{-1} which showed at 5th day. Furthermore, in the 10 ppm was 16.8 mg L^{-1} at 5th day, the 30 ppm was 24.2 mg L^{-1} at the 5th day and the 50 ppm treatment was 34.5 mg L^{-1} at the 6th day. Meanwhile, for the stabilized period, in the control, 10, 30 and 50 ppm treatment were found at 10th, 12th, 15th and 20th day, respectively (Figure 3.6 and Table 3.10). The NO_2-N concentration at the beginning of the experiment in all treatments was 0.78 mg L^{-1} approximately. The highest NO_2-N concentration in the control, 10, 30 and 50 ppm treatment were 1.22, 1.23, 1.45 and 1.87 mg L^{-1}, which occurred at 6th, 8th, 9th, and 11th day, respectively (Figure 3.6 and Table 3.11). The NO_3-N concentration in the control, 10, 20 and 30 ppm were 89.92, 74.77, 47.55, and 29.76 mg L^{-1}, respectively. At the end of the experiment, the concentrations were found in the control, 10, 20 and 30 ppm treatment were 171.5, 127.5, 110.5 and 69 mg L^{-1}, respectively (Figure 3.6 and Table 3.12).

Table 3.7. Short period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.61^{a}	5.05^{b}	10.83^{c}	16.71^{d}	2.52^{a}	2.88^{a}	5.05^{b}	6.19^{b}	2.43^{a}	3.57^{a}	7.44^{b}	12.20^{c}
TAN outlet (mg L^{-1})	2.52^{a}	4.97^{b}	10.78^{c}	16.68^{d}	2.42^{a}	2.80^{a}	4.98^{b}	6.13^{b}	2.35^{a}	3.48^{a}	7.37^{b}	12.17^{c}
Removal per pass (mg L^{-1})	0.088^{a}	0.072^{b}	0.055^{c}	0.033^{d}	0.094^{a}	0.088^{a}	0.061^{b}	0.055^{b}	0.094^{a}	0.083^{a}	0.057^{b}	0.027^{c}
Vol. removal rate (g m^{-3} d^{-1})	245.76^{a}	199.43^{b}	153.60^{c}	92.16^{d}	261.12^{a}	245.76^{a}	168.96^{b}	153.60^{b}	261.12^{a}	230.40^{a}	184.32^{b}	76.80^{c}
Areal removal rate (mg m^{-2} d^{-1})	74.77^{a}	60.75^{b}	46.73^{c}	28.04^{d}	79.44^{a}	74.77^{a}	51.40^{b}	46.73^{b}	79.44^{a}	70.09^{a}	56.08^{b}	27.36^{c}
Removal efficiency (%)	3.40^{a}	1.43^{b}	0.51^{c}	0.20^{d}	3.74^{a}	3.08^{a}	1.21^{b}	0.90^{b}	3.46^{a}	2.33^{a}	0.90^{b}	0.23^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.8. Short period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_2-N inlet (mg L^{-1})	0.76^a	0.89^b	1.04^c	1.24^d	0.85^a	0.87^a	1.14^b	1.23^b	0.80^a	0.79^a	1.01^b	1.15^c
NO_2-N outlet (mg L^{-1})	0.72^a	0.86^b	1.01^c	1.22^d	0.81^a	0.83^a	1.12^b	1.21^b	0.76^a	0.76^a	0.99^b	1.13^c
Removal per pass (mg L^{-1})	0.038^a	0.028^b	0.023^c	0.018^d	0.042^a	0.041^a	0.023^b	0.020^b	0.034^a	0.032^a	0.020^b	0.015^c
Vol. removal rate (g m^{-3} d^{-1})	107.52^a	79.87^b	64.51^c	52.22^d	116.74^a	113.66^a	64.51^b	55.30^b	95.23^a	89.09^a	55.30^b	43.01^c
Areal removal rate (mg m^{-2} d^{-1})	14.02^a	10.41^b	8.41^c	6.41^d	35.51^a	34.58^a	19.63^b	16.82^b	28.97^a	27.01^a	16.82^b	13.08^c
Removal efficiency (%)	5.10^a	3.22^b	2.24^c	1.52^d	4.94^a	4.70^a	2.04^b	1.62^b	5.44^a	4.86^a	2.13^b	1.80^c

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.9. Short period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	6.64^a	4.12^b	2.72^c	2.25^d	5.55^a	5.20^a	3.25^b	2.64^b	6.17^a	5.61^a	3.01^b	2.29^c
NO_3-N outlet (mg L^{-1})	7.02^a	4.34^b	2.85^c	2.33^d	5.92^a	5.50^a	3.42^b	2.77^b	6.50^a	5.90^a	3.17^b	2.40^c
Production per pass (mg L^{-1})	0.383^a	0.222^b	0.133^c	0.077^d	0.367^a	0.300^a	0.167^b	0.133^b	0.333^a	0.289^a	0.156^b	0.111^c
Vol. production rate (g m^{-3} d^{-1})	$1,059.84^a$	614.40^b	368.64^c	215.04^d	$1,013.76^a$	829.44^a	460.80^b	368.64^b	921.60^a	798.72^a	430.08^b	307.20^c
Areal prod. rate (mg m^{-2} d^{-1})	322.43^a	186.91^b	112.15^c	65.42^d	308.41^a	252.34^a	140.18^b	112.15^b	280.37^a	242.99^a	130.84^b	93.46^c
Production efficiency (%)	5.45^a	5.12^a	4.67^b	3.33^c	6.19^a	5.45^a	4.87^b	4.80^b	5.07^a	$4.89^{a,b}$	$4.74^{a,b}$	4.58^b

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

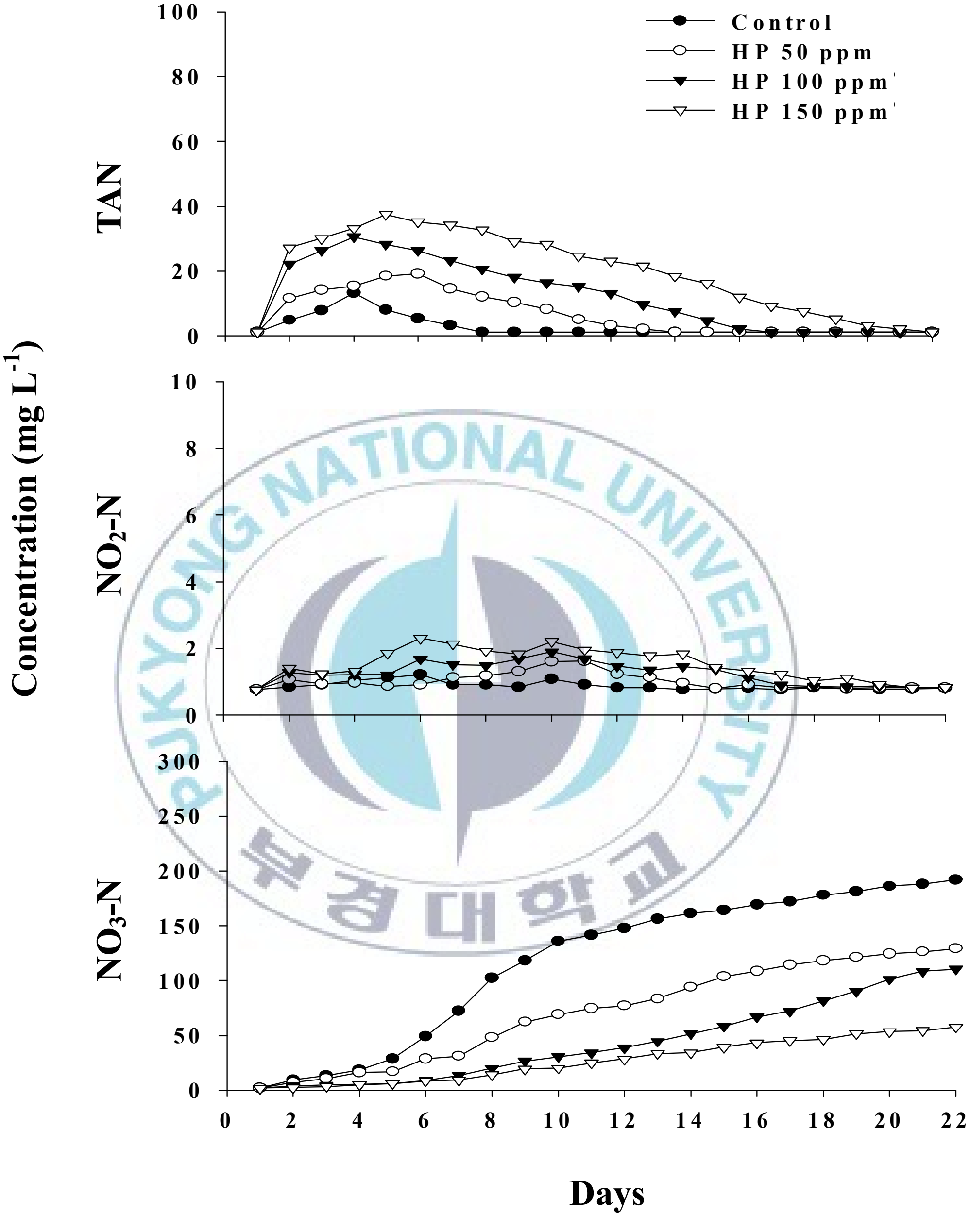

Fig. 3.4. Long period of nitrification rate of biofilter under hydrogen peroxide (HP) treatment at 20 °C in freshwater

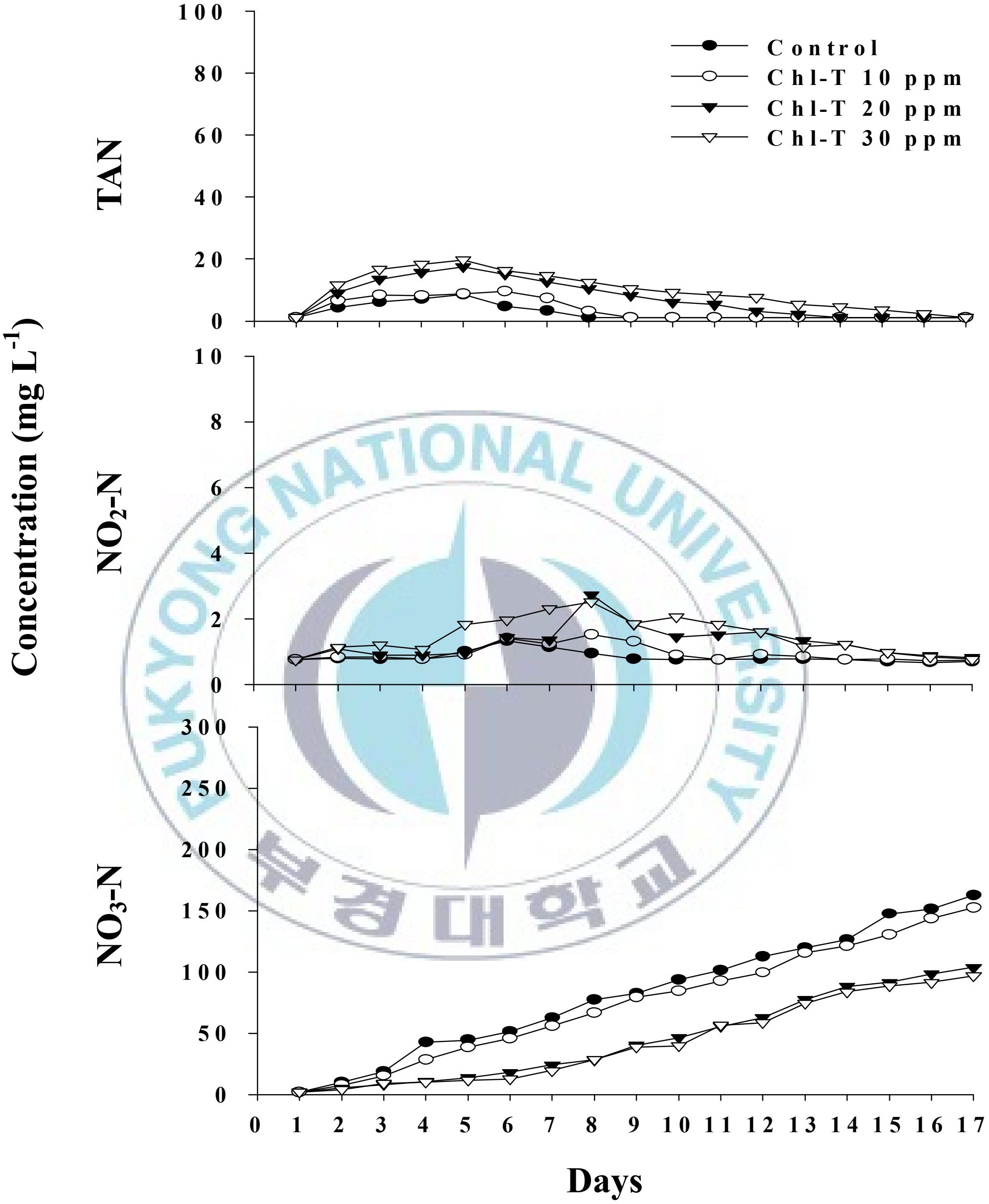

Fig. 3.5. Long period of nitrification rate of biofilter under chloramine-T (Chl-T) treatment at 20 °C in freshwater

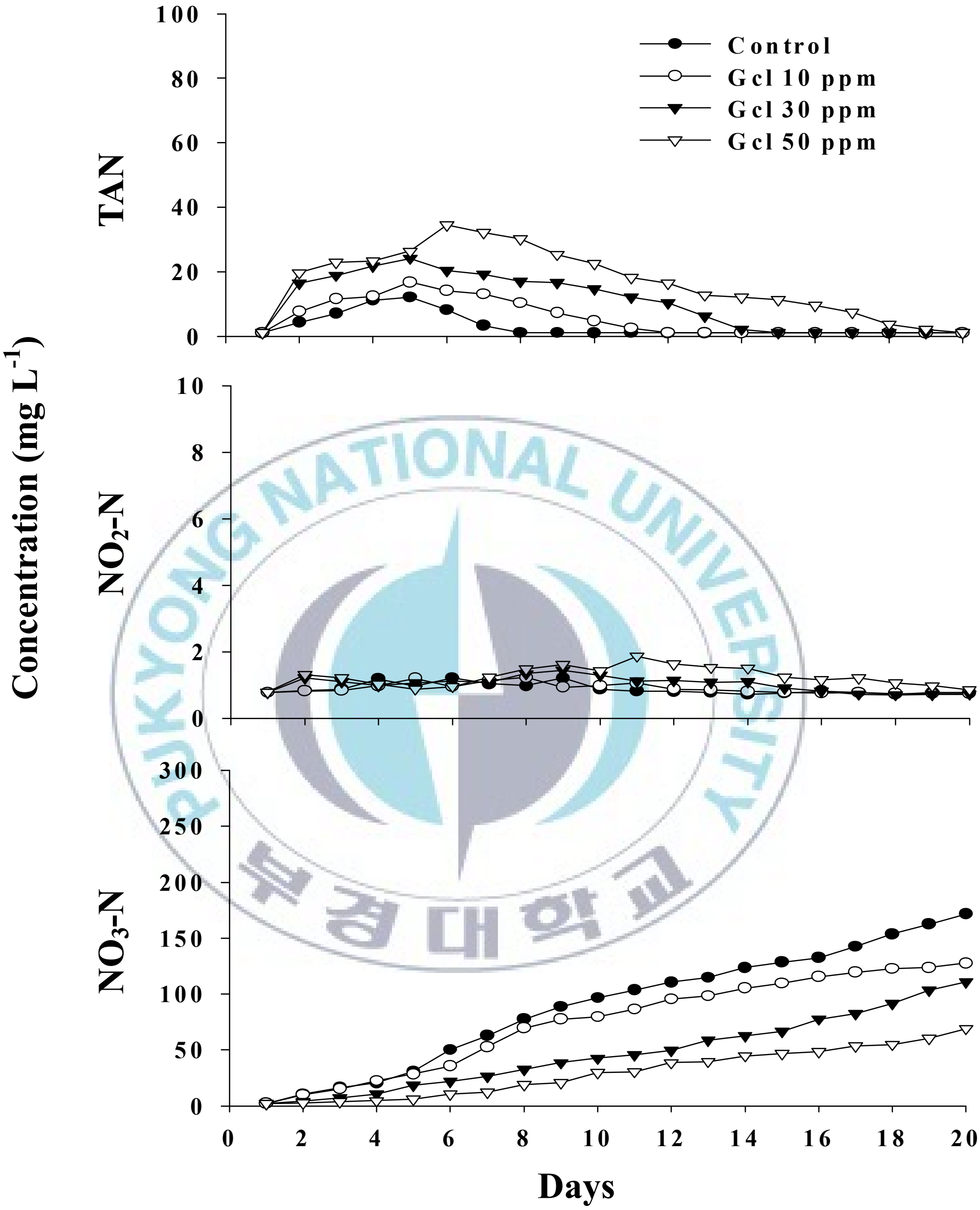

Fig. 3.6. Long period of nitrification rate of biofilter under guaiacol (Gcl) treatment at 20 °C in freshwater

Table 3.10. Long period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20^{o}C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.75^{a}	6.62^{b}	12.39^{c}	19.67^{d}	2.74^{a}	3.73^{a}	7.31^{b}	9.60^{b}	3.10^{a}	5.60^{a}	10.41^{b}	16.66^{c}
TAN outlet (mg L^{-1})	2.66^{a}	6.55^{b}	12.32^{c}	19.62^{d}	2.64^{a}	3.64^{a}	7.24^{b}	9.54^{b}	3.01^{a}	5.51^{a}	10.34^{b}	16.61^{c}
Removal per pass (mg L^{-1})	0.095^{a}	0.075^{b}	0.063^{c}	0.047^{d}	0.094^{a}	0.088^{a}	0.073^{b}	0.061^{b}	0.095^{a}	0.085^{a}	0.070^{b}	0.047^{c}
Vol. removal rate (g m^{-3} d^{-1})	263.91^{a}	207.36^{b}	175.94^{c}	131.96^{d}	260.22^{a}	243.95^{a}	203.29^{b}	170.77^{b}	238.78^{a}	213.64^{a}	175.94^{b}	119.39^{c}
Areal removal rate (mg m^{-2} d^{-1})	80.29^{a}	63.08^{b}	53.53^{c}	40.14^{d}	112.15^{a}	105.14^{a}	87.62^{b}	73.60^{b}	72.64^{a}	65.00^{a}	53.53^{b}	36.32^{c}
Removal efficiency (%)	3.47^{a}	1.13^{b}	0.51^{c}	0.24^{d}	3.43^{a}	2.37^{a}	1.01^{b}	0.64^{b}	3.06^{a}	1.51^{a}	0.67^{b}	0.28^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.11. Long period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.87^a	1.01^b	1.25^c	1.50^d	0.84^a	0.94^a	1.28^b	1.48^b	0.88^a	0.90^a	1.02^b	1.25^c
NO_2-N outlet (mg L^{-1})	0.83^a	0.98^b	1.22^c	1.48^d	0.79^a	0.90^a	1.26^b	1.46^b	0.84^a	0.86^a	1.00^b	1.23^c
Removal per pass (mg L^{-1})	0.040^a	0.038^b	0.024^c	0.018^d	0.044^a	0.042^a	0.024^b	0.022^b	0.038^a	0.036^a	0.024^b	0.018^c
Vol. removal rate (g m^{-3} d^{-1})	110.59^a	77.92^b	67.86^c	51.53^d	109.14^a	104.77^a	59.66^b	55.30^b	105.66^a	99.53^a	66.36^b	49.77^c
Areal removal rate (mg m^{-2} d^{-1})	33.65^a	23.70^b	20.65^c	15.68^d	33.20^a	31.87^a	18.15^b	16.82^b	31.96^a	30.28^a	20.19^b	15.14^c
Removal efficiency (%)	4.55^a	2.77^b	1.96^c	1.24^d	5.23^a	4.47^a	1.88^b	1.51^b	4.31^a	4.00^a	2.34^b	1.44^c

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.12. Long period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	117.70^a	71.32^b	44.53^c	27.42^d	82.72^a	75.22^a	45.57^b	42.72^b	89.92^a	74.77^a	47.57^b	29.76^c
NO_3-N outlet (mg L^{-1})	118.10^a	71.54^b	44.68^c	27.50^d	83.12^a	75.56^a	45.73^b	45.88^b	90.37^a	75.09^a	47.75^b	29.88^c
Production per pass (mg L^{-1})	0.388^a	0.222^b	0.152^c	0.084^d	0.391^a	0.341^a	0.176^b	0.158^b	0.387^a	0.320^a	0.205^b	0.117^c
Vol. production rate (g m^{-3} d^{-1})	1,074.50^a	615.79^b	421.00^c	232.49^d	1,081.52^a	943.28^a	487.90^b	439.15^b	1,071.36^a	884.74^a	566.78^b	324.86^c
Areal prod. rate (mg m^{-2} d^{-1})	326.89^a	187.34^b	128.08^c	70.73^d	329.03^a	286.97^a	148.43^b	133.59^b	325.94^a	269.16^a	172.43^b	98.83^c
Production efficiency (%)	0.33^a	0.30^a	0.28^a	0.25^a	0.48^a	0.45^a	0.39^a	0.37^a	0.43^a	0.42^a	0.40^a	0.38^a

Values in same treatment and same row with different letters are significantly different (*p*<0.05)

3.1.3. Nitrification efficiency at 15°C

During this experiment, water temperature was maintained at 14.8 - 15.1°C, and dissolved oxygen was maintained at 7.3 - 8.9 mg L^{-1} in all systems. The pH values reached the range between 6.90 and 7.80.

Short period observation

The short period observation of HP treatment showed that by increasing the concentration was able to decrease the volumetric removal rate of TAN. It was causing the differences of the mean of TAN concentrations in each treatment. The TAN concentration in the control, 50, 100 and 150 ppm treatment were 2.41, 4.65, 9.25 and 17.35 mg L^{-1}, respectively. Furthermore, in the treatment of Chl-T, the TAN concentration in the control, 10, 20 and 30 ppm treatment were 2.48, 3.18, 9.47 and 12.50 mg L^{-1}, respectively. Meanwhile in the Gcl treatment, the TAN concentration in the control, 10, 30 and 50 ppm treatment were 3.25, 4.37, 7.84 and 12.91 mg L^{-1}, respectively (Table 3.13).

Furthermore, the NO_2-N concentration of HP treatment in the control, 50, 100 and 150 ppm were 0.80, 0.90, 1.14 and 1.47 mg L^{-1}, respectively. Meanwhile, in the Chl-T treatment showed the NO_2-N concentration in the control, 10, 20 and 30 ppm were 0.81, 0.84, 1.00 and 1.11 mg L^{-1}, respectively. Then, in the Gcl treatment, showed the NO_2-N concentration in the control, 10, 30 and 50 ppm were 0.80, 0.81, 1.02 and 1.21 mg L^{-1}, respectively (Table 3.14).

In the HP treatment, the NO_3-N concentration in the control, 50, 100 and 150 ppm were 7.22, 4.57, 3.53 and 2.53 mg L^{-1}, respectively. While in the Chl-T treatment, the NO_3-N concentration in the control, 10, 20 and 30 ppm were 7.03, 6.11, 3.54 and 2.75 mg L^{-1}, respectively. Furthermore, in the Gcl treatment, the NO_3-N concentration in the control, 10, 30 and 50 ppm were 6.86, 5.65, 3.50 and 2.25 mg L^{-1}, respectively (Table 3.15).

Long period observation

In the long period observation of HP treatment showed TAN concentrations in the control, 50, 100 and 150 ppm were 2.95, 7.11, 11.47 and 19.36 mg L^{-1}, respectively. The highest concentrations were found in these treatments were 11.6, 20.7, 32.6 and 34.8 mg L^{-1}, respectively. At the end of experiment, the concentrations were 1.10 mg L^{-1} in all treatments (Figure 3.7 and Table 3.16). The highest NO_2-N concentration in the control, 50, 100 and 150 ppm were 1.21, 1.63, 1.91 and 2.88 mg L^{-1}, while the concentration means were 0.90, 1.08, 1.32 and 1.72 mg L-1, respectively (Figure 3.7 and Table 3.17). At the beginning of experiment, the NO_3-N concentrations in all treatments were 2.2 mg L^{-1} and then tend to increasing with the difference of increasing rate due to certain responses caused by chemotherapeutants. At the end of experiment, the NO_3-N concentration in the control, 50, 100 and 150 ppm treatment were 175.25, 138.25, 93.5 and 62.5 mg L^{-1}, respectively (Figure 3.7 and Table 3.18).

Upon Chl-T treatment, the TAN concentration in the control, 10 ppm, 20 and 30 ppm treatment were 2.77, 3.93, 7.57 and 11.52 mg L^{-1}, respectively. The stabilized period that occurred in these certain treatments were at 9th, 10th, 14th and 19th day, respectively (Figure 3.8 and Table 3.16). The highest NO_2-N concentration in the control, 10 ppm, 20 ppm and 30 ppm were 1.26, 1.28, 1.78 and 2.14 mg L^{-1}, respectively. Furthermore, the NO_2-N concentrations in these certain treatments were 0.92, 1.00, 1.27 and 1.42 mg L^{-1}, respectively (Figure 3.8 and Table 3.17). The NO_3-N concentration in the control, 10, 20 and 30 ppm treatment were 65.86, 59.83, 33.63 and 30.79 mg L^{-1}, respectively. At the end of experiment, the concentrations were 149.75, 130.75, 76.5 and 60.5 mg L-1, respectively (Figure 3.8 and Table 3.18)

In the treatment of Gcl, the highest TAN concentrations were found in the control, 10, 30 and 50 ppm treatment were 12.5, 17.7, 25.1 and 36.7 mg L^{-1}, respectively. Whereas, the TAN concentration in each treatments were 2.95, 5.09, 9.58 and 16.76 mg L^{-1}, respectively (Figure 3.9 and Table 3.16). At the beginning of experiment, the NO_2-N concentrations in all treatments were 0.73 mg L^{-1} and fluctuated during declining period until stabilized. The highest NO_2-N concentration in the control, 10, 30 and 50 ppm were 1.18, 1.12, 1.38 and 1.92 mg L^{-1}, respectively (Figure 3.9 and Table 3.17). In the Gcl treatment, the NO_3-N concentration in the control, 10, 30 and 50 ppm were 92.70, 73.04, 43.56 and 26.52 mg L^{-1}, respectively. Furthermore, at the end of experiment, the concentrations in each treatment were 171.5, 123.5, 110.5 and 68.5 mg L^{-1}, respectively (Figure 3.9 and Table 3.18).

3.1.4. Comparison of TAN concentration in freshwater

Upon short period observations, 10 ppm Chl-T showed lowest TAN concentrations among chemotherapeutants treatment at 25, 20 and 15°C of water temperature. The TAN concentrations at 25, 20 and 15°C were 2.75, 2.88 and 3.18 mg L^{-1}, respectively. Therefore, 150 ppm HP pointed highest TAN concentrations which were 16.11, 16.71 and 17.35 mg L^{-1}, respectively (Fig. 3.10).

In the long period observations, 150 ppm HP caused highest TAN concentrations among chemotherapeutants treatment at 25, 20 and 15°C of water temperature which were 16.64, 19.67 and 19.37 mg L^{-1}, respectively. In the other hand, 10 ppm Chl-T showed lowest TAN concentrations which were 3.29, 3.73 and 3.93 mg L^{-1}, respectively (Fig 3.11).

Table 3.13. Short period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.41^{a}	4.65^{b}	9.25^{c}	17.35^{d}	2.48^{a}	3.18^{a}	9.47^{b}	12.50^{b}	3.25^{a}	4.37^{a}	7.84^{b}	12.91^{c}
TAN outlet (mg L^{-1})	2.32^{a}	4.58^{b}	9.20^{c}	17.32^{d}	2.40^{a}	3.10^{a}	9.42^{b}	12.45^{b}	3.17^{a}	4.30^{a}	7.78^{b}	12.89^{c}
Removal per pass (mg L^{-1})	0.083^{a}	0.072^{b}	0.050^{c}	0.027^{d}	0.088^{a}	0.083^{a}	0.055^{b}	0.050^{b}	0.088^{a}	0.077^{a}	0.056^{b}	0.022^{c}
Vol. removal rate (g m^{-3} d^{-1})	230.40^{a}	199.68^{b}	138.24^{c}	76.80^{d}	245.76^{a}	230.40^{a}	153.60^{b}	138.24^{b}	245.75^{a}	215.64^{a}	153.60^{b}	61.44^{c}
Areal removal rate (mg m^{-2} d^{-1})	70.03^{a}	60.75^{b}	42.06^{c}	23.36^{d}	74.77^{a}	70.09^{a}	46.73^{b}	42.06^{b}	74.77^{a}	65.42^{a}	46.73^{b}	18.69^{c}
Removal efficiency (%)	3.46^{a}	1.55^{b}	0.54^{c}	0.16^{d}	3.57^{a}	2.61^{a}	0.59^{b}	0.40^{b}	2.70^{a}	1.76^{a}	0.70^{b}	0.17^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.14. Short period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15°C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.80^{a}	0.90^{b}	1.14^{c}	1.47^{d}	0.81^{a}	0.84^{a}	1.00^{b}	1.11^{b}	0.80^{a}	0.81^{a}	1.02^{b}	1.21^{b}
NO_2-N outlet (mg L^{-1})	0.76^{a}	0.86^{b}	1.11^{c}	1.45^{d}	0.77^{a}	0.80^{a}	0.98^{b}	1.09^{b}	0.77^{a}	0.78^{a}	1.00^{b}	1.20^{b}
Removal per pass (mg L^{-1})	0.037^{a}	0.036^{a}	0.022^{b}	0.010^{c}	0.042^{a}	0.040^{a}	0.023^{b}	0.019^{b}	0.032^{a}	0.030^{a}	0.017^{b}	0.012^{b}
Vol. removal rate (g m^{-3} d^{-1})	104.45^{a}	101.38^{a}	61.44^{b}	49.15^{c}	116.74^{a}	110.59^{a}	64.51^{b}	52.22^{b}	89.09^{a}	82.94^{a}	49.15^{b}	33.79^{b}
Areal removal rate (mg m^{-2} d^{-1})	13.62^{a}	13.22^{a}	8.01^{b}	6.41^{c}	35.51^{a}	33.65^{a}	19.63^{b}	15.89^{b}	27.10^{a}	25.23^{a}	14.95^{b}	10.28^{b}
Removal efficiency (%)	4.72^{a}	4.05^{a}	1.95^{b}	1.21^{b}	5.17^{a}	4.76^{a}	2.32^{b}	1.69^{b}	5.44^{a}	4.86^{a}	2.13^{b}	1.80^{b}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.15. Short period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15°C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_3-N inlet (mg L^{-1})	7.22^a	4.57^b	3.13^c	2.35^d	7.03^a	6.11^a	3.54^b	2.75^b	6.86^a	5.65^a	3.50^b	2.25^b
NO_3-N outlet (mg L^{-1})	7.58^a	4.78^b	3.25^c	2.42^d	7.36^a	6.38^a	3.70^b	2.87^b	7.19^a	5.91^a	3.64^b	2.34^b
Production per pass (mg L^{-1})	0.367^a	0.211^b	0.122^c	0.067^d	0.333^a	0.277^a	0.155^b	0.122^b	0.322^a	0.256^a	0.144^b	0.089^b
Vol. production rate (g m^{-3} d^{-1})	$1{,}013.76^a$	583.68^b	337.92^c	184.32^d	921.60^a	768.00^a	430.08^b	337.92^b	890.88^a	706.56^a	399.36^b	245.76^b
Areal prod. rate (mg m^{-2} d^{-1})	308.41^a	177.57^b	102.80^c	56.07^d	280.37^a	233.64^a	130.84^b	102.80^b	271.03^a	214.96^a	121.49^b	74.76^b
Production efficiency (%)	4.83^a	4.41^a	3.75^a	2.75^b	4.60^a	4.53^a	4.37^a	4.34^a	4.46^a	4.33^a	4.00^a	3.80^a

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

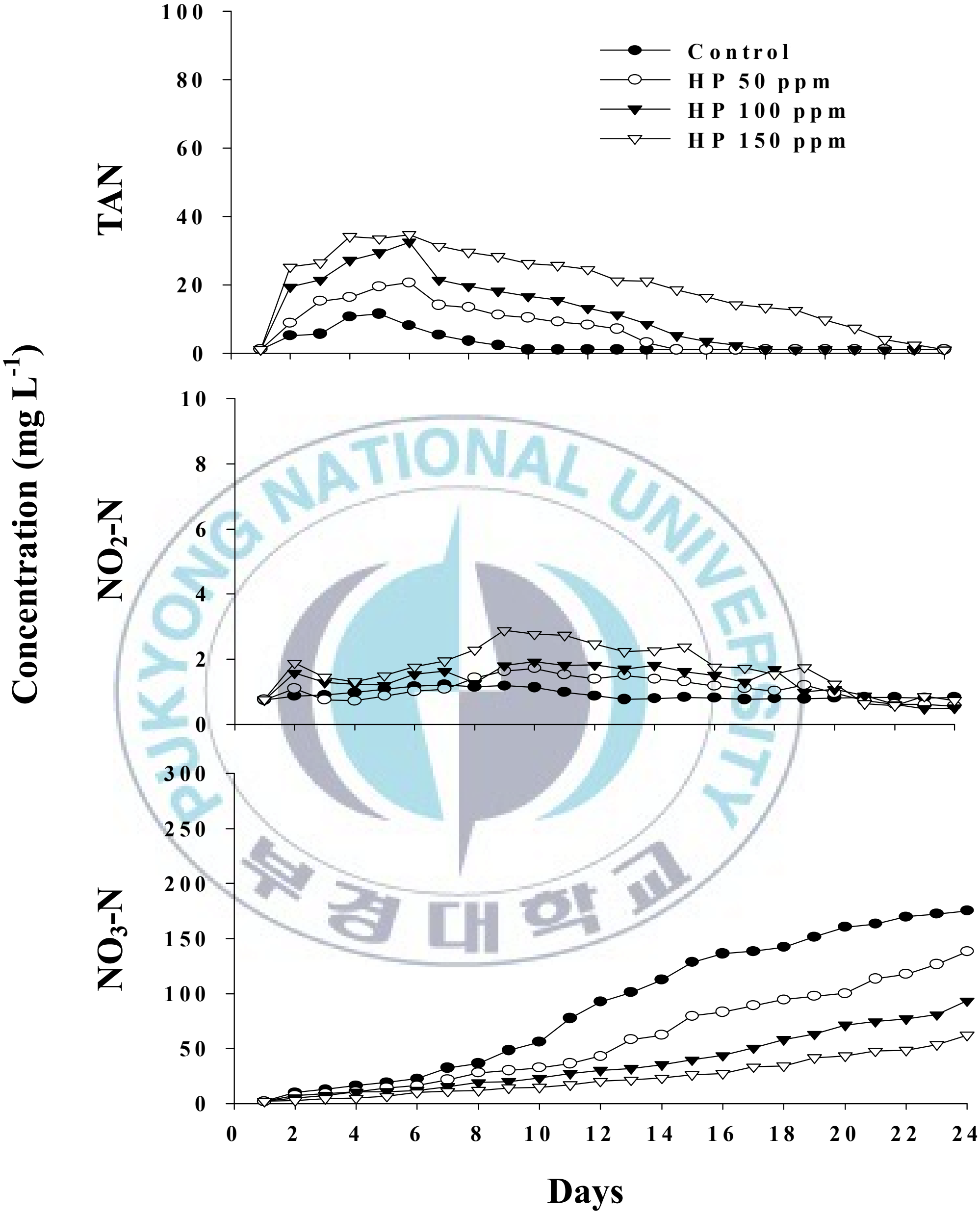

Fig. 3.7. Long period of nitrification rate of biofilter under hydrogen peroxide (HP) treatment at 15 °C in freshwater

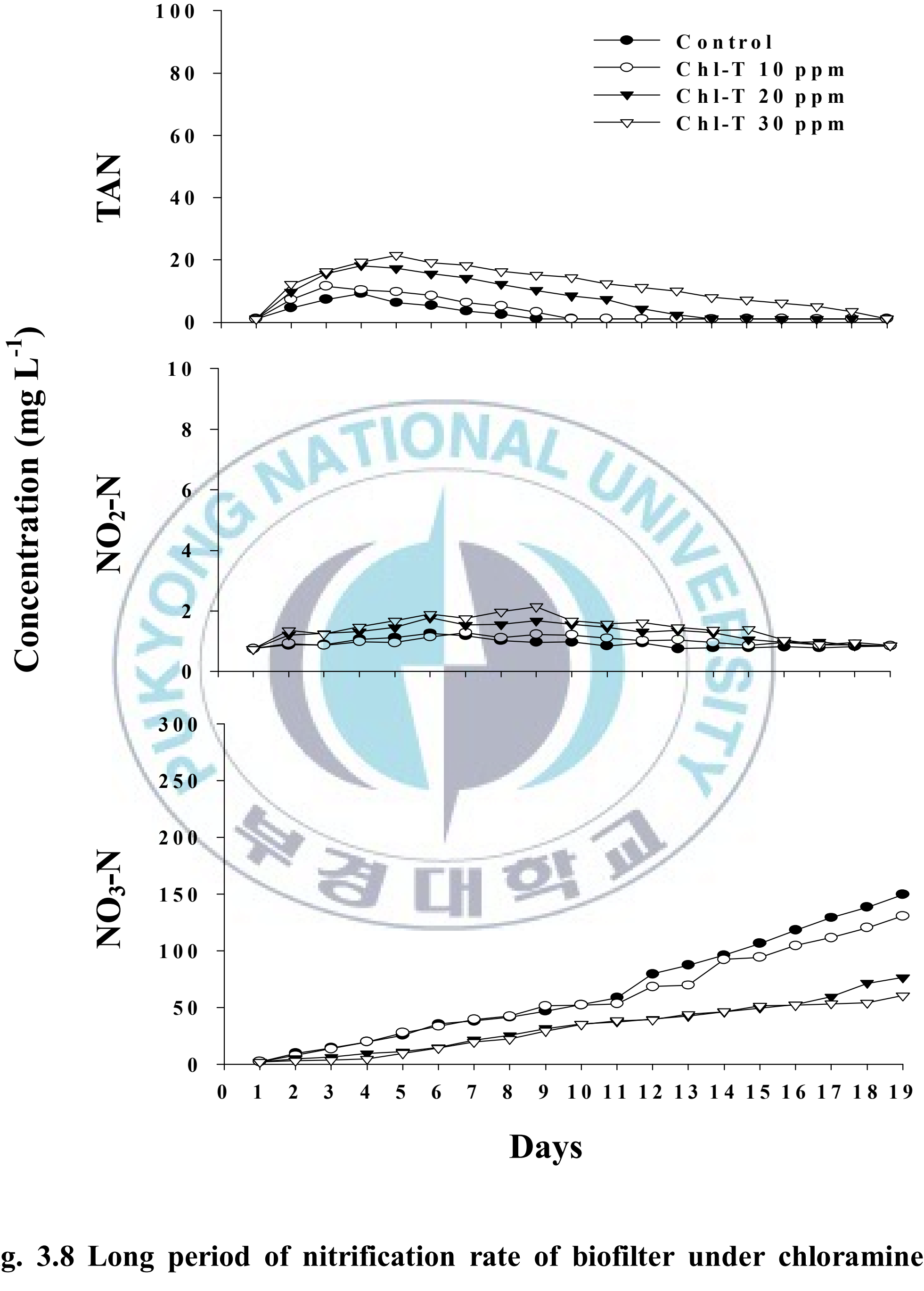

Fig. 3.8 Long period of nitrification rate of biofilter under chloramine-T (Chl-T) treatment at 15 °C in freshwater

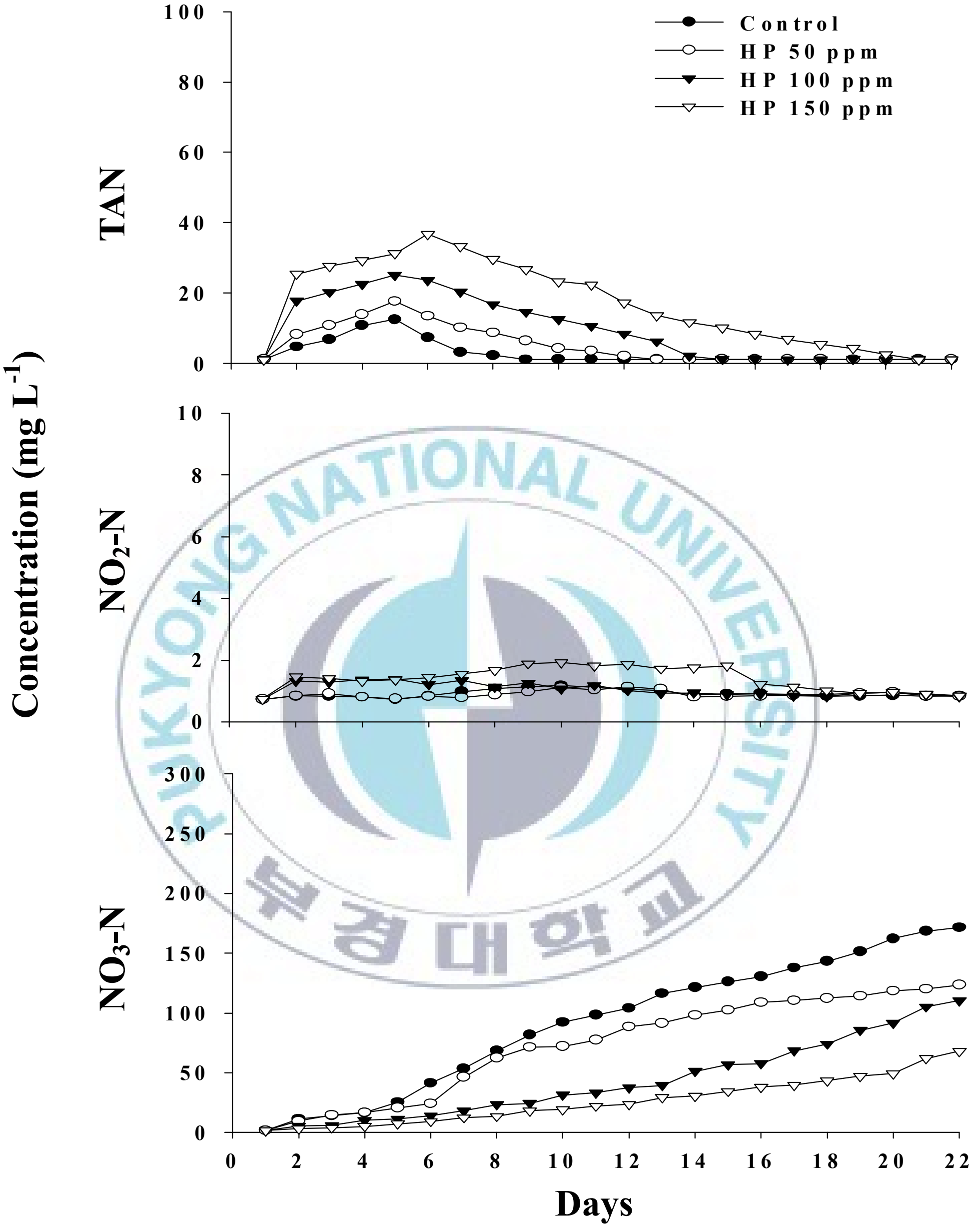

Fig. 3.9. Long period of nitrification rate of biofilter under guaiacol (Gcl) treatment at 15 °C in freshwater

Table 3.16. Long period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15^{o}C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.95^{a}	7.11^{b}	11.47^{c}	19.37^{d}	2.77^{a}	3.93^{a}	7.57^{b}	11.52^{b}	2.93^{a}	5.09^{a}	9.58^{b}	16.76^{c}
TAN outlet (mg L^{-1})	2.87^{a}	7.04^{b}	11.41^{c}	19.32^{d}	2.67^{a}	3.85^{a}	7.50^{b}	11.47^{b}	2.84^{a}	5.00^{a}	9.52^{b}	16.72^{c}
Removal per pass (mg L^{-1})	0.085^{a}	0.071^{b}	0.056^{c}	0.045^{d}	0.092^{a}	0.086^{a}	0.073^{b}	0.055^{b}	0.093^{a}	0.082^{a}	0.068^{b}	0.045^{c}
Vol. removal rate (g m^{-3} d^{-1})	236.16^{a}	195.84^{b}	155.52^{c}	126.72^{d}	254.65^{a}	240.13^{a}	258.05^{b}	193.54^{b}	257.63^{a}	226.21^{a}	188.51^{b}	125.67^{c}
Areal removal rate (mg m^{-2} d^{-1})	71.85^{a}	59.58^{b}	47.31^{c}	38.55^{d}	77.47^{a}	73.05^{a}	78.51^{b}	58.88^{b}	78.38^{a}	68.82^{a}	57.35^{b}	38.23^{c}
Removal efficiency (%)	2.89^{a}	1.00^{b}	0.49^{c}	0.24^{d}	3.32^{a}	2.21^{a}	0.97^{b}	0.48^{b}	3.17^{a}	1.60^{a}	0.63^{b}	0.23^{c}

Values in same treatment and same row with different letters are significantly different (p<0.05)

Table 3.17. Long period of NO$_2$-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15^{o}C in freshwater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO$_2$-N inlet (mg L^{-1})	0.90^a	1.08^b	1.32^c	1.72^d	0.92^a	1.00^a	1.27^b	1.42^b	0.91^a	0.89^a	1.05^b	1.39^c
NO$_2$-N outlet (mg L^{-1})	0.87^a	1.05^b	1.30^c	1.70^d	0.88^a	0.96^a	1.25^b	1.40^b	0.87^a	0.85^a	1.03^b	1.38^c
Removal per pass (mg L^{-1})	0.037^a	0.029^b	0.022^c	0.016^d	0.042^a	0.040^a	0.022^b	0.020^b	0.035^a	0.034^a	0.022^b	0.015^c
Vol. removal rate (g m^{-3} d^{-1})	104.83^a	81.79^b	63.36^c	46.08^d	116.41^a	110.59^a	62.57^b	55.30^b	96.77^a	94.25^a	62.84^b	43.99^c
Areal removal rate (mg m^{-2} d^{-1})	31.89^a	24.88^b	19.28^c	14.02^d	35.42^a	33.65^a	19.04^b	16.82^b	29.44^a	28.67^a	19.12^b	13.38^c
Removal efficiency (%)	4.17^a	2.72^b	1.73^c	0.97^d	4.56^a	3.99^a	1.78^b	1.40^b	3.84^a	3.82^a	2.09^b	1.07^c

Values in same treatment and same row with different letters are significantly different (*p*<0.05)

Table 3.18. Long period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 15°C in freshwater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	90.82^a	58.09^b	37.82^c	24.48^d	65.86^a	59.84^a	33.63^b	30.79^b	92.70^a	73.04^a	43.56^b	26.52^c
NO_3-N outlet (mg L^{-1})	91.17^a	59.21^b	37.96^c	24.57^d	66.22^a	60.16^a	33.80^b	30.95^b	93.05^a	73.35^a	43.73^b	26.64^c
Production per pass (mg L^{-1})	0.350^a	0.214^b	0.139^c	0.093^d	0.365^a	0.321^a	0.168^b	0.157^b	0.347^a	0.306^a	0.165^b	0.111^c
Vol. production rate (g m^{-3} d^{-1})	967.68^a	593.28^b	385.92^c	259.20^d	$1{,}011.33^a$	887.64^a	465.65^b	436.54^b	961.39^a	848.29^a	458.70^b	307.89^c
Areal prod. rate (mg m^{-2} d^{-1})	294.39^a	180.49^b	117.40^c	78.85^d	307.67^a	270.04^a	141.66^b	110.67^b	292.48^a	258.07^a	139.55^b	93.67^c
Production efficiency (%)	0.38^a	0.36^b	0.34^c	0.32^d	0.55^a	0.53^a	0.50^b	0.49^b	0.42^a	0.41^a	0.37^b	0.33^c

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

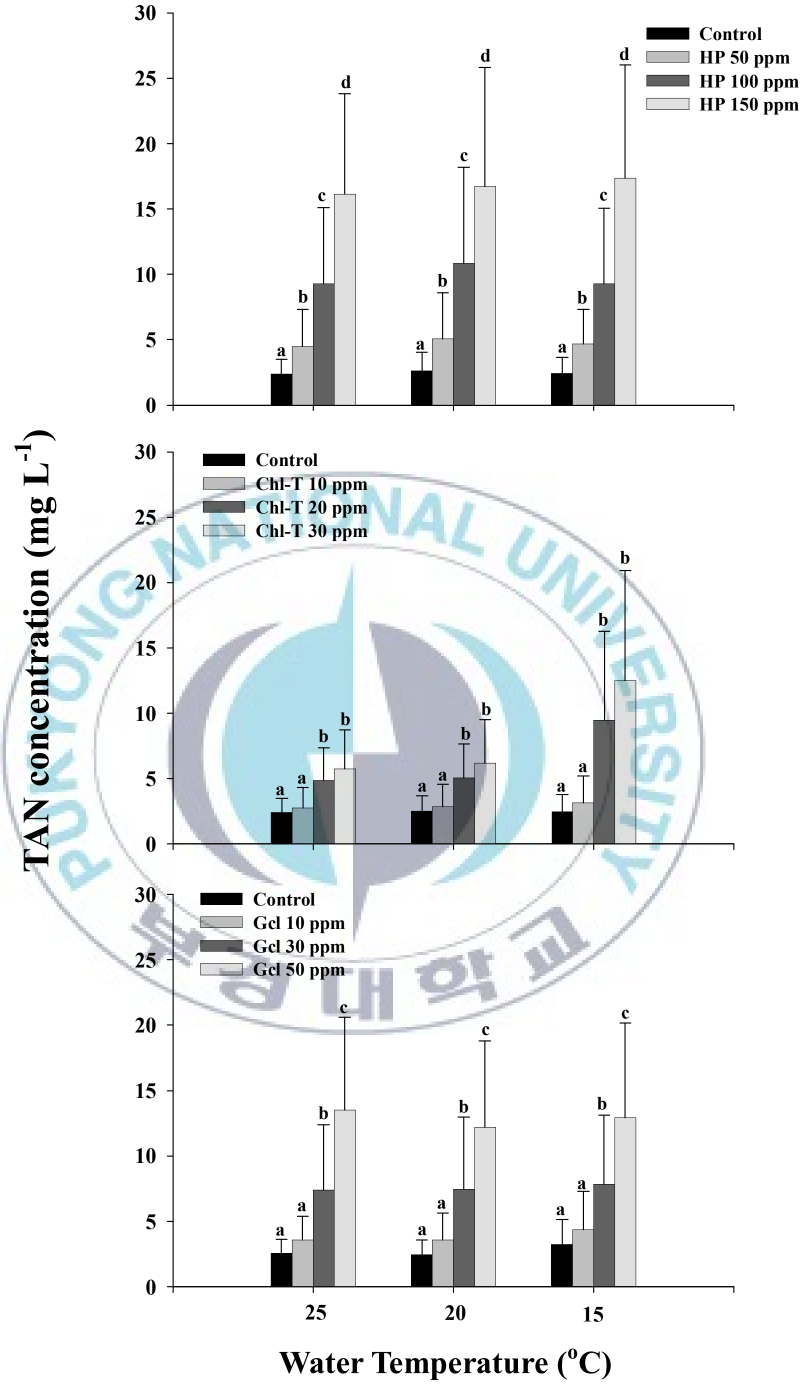

Fig. 3.10. TAN concentration in the short period observation at 25, 20 and 15°C of water temperature in freshwater

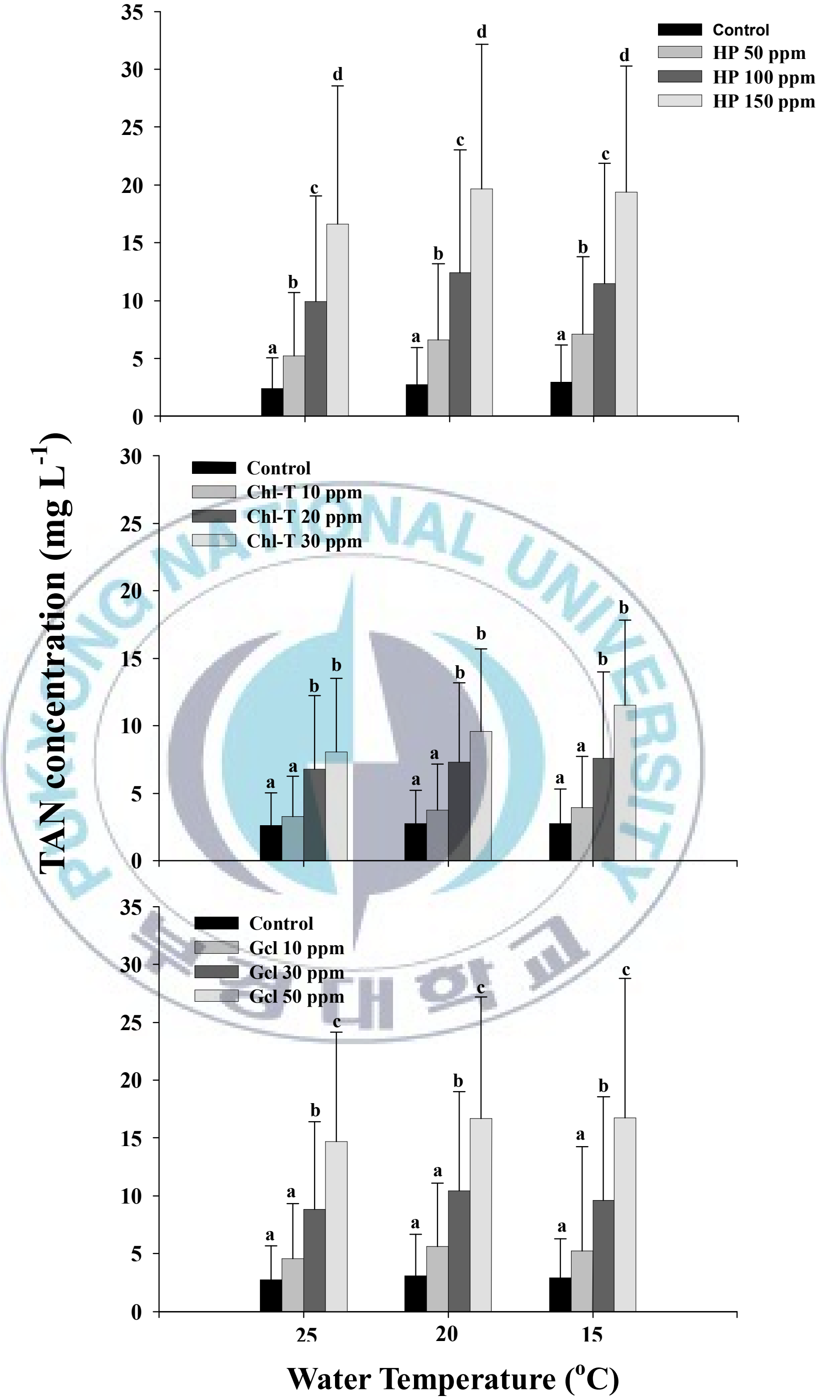

Fig. 3.11. TAN concentration in the long period observation at 25, 20 and 15°C of freshwater water temperature in freshwater

3.2. Nitrification efficiency in seawater

3.2.1. Nitrification efficiency at 25°C

Water temperature was maintained at 24.7 - 25.2°C, and dissolved oxygen was maintained at 7.1 - 8.8 mg L^{-1}. The pH values reached in the range between 7.20 and 8.26 and the salinity was maintained at 32-34 psu.

Short period observation

In short period observation of HP treatment, TAN concentration in the control, 50 ppm, 100 and 150 ppm treatment were 2.60 5.43, 11.52, 21.59 mg L^{-1}, respectively. At the end of observation, the TAN concentration in the control, 50, 100 and 150 ppm treatment were 4.81, 11.82, 22.36 and 37.62 mg L^{-1}, respectively. These differences caused by higher HP concentration delivered lower volumetric removal rate. During observation, the control showed the volumetric removal rate of 236.54 g TAN m^{-3} d^{-1}, while 50, 100 and 150 ppm treatment were 172.03, 119.81 and 61.44 g TAN m^{-3} d^{-1}, respectively. Furthermore, in the treatment of Chl-T, the TAN concentration in the control, 10, 20 and 30 ppm treatment were 2.90, 3.22, 6.20 and 6.90 mg L^{-1}, respectively. The volumetric removal rate achieved by the control, 10, 20 and 30 ppm treatment were 221.18, 208.90, 159.74, 132.10 g TAN m^{-3} d^{-1}, respectively. In the Gcl treatment, the TAN concentration in the control, 10 ppm, 30 and 50 ppm were 2.76, 3.61, 8.28 and 15.39 mg L^{-1}, respectively. These concentrations produced by the volumetric removal rates in the control, 10, 30, and 50 ppm which were 236.54, 215.04, 135.17, 76.80 g TAN m^{-3} d^{-1}, respectively (Table 3.19).

At the end of observation, NO$_2$-N concentration of HP treatment in the control, 50, 100 and 150 ppm were 0.46, 0.61, 0.94, 1.26 mg L^{-1}, respectively. This similar trend followed caused by higher concentration of HP produced lower NO$_2$-N volumetric removal rate. The volumetric removal rates in the control, 50, 100 and 150 ppm treatment were 95.23, 73.33, 55.30 and 39.40 g

TAN m^{-3} d^{-1}, respectively. Upon the Chl-T treatment, volumetric removal rate of NO_2-N in the control, 10, 20 and 30 ppm were 110.59, 101.38, 58.37 and 52.22 g NO_2-N m^{-3} d^{-1}, respectively. The NO_2-N concentrations in these treatments were 0, 65, 0.64, 0.93 and 0.95 mg L^{-1}, respectively. Furthermore, in the Gcl treatment, the volumetric removal rate were found in the control, 10, 30 and 50 ppm were 76.80, 64.51, 46.08 and 36.86 g NO_2-N m^{-3} d^{-1}, respectively (Table 3.20).

NO_3-N concentrations of HP treatment in the control, 50, 100 and 150 ppm were 6.15, 3.72, 2.35 and 1.80 mg L^{-1}, respectively. The volumetric production rates were 936.96, 583.68, 353.28 and 168.96 g of NO_3-N m^{-3} d^{-1}, respectively. In the Chl-T treatment, the NO_3-N volumetric production rate in the control, 10, 20 and 30 ppm were 890.88, 798.72, 430.08, and 368.64 g NO_3-N m^{-3} d^{-1}, respectively. These rates resulted NO_3-N concentrations in each treatment were 5.41, 5.2, 2.72, and 2.51 mg L^{-1}, respectively. In the Gcl treatment, the NO_3-N volumetric production rates in the control, 10, 30 and 50 ppm were 952.32, 737.28, 430.08, and 307.20 g of NO_3-N m^{-3} d^{-1} and caused the NO_3-N concentration in each treatment were 6.37, 4.78, 2.93 and 2.27 mg L^{-1}, respectively (Table 3.21).

Long period observation

Upon long period observation of HP treatment, TAN concentration in the control, 50, 100 and 150 ppm treatment were 3.83, 7.66, 14.59 and 24.27 mg L^{-1}, respectively. In the control, the highest concentration was 15.83 mg L^{-1}, whereas in the 50, 100 and 150 ppm were 24.34, 39.61 and 51.83 mg L^{-1} occurred at 5th, 5th, 6th and 5th day, respectively. Furthermore, stabilized period in the control, 50, 100 and 150 ppm treatment were found at 10th, 14th, 17th and 24th day, respectively (Figure 3.12 and Table 3.22). The NO_2-N concentration in the control, 50, 100 and 150 ppm treatment were 0.47, 0.63, 0.87 and 1.05 mg L^{-1}, respectively. The highest NO_2-N concentration in the control was 0.78 mg L^{-1}, and in the 50, 100 and 150 ppm treatment were 0.78, 0.92, 1.21 and 1.34 mg L^{-1}, respectively (Figure 3.12 and Table 3.23). The concentration of NO_3-N in all treatments at the first day was 1.2 mg L^{-1}, and increased along with the nitrification process. At the end of experiment, NO_3-N concentration in the control, 50, 100 and 150 ppm treatment were 177.5, 115.5, 85.5 and 57.5 mg L^{-1}, respectively (Figure 3.12 and Table 3.24).

In the long period observation of Chl-T treatment, the highest TAN concentration in the control was 11.26 mg L^{-1}, followed by 10, 20 and 30 ppm treatment which were 12.81, 18.51, and 22.15 mg L^{-1}, respectively. Furthermore, the stabilized period were found in the control, 10, 20 and 30 ppm treatment were at 11th, 12th, 15th and 17th day, respectively (Figure 3.13 and Table 3.22). The highest NO_2-N concentrations in the control, 10, 20 and 30 ppm treatment were 0.77, 0.94, 1.21 and 1.44 mg L^{-1} which occurred at 6th, 8th, 9th, and 6th day, respectively. The NO_2-N concentrations in each treatment were 0.48, 061, 0.81 and 1.02 mg L^{-1}, respectively (Figure 3.13 and Table 3.23). At the first day of experiment, the concentration of NO_3-N in all treatments was 1.3 mg L^{-1}, and increased as the result of nitrification process. The NO_3-N concentration in the 10, 20 and 30 ppm treatment were 78.74, 67.27, 42.14 and 36.11 mg L^{-1}, respectively. At the end of experiment, these concentrations were 141.75, 131.25, 88.5 and 77.75, respectively (Figure 3.13 and Table 3.24).

In the Gcl treatment, the highest TAN concentration in the control, 10, 30 and 50 ppm treatment were 16.14, 18.31, 28.45, 36.25 mg L^{-1}, respectively, and stabilized period were at 10th, 12th, 17th and 22th day, respectively (Figure 3.14 and Table 3.22). The NO_2-N concentration at the beginning of experiment in all treatments was 0.24 mg L-1 and subsequently fluctuated increase. The NO_2-N concentrations in the control, 10, 30 and 50 ppm treatment were 0.58, 0.64, 0.79 and 0.96 mg L-1, respectively. At the end of the experiment, these concentrations were 0.42, 0.46, 0.41 and 0.48 mg L^{-1}, respectively (Figure 3.14 and Table 3.23). At the beginning of the experiment, the NO_3-N concentrations in the control, 10, 30 and 50 ppm treatment was 2.1 mg L^{-1}. Furthermore, after running of treatment, these concentrations increased with various levels. At the end of the experiment, the concentration in the control, 10, 30 and 50 ppm treatment were 175.5, 168.25, 123.5 and 82.25 mg L^{-1}, respectively (Figure 3.14 and Table 3.24).

Table 3.19. Short period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25^{o}C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
TAN inlet (mg L^{-1})	2.60^{a}	5.43^{b}	11.52^{c}	21.59^{d}	2.90^{a}	3.22^{a}	6.20^{b}	6.90^{b}	2.76^{a}	3.61^{a}	8.28^{b}	15.39^{c}
TAN outlet (mg L^{-1})	2.52^{a}	5.37^{b}	11.47^{c}	21.57^{d}	2.82^{a}	3.14^{a}	6.14^{b}	6.85^{b}	2.67^{a}	3.53^{a}	8.23^{b}	15.36^{c}
Removal per pass (mg L^{-1})	0.085^{a}	0.062^{b}	0.043^{c}	0.022^{d}	0.080^{a}	0.075^{a}	0.057^{b}	0.047^{b}	0.085^{a}	0.077^{a}	0.048^{b}	0.027^{c}
Vol. removal rate (g m^{-3} d^{-1})	236.54^{a}	172.03^{b}	119.81^{c}	61.44^{d}	221.18^{a}	208.90^{a}	159.74^{b}	132.10^{b}	236.54^{a}	215.04^{a}	135.17^{b}	76.80^{c}
Areal removal rate (mg m^{-2} d^{-1})	71.96^{a}	52.34^{b}	36.45^{c}	18.69^{d}	67.29^{a}	63.55^{a}	48.60^{b}	40.19^{b}	71.96^{a}	65.42^{a}	41.12^{b}	23.36^{c}
Removal efficiency (%)	3.27^{a}	1.14^{b}	0.37^{c}	0.10^{d}	2.75^{a}	2.32^{a}	0.91^{b}	0.68^{b}	3.07^{a}	2.18^{a}	0.57^{b}	0.17^{c}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.20. Short period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_2-N inlet (mg L^{-1})	0.39^a	0.49^b	0.67^c	0.97^d	0.65^a	0.64^a	0.93^b	0.95^b	0.47^a	0.51^a	0.75^b	1.05^b
NO_2-N outlet (mg L^{-1})	0.35^a	0.46^b	0.65^c	0.96^d	0.61^a	0.61^a	0.91^b	0.93^b	0.44^a	0.49^a	0.73^b	1.04^b
Removal per pass (mg L^{-1})	0.034^a	0.036^b	0.020^c	0.014^d	0.040^a	0.036^a	0.021^b	0.018^b	0.027^a	0.023^a	0.016^b	0.013^b
Vol. removal rate (g m^{-3} d^{-1})	95.23^a	73.73^b	55.30^c	39.94^d	110.59^a	101.38^a	58.37^b	52.22^b	76.80^a	64.51^a	46.08^b	38.86^b
Areal removal rate (mg m^{-2} d^{-1})	12.42^a	9.61^b	7.21^c	5.21^d	33.65^a	30.84^a	17.76^b	15.89^b	23.76^a	19.63^a	14.02^b	11.22^b
Removal efficiency (%)	8.71^a	5.28^b	2.94^c	1.43^c	6.15^a	5.55^a	2.25^b	1.97^b	5.74^a	4.47^a	2.13^b	1.25^b

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.21. Short period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	6.15^a	3.72^b	2.35^c	1.80^d	5.41^a	5.20^a	2.72^b	2.51^b	6.37^a	4.78^a	2.93^b	2.27^c
NO_3-N outlet (mg L^{-1})	6.49^a	3.93^b	2.48^c	1.86^d	5.73^a	5.48^a	2.87^b	2.64^b	6.72^a	5.06^a	3.08^b	2.37^c
Production per pass (mg L^{-1})	0.338^a	0.211^b	0.127^c	0.061^d	0.322^a	0.288^a	0.155^b	0.133^b	0.344^a	0.267^a	0.156^b	0.111^c
Vol. production rate (g m^{-3} d^{-1})	936.96^a	583.68^b	353.28^c	168.96^d	890.88^a	798.72^a	430.08^b	368.64^b	952.32^a	737.28^a	430.08^b	307.20^c
Areal prod. rate (mg m^{-2} d^{-1})	285.05^a	177.57^b	107.47^c	51.40^d	271.03^a	242.99^a	130.84^b	112.15^b	289.72^a	224.30^a	130.84^b	93.45^c
Production efficiency (%)	5.23^a	5.12^a	4.83^a	3.22^a	5.58^a	5.53^a	5.40^a	5.17^a	5.11^a	4.94^a	4.87^a	4.66^a

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

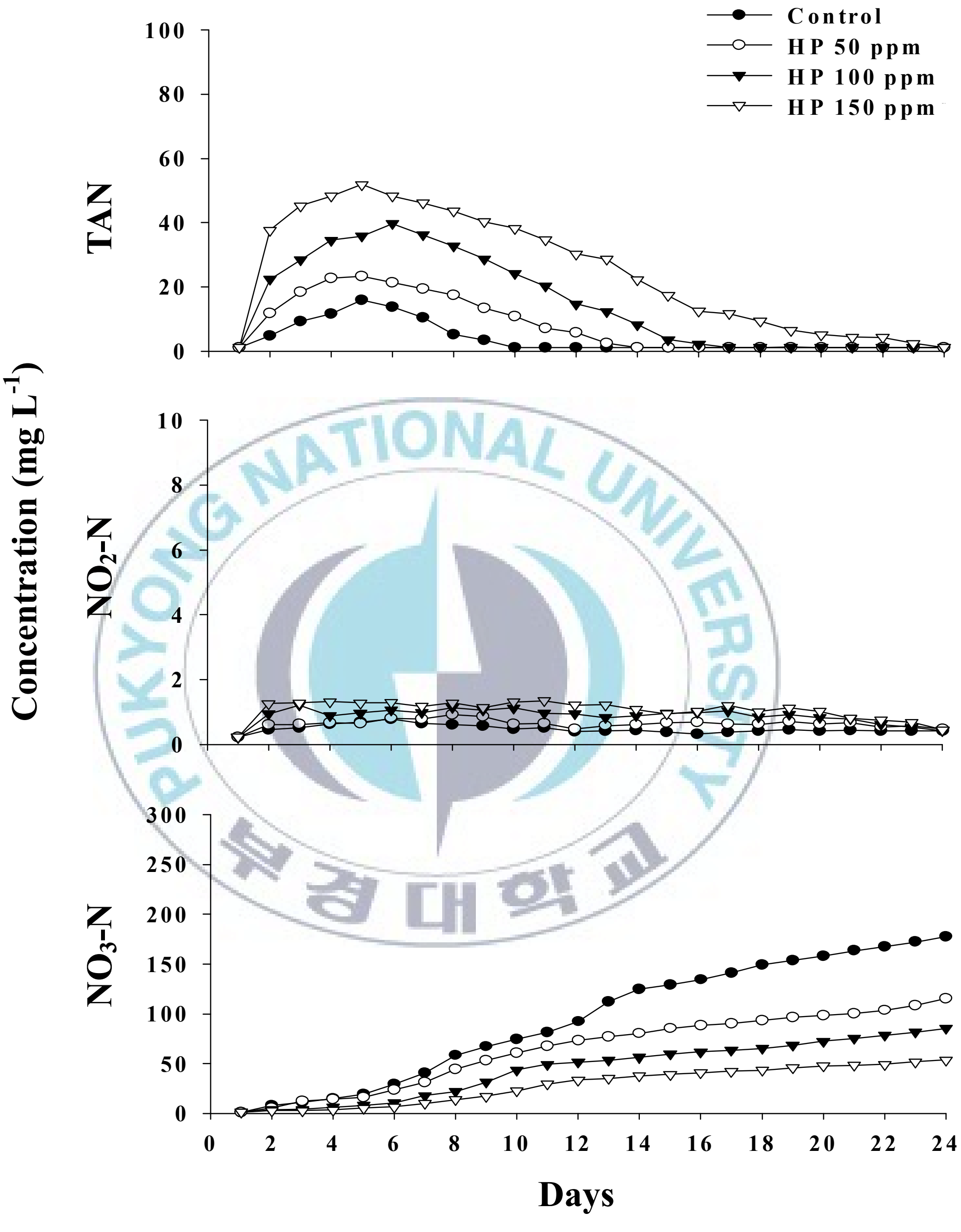

Fig. 3.12. Long period of nitrification rate of biofilter under hydrogen peroxide (HP) treatment at 25 °C in seawater

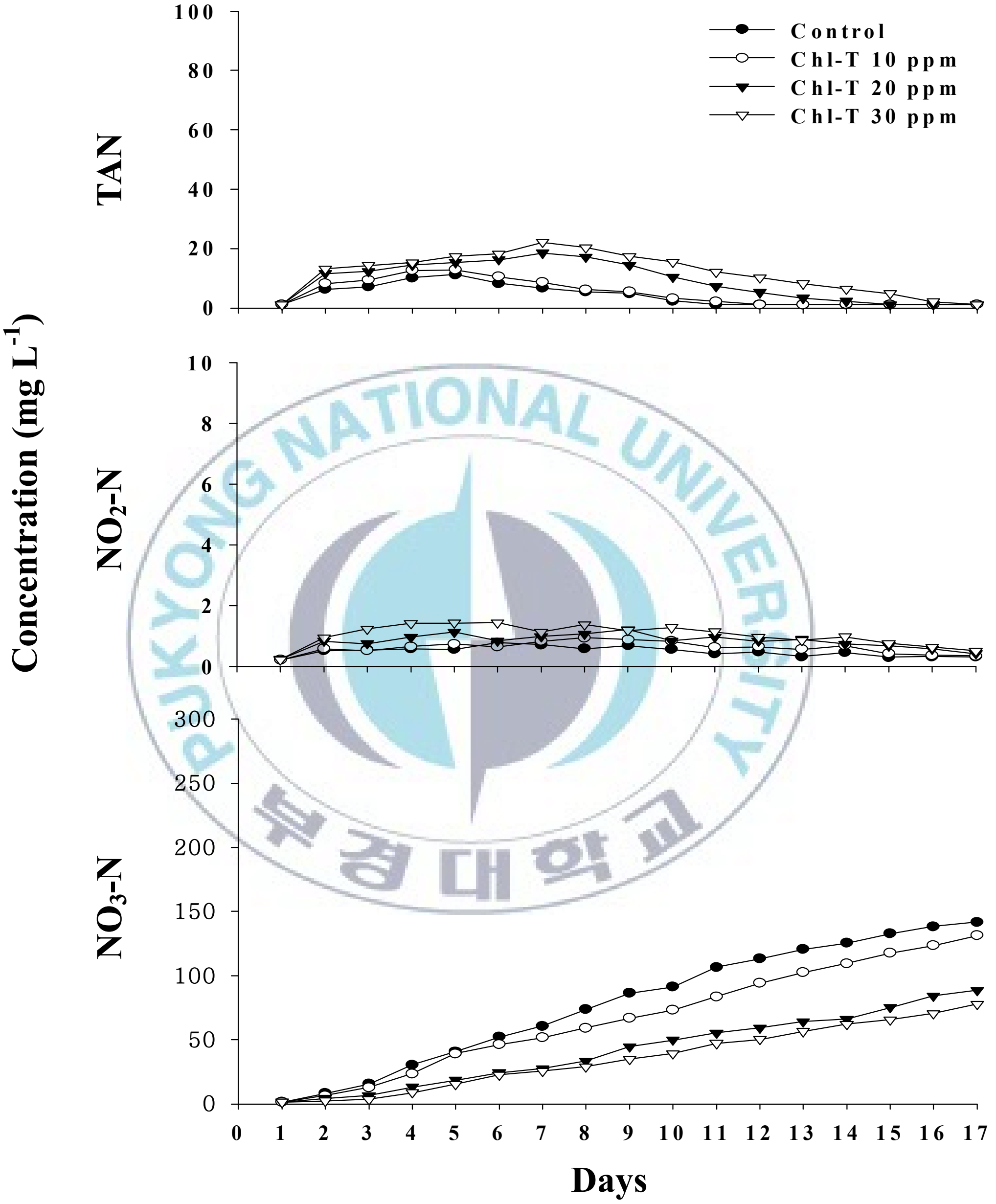

Fig. 3.13. Long period of nitrification rate of biofilter under Chloramine-T (Chl-T) treatment at 25 °C in seawater

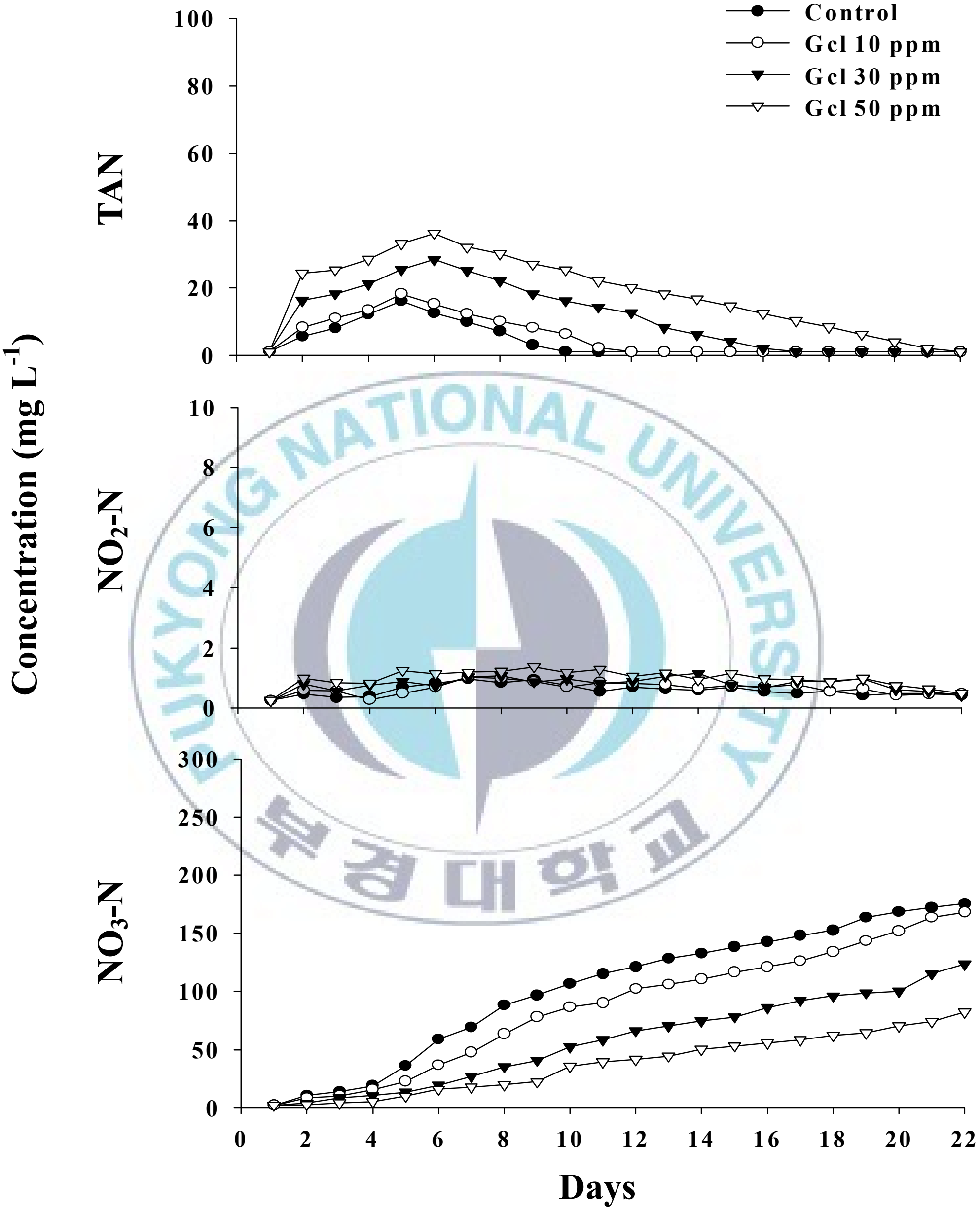

Fig. 3.14. Long period of nitrification rate of biofilter under Guaiacol (Gcl) treatment at 25 °C in seawater

Table 3.22. Long period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25^{o}C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	3.83^{a}	7.66^{b}	14.59^{c}	24.27^{d}	4.19^{a}	5.10^{a}	8.97^{b}	11.73^{b}	4.12^{a}	5.42^{a}	11.24^{b}	18.22^{c}
TAN outlet (mg L^{-1})	3.75^{a}	7.74^{b}	14.68^{c}	24.55^{d}	4.11^{a}	5.03^{a}	8.90^{b}	11.67^{b}	4.04^{a}	5.34^{a}	11.19^{b}	18.18^{c}
Removal per pass (mg L^{-1})	0.085^{a}	0.065^{b}	0.047^{c}	0.037^{d}	0.080^{a}	0.076^{a}	0.066^{b}	0.061^{b}	0.085^{a}	0.078^{a}	0.054^{b}	0.035^{c}
Vol. removal rate (g m^{-3} d^{-1})	237.31^{a}	180.86^{b}	132.48^{c}	102.53^{d}	222.81^{a}	211.43^{a}	183.78^{b}	169.14^{b}	235.01^{a}	216.16^{a}	149.55^{b}	96.77^{c}
Areal removal rate (mg m^{-2} d^{-1})	72.20^{a}	55.02^{b}	40.30^{c}	31.19^{d}	67.79^{a}	64.32^{a}	55.91^{b}	51.46^{b}	71.50^{a}	65.76^{a}	45.50^{b}	29.44^{c}
Removal efficiency (%)	2.26^{a}	0.84^{b}	0.32^{c}	0.15^{d}	1.90^{a}	1.48^{a}	0.73^{b}	0.52^{b}	2.05^{a}	1.43^{a}	0.48^{b}	0.19^{c}

Values in same treatment and same row with different letters are significantly different (*p*<0.05)

Table 3.23. Long period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in seawater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.47^{a}	0.63^{b}	0.87^{c}	1.05^{d}	0.48^{a}	0.61^{a}	0.81^{b}	1.02^{b}	0.58^{a}	0.64^{a}	0.79^{b}	0.96^{b}
NO_2-N outlet (mg L^{-1})	0.44^{a}	0.60^{b}	0.85^{c}	1.04^{d}	0.45^{a}	0.58^{a}	0.79^{b}	1.00^{b}	0.55^{a}	0.61^{a}	0.76^{b}	0.94^{b}
Removal per pass (mg L^{-1})	0.034^{a}	0.028^{b}	0.022^{c}	0.017^{d}	0.034^{a}	0.031^{a}	0.023^{b}	0.022^{b}	0.032^{a}	0.029^{a}	0.023^{b}	0.019^{b}
Vol. removal rate (g m^{-3} d^{-1})	94.46^{a}	79.49^{b}	63.36^{c}	48.38^{d}	94.33^{a}	86.20^{a}	65.05^{b}	61.80^{b}	89.23^{a}	80.43^{a}	65.35^{b}	54.04^{b}
Areal removal rate (mg m^{-2} d^{-1})	28.74^{a}	24.18^{b}	19.28^{c}	14.72^{d}	28.70^{a}	26.22^{a}	19.79^{b}	18.80^{b}	27.15^{a}	24.47^{a}	19.88^{b}	16.44^{b}
Removal efficiency (%)	7.17^{a}	4.40^{b}	2.50^{c}	1.65^{c}	6.96^{a}	5.06^{a}	2.81^{b}	2.15^{b}	5.50^{a}	4.51^{a}	2.91^{b}	1.97^{b}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.24. Long period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 25°C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	95.08^a	64.26^b	44.61^c	28.44^d	78.74^a	67.27^a	42.14^b	36.11^b	102.80^a	86.72^a	57.86^b	37.75^c
NO_3-N outlet (mg L^{-1})	95.47^a	64.47^b	44.74^c	28.53^d	79.07^a	67.54^a	42.30^b	36.17^b	103.13^a	87.01^a	58.03^b	37.87^c
Production per pass (mg L^{-1})	0.387^a	0.210^b	0.147^c	0.083^d	0.323^a	0.270^a	0.164^b	0.138^b	0.327^a	0.293^a	0.168^b	0.115^c
Vol. production rate (g m^{-3} d^{-1})	$1,071.36^a$	581.76^b	408.96^c	230.40^d	894.49^a	748.12^a	455.37^b	382.19^b	904.84^a	810.58^a	464.98^b	320.46^c
Areal prod. rate (mg m^{-2} d^{-1})	325.93^a	176.98^b	124.41^c	70.09^d	272.13^a	227.60^a	138.53^b	116.27^b	275.28^a	246.60^a	141.46^b	97.49^c
Production efficiency (%)	0.40^a	0.33^a	0.32^a	0.29^a	0.41^a	0.40^a	0.37^a	0.36^a	0.33^a	0.31^a	0.30^a	0.29^a

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

3.2.2. Nitrification efficiency at 20^{o}C of water temperature

During this experiment, water temperature and dissolved oxygen were maintained at 19.8 - 20.3^{o}C and 7.5 - 8.6 mg L^{-1} in all systems, respectively. The pH values reached in the range between 7.31 and 8.36 and the salinity was in the range at 32-34 psu.

Short period observation

In short period observation of HP treatment, TAN concentrations in the control, 50, 100 and 150 ppm were 2.83, 5.76, 12.25 and 22.19 mg L^{-1}, respectively. The trend caused by differences of volumetric removal rates, which were 211.97, 162.82, 110.59 and 58.37 g TAN m^{-3} d^{-1}, respectively. Meanwhile, in Chl-T treatment, in the control, 10, 20, and 30 ppm showed the TAN concentrations were 3.16, 3.57, 6.58 and 7.59 mg L^{-1}, respectively. This each of treatments showed volumetric removal rates of 205.82, 199.68, 144.38 and 122.88 g TAN m^{-3} d^{-1}, respectively. Furthermore, in the Gcl treatment, the TAN concentration in the control, 10, 30 and 50 ppm were 2.86, 3.79, 8.63, 15.97 mg L^{-1} caused by the volumetric removal rates which were 202.75, 190.46, 132.10 and 70.66 g TAN m^{-3} d^{-1}, respectively (Table 3.25).

In the HP treatment, NO_2-N concentrations in the control, 50, 100 and 150 ppm were 0.43, 0.54, 0.72 and 1.08 mg L^{-1}, respectively. Then these each treatment showed volumetric removal rate which were 86.02, 64.51, 49.65 and 33.79 g NO_2-N m^{-3} d^{-1}, respectively. Furthermore, in the Chl-T treatment, the NO_2-N concentration in the control, 10, 20 and 30 ppm were 0.68, 0.66, 1.02 and 1.05 mg L^{-1}, respectively. The control, 10, 20 and 30 ppm treatment showed volumetric removal rates of 87.55, 79.87, 56.83, 50.69 g NO_2-N m^{-3} d^{-1}, respectively. Furthermore, in the treatment of Gcl, the mean of NO_2-N concentration in the control, 10, 20 and 30 ppm were 0.50, 0.56, 0.78 and 1.08 mg L^{-1} which caused by certain volumetric removal rate among those treatments. In the control, the volumetric removal rate was 70.66 g NO_2-N m^{-3} d^{-1} whereas in the 10, 20 and 30 ppm were 58.37, 39.94 and 30.72 g NO_2-N m^{-3} d^{-1}, respectively (Table 3.26).

The NO_3-N concentration in the control, 50, 100, and 150 ppm while treated by HP were 5.80, 3.52, 2.21 and 1.62 mg L^{-1}, respectively. Then the volumetric production rates in each treatment were 829.44, 491.52, 276.48 and 153.60 g NO_3-N m^{-3} d^{-1}, respectively. In the Chl-T treatment, the NO_3-N concentration in the control, 10, 20 and 30 ppm were 5.10, 4.80, 2.51 and 2.05 mg L^{-1}, respectively. Furthermore, for the volumetric removal rates were 768, 706.56, 384 and 322.56 g NO_3-N m^{-3} d^{-1}, respectively. In the Gcl treatment, in the control, 10, 30 and 50 ppm showed the NO_3-N concentrations which were 5.51, 4.62, 2.62 and 1.94 mg L^{-1}, respectively. Then for the volumetric production rates were found at 829.44, 691.20, 399.36 and 261.12 g NO_3-N m^{-3} d^{-1}, respectively (Table 3.27).

Long period observation

In the long period observation of HP treatment, the TAN concentration at the beginning of experiment in all treatments was 1.18 mg L^{-1}. Then started to increase in any stages, where the highest concentration occurred in the control was 17.15 mg L^{-1}, meanwhile in the 50, 100 and 150 ppm treatment were 25.64, 41.46 and 53.31 mg L^{-1}, respectively. Furthermore, the stabilized period occurred in the control, 50, 100 and 150 ppm treatment were at 11th, 16th, 19th, and 25th day, respectively (Figure 3.15 and Table 3.28). The NO_2-N concentration in the control, 50, 100 and 150 ppm treatment were 0.55, 0.70, 0.94, 1.13 mg L^{-1}, respectively. Then the highest concentrations in each treatment were 0.91, 1.01, 1.34 and 1.46 mg L^{-1}, respectively. Volumetric removal rates achieved by the control, 50, 100 and 150 ppm were 87.37, 74.10, 55.30 and 48.43 g NO_2-N m^{-3} d^{-1} (Figure 3.15 and Table 3.29). Furthermore, NO_3-N concentration in the control, 50, 100 and 150 ppm treatment were 94.49, 63, 59, 43.81and 27.72 mg L^{-1}, respectively. The volumetric production rate of

NO_3-N in the control, 50, 100 and 150 were 1,006.39, 575.07, 381.54 and 215.65 g NO_3-N m^{-3} d^{-1}. At the end of experiment, the NO3-N concentrations in each of these treatments were 175.75, 112.25, 84.25 and 57.25 mg L^{-1}, respectively (Figure 3.15 and Table 3.30).

The TAN concentration of Chl-T treatment at the beginning of long period observation was 1.14 mg L^{-1} and then started to increase at certain level until returned to stabilize. The highest concentration in the control, 10, 20 and 30 ppm treatment were 13.57, 16.47, 23.17 and 25.56 mg L^{-1}, respectively and then the stabilized period were at 11th, 12th, 17th and 18th day, respectively (Figure 3.16 and Table 3.28). NO_2-N concentration at the beginning of experiment was 0.25 mg L^{-1} and continuously fluctuated until stabilized. At the end of experiment, in the control, 10, 20 and 30 ppm treatment reached the concentration at 0.47, 0.45, 0.44 and 0.44 mg L^{-1}, respectively. The concentrations mean in each treatment were 0.60, 0.66, 0.93 and 1.13 mg L^{-1}, respectively (Figure 3.16 and Table 3.29). Furthermore, NO_3-N concentration in the control, 10, 20 and 30 ppm treatment were 75.61, 64.53, 40.83 and 35.25 mg L^{-1}, respectively. At the end of experiment, each treatment showed the concentration at 140.25, 126.25, 90.25 and 87.75 mg L^{-1}, respectively (Figure 3.16 and Table 3.30).

In the Gcl treatment, TAN concentration in the control, 10, 30 and 50 ppm were 4.43, 5.74, 11.68 and 18.31 mg L^{-1}, respectively. These treatments showed stabilized period at 11th, 13th, 18th and 24th day, respectively (Figure 3.17 and Table 3.28). The NO_2-N concentration in the control, 10, 30 and 50 ppm were 0.58, 0.68, 0.82 and 0.99 mg L^{-1} and the highest concentration achieved by each treatments were 1.00, 1.08, 1.22 and 1.43 mg L^{-1}, respectively (Figure 3.17 and Table 3.29). Furthermore, NO_3-N concentration in the control, 10, 30 and 50 ppm treatment were 98.12, 83.42, 54.53 and 35.90 mg L^{-1}, respectively. The highest concentration achieved at the end of experiment by control, 10, 30 and 50 ppm treatment were 204.25, 162.25, 118.25 and 75.5 mg L^{-1}, respectively (Figure 3.17 and Table 3.30).

3.2.3. Comparison of TAN concentration in seawater

In the short period observations, 10 ppm Chl-T produced lowest TAN concentrations at 25 and 20°C of water temperature among chemotherapeutants treatment were 3.22 and 3.57 mg L^{-1}, respectively. The 150 ppm HP showed highest TAN concentrations were 21.59 and 22.19 mg L^{-1}, respectively (Fig. 3.18.).

Upon long period observations, among chemotherapeutants treatment the highest TAN concentration at 25 and 20°C were 24.27 and 26.3 mg L^{-1} which occurred in 150 ppm HP treatment. Furthermore, the lowest TAN concentrations were 5.1 and 6 mg L^{-1} which produced by 10 ppm Chl-T treatments (Fig. 3.19.).

Table 3.25. Short period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20^{o}C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	2.83^a	5.76^b	12.25^c	22.19^d	3.16^a	3.57^a	6.58^b	7.59^b	2.86^a	3.79^a	8.63^b	15.97^c
TAN outlet (mg L^{-1})	2.76^a	5.70^b	12.21^c	22.17^d	3.09^a	3.50^a	6.52^b	7.54^b	2.79^a	3.73^a	8.58^b	15.94^c
Removal per pass (mg L^{-1})	0.076^a	0.058^b	0.040^c	0.021^d	0.074^a	0.072^a	0.052^b	0.044^b	0.073^a	0.068^a	0.047^b	0.025^c
Vol. removal rate (g m^{-3} d^{-1})	211.97^a	162.82^b	110.59^c	58.37^d	205.82^a	199.68^a	144.38^b	122.88^b	202.75^a	190.46^a	132.10^b	70.66^c
Areal removal rate (mg m^{-2} d^{-1})	64.49^a	49.53^b	33.65^c	17.76^d	62.62^a	60.75^a	43.93^b	37.38^b	61.68^a	57.94^a	40.19^b	21.50^c
Removal efficiency (%)	2.68^a	1.00^b	0.32^c	0.09^d	2.34^a	2.01^a	0.79^b	0.58^b	2.55^a	1.79^a	0.54^b	0.15^c

Values in same treatment and same row with different letters are significantly different (p<0.05)

Table 3.26. Short period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20^{o}C in seawater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.43^{a}	0.54^{b}	0.72^{c}	1.08^{d}	0.68^{a}	0.66^{a}	1.02^{b}	1.05^{b}	0.50^{a}	0.56^{a}	0.78^{b}	1.08^{c}
NO_2-N outlet (mg L^{-1})	0.40^{a}	0.52^{b}	0.70^{c}	1.07^{d}	0.64^{a}	0.63^{a}	1.00^{b}	1.03^{b}	0.47^{a}	0.54^{a}	0.76^{b}	1.07^{c}
Removal per pass (mg L^{-1})	0.031^{a}	0.023^{b}	0.017^{c}	0.012^{d}	0.035^{a}	0.033^{a}	0.018^{b}	0.016^{b}	0.025^{a}	0.021^{a}	0.014^{b}	0.011^{c}
Vol. removal rate (g m^{-3} d^{-1})	86.02^{a}	64.51^{b}	49.15^{c}	33.79^{d}	98.30^{a}	92.16^{a}	52.22^{b}	46.08^{b}	70.66^{a}	58.37^{a}	39.94^{b}	30.72^{c}
Areal removal rate (mg m^{-2} d^{-1})	11.22^{a}	8.41^{b}	6.41^{c}	4.41^{d}	29.91^{a}	28.04^{a}	15.89^{b}	14.02^{b}	21.50^{a}	17.76^{a}	12.15^{b}	9.35^{c}
Removal efficiency (%)	7.75^{a}	4.41^{b}	$2.52^{b,c}$	1.12^{c}	5.11^{a}	4.96^{a}	1.76^{b}	1.59^{b}	5.00^{a}	$3.71^{a,b}$	$1.78^{b,c}$	$1.01^{b,c}$

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

Table 3.27. Short period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	50 ppm	100 ppm	150 ppm	control	10 ppm	20 ppm	30 ppm	control	10 ppm	30 ppm	50 ppm
NO_3-N inlet (mg L^{-1})	5.80^a	3.52^b	2.21^c	1.62^d	5.10^a	4.80^a	2.51^b	2.05^b	5.51^a	4.62^a	2.62^b	1.94^b
NO_3-N outlet (mg L^{-1})	6.10^a	3.70^b	2.31^c	1.67^d	5.37^a	5.05^a	2.65^b	2.17^b	5.81^a	4.87^a	2.76^b	2.04^b
Production per pass (mg L^{-1})	0.300^a	0.177^b	0.100^c	0.055^d	0.277^a	0.255^a	0.138^b	0.116^b	0.300^a	0.250^a	0.144^b	0.094^b
Vol. production rate (g m^{-3} d^{-1})	829.44^a	491.52^b	276.48^c	153.60^d	768.00^a	706.56^a	384.00^b	322.56^b	829.44^a	691.20^a	399.36^b	261.12^b
Areal prod. rate (mg m^{-2} d^{-1})	252.33^a	149.53^b	84.11^c	46.73^d	233.64^a	214.95^a	116.82^b	98.13^b	252.33^a	210.28^a	121.49^b	79.44^b
Production efficiency (%)	5.17^a	5.02^a	4.52^a	3.43^a	5.58^a	5.53^a	5.40^a	5.17^a	5.16^a	5.13^a	5.07^a	4.61^a

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

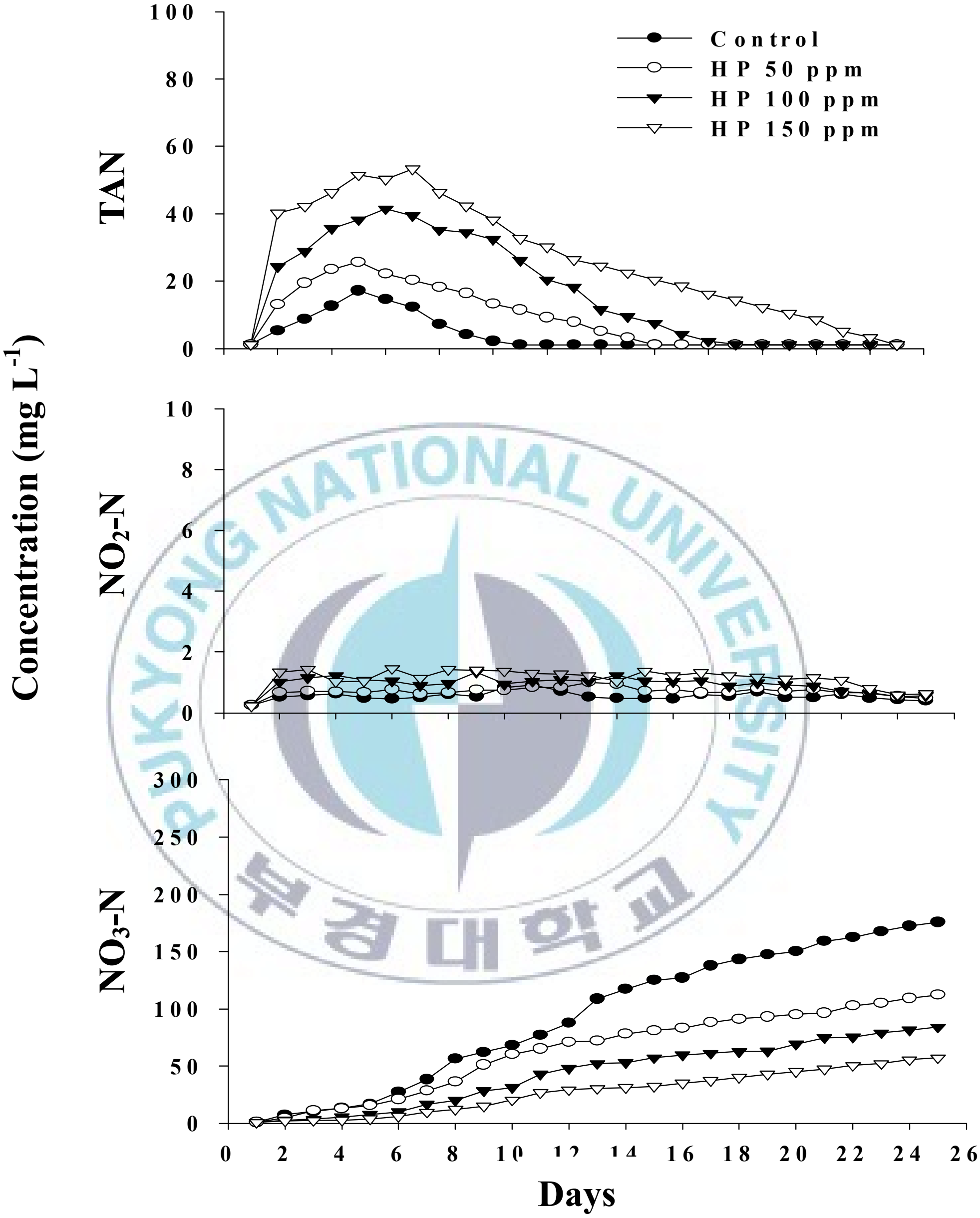

Fig. 3.15. Long period of nitrification rate of biofilter under hydrogen peroxide (HP) treatment at 20 °C in seawater

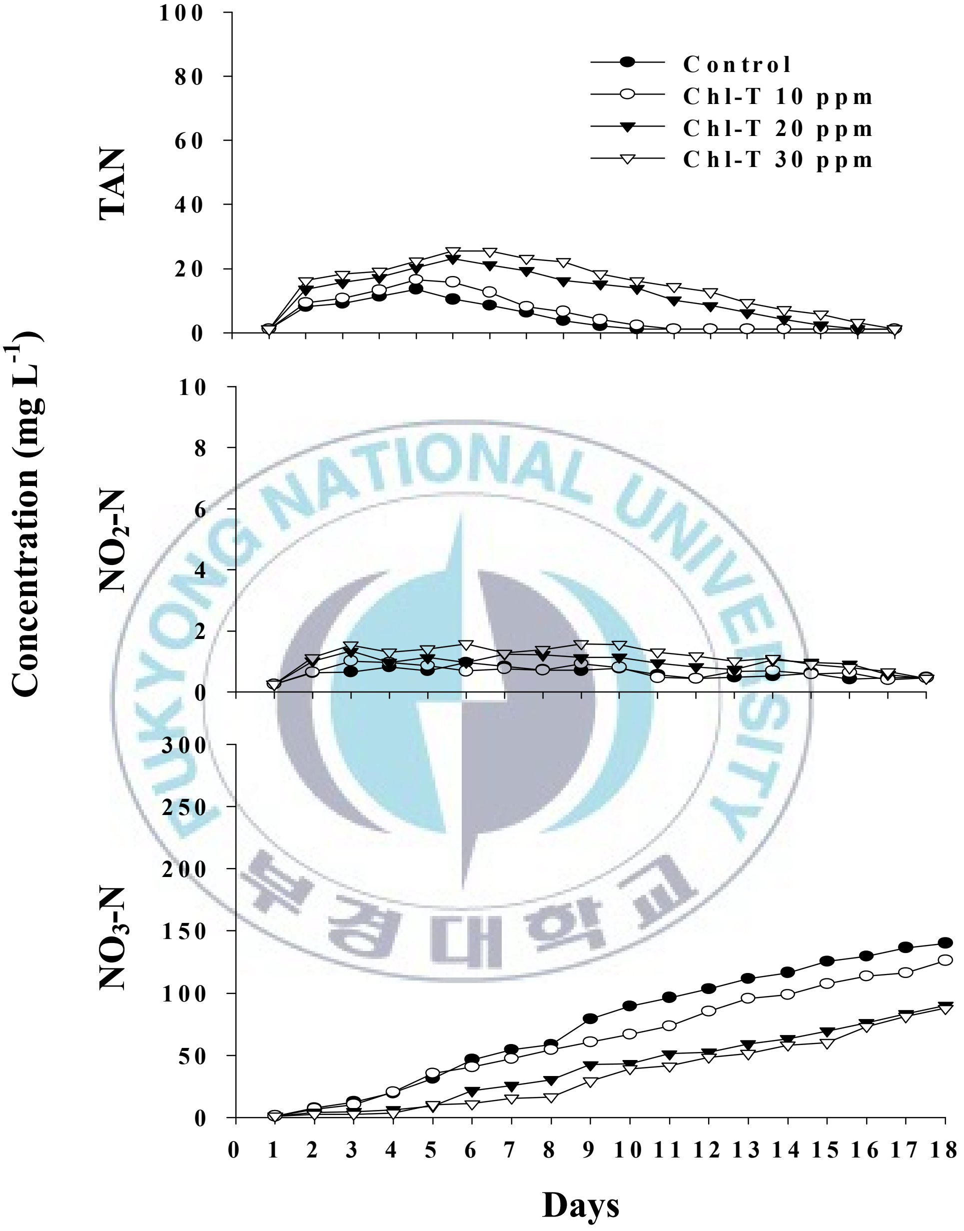

Fig. 3.16. Long period of nitrification rate of biofilter under chloramine-T (Chl-T) treatment at 20 °C in seawater

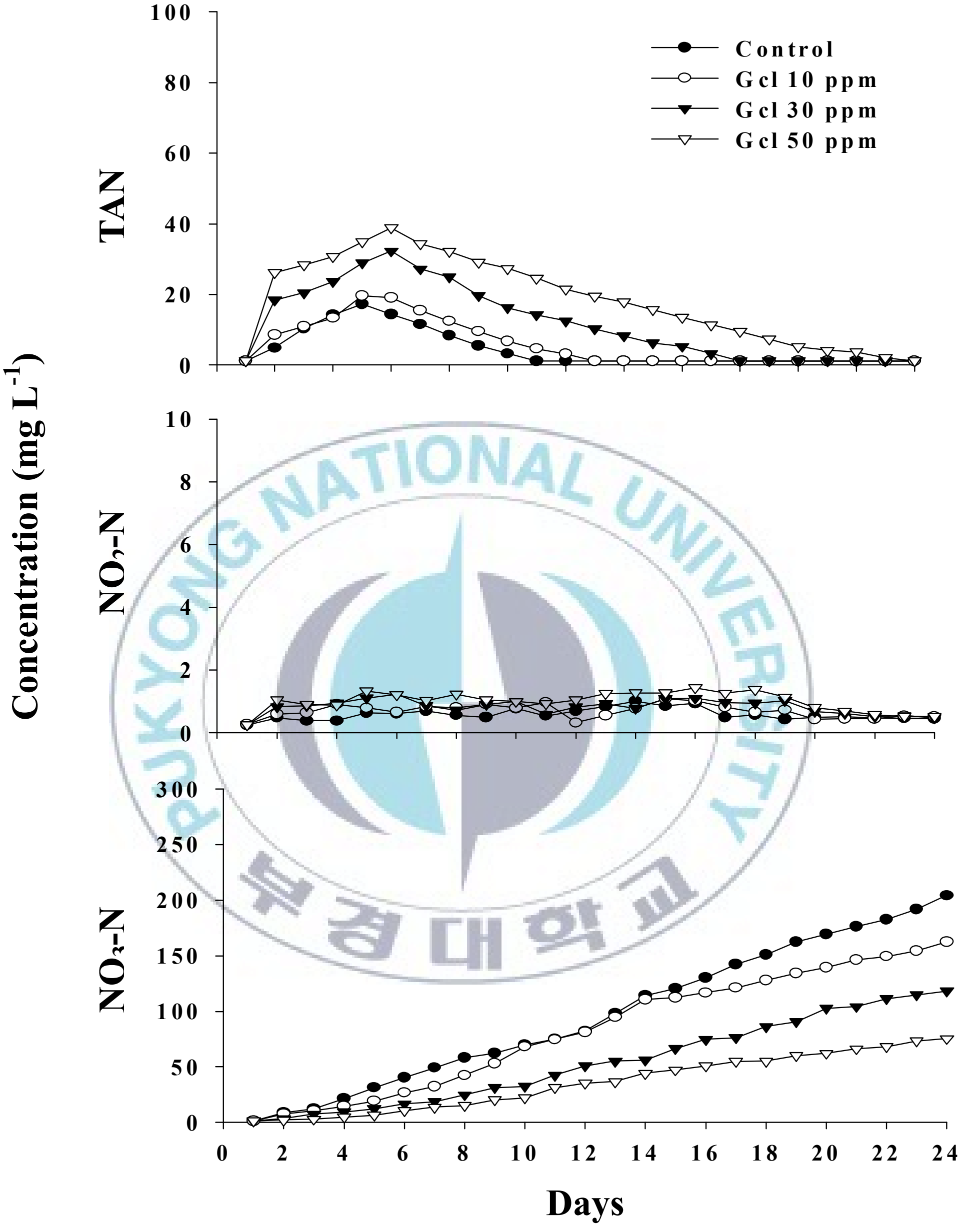

Fig. 3.17. Long period of nitrification rate of biofilter under guaiacol (Gcl) treatment at 20 °C in seawater

Table 3.28. Long period of TAN removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20^{o}C in seawater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
TAN inlet (mg L^{-1})	4.09^{a}	8.58^{b}	16.74^{c}	26.30^{d}	4.62^{a}	6.00^{a}	11.67^{b}	14.53^{b}	4.43^{a}	5.74^{a}	11.68^{b}	18.31^{c}
TAN outlet (mg L^{-1})	4.01^{a}	8.79^{b}	16.69^{c}	26.27^{d}	4.54^{a}	5.93^{a}	11.61^{b}	14.47^{b}	4.36^{a}	5.67^{a}	11.63^{b}	18.28^{c}
Removal per pass (mg L^{-1})	0.078^{a}	0.059^{b}	0.042^{c}	0.032^{d}	0.078^{a}	0.073^{a}	0.063^{b}	0.057^{b}	0.077^{a}	0.072^{a}	0.051^{b}	0.031^{c}
Vol. removal rate (g m^{-3} d^{-1})	217.87^{a}	164.78^{b}	116.12^{c}	90.69^{d}	216.58^{a}	202.75^{a}	176.64^{b}	159.74^{b}	213.12^{a}	201.60^{a}	141.70^{b}	87.55^{c}
Areal removal rate (mg m^{-2} d^{-1})	66.28^{a}	50.13^{b}	35.33^{c}	27.59^{d}	65.89^{a}	61.68^{a}	53.74^{b}	48.60^{b}	64.84^{a}	61.33^{a}	43.11^{b}	26.64^{c}
Removal efficiency (%)	1.90^{a}	0.66^{b}	0.25^{c}	0.12^{d}	1.68^{a}	1.21^{a}	0.53^{b}	0.40^{b}	1.73^{a}	1.21^{a}	0.43^{b}	0.16^{c}

Values in same treatment and same row with different letters are significantly different (*p*<0.05)

Table 3.29. Long period of NO_2-N removal rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in seawater

	Hydrogen Peroxide				Chloramine-T				Guaiacol			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_2-N inlet (mg L^{-1})	0.55^a	0.70^b	0.94^c	1.13^d	0.60^a	0.66^a	0.93^b	1.13^b	0.58^a	0.68^a	0.82^b	0.99^b
NO_2-N outlet (mg L^{-1})	0.52^a	0.68^b	0.92^c	1.10^d	0.57^a	0.63^a	0.91^b	1.11^b	0.55^a	0.65^a	0.80^b	0.97^b
Removal per pass (mg L^{-1})	0.031^a	0.026^b	0.020^c	0.015^d	0.031^a	0.028^a	0.020^b	0.018^b	0.031^a	0.027^a	0.022^b	0.018^b
Vol. removal rate (g m^{-3} d^{-1})	87.37^a	74.10^b	55.30^c	98.43^d	87.55^a	79.87^a	56.83^b	50.69^b	86.40^a	76.03^a	61.06^b	50.69^b
Areal removal rate (mg m^{-2} d^{-1})	26.58^a	22.54^b	16.82^c	29.94^d	26.64^a	24.30^a	17.29^b	15.42^b	26.29^a	23.13^a	18.57^b	15.42^b
Removal efficiency (%)	5.69^a	3.79^b	2.11^c	1.39^c	5.18^a	4.37^a	2.17^b	1.61^b	5.17^a	3.97^a	2.55^b	1.80^b

Values in same treatment and same row with different letters are significantly different (*p*<0.05)

Table 3.30. Long period of NO_3-N production rate of polystyrene microbead (MB) under three different chemotherapeutants and 25 g m^{-3} d^{-1} of ammonia loading rate at 20°C in seawater

	Hydrogen Peroxide				**Chloramine-T**				**Guaiacol**			
	control	**50 ppm**	**100 ppm**	**150 ppm**	**control**	**10 ppm**	**20 ppm**	**30 ppm**	**control**	**10 ppm**	**30 ppm**	**50 ppm**
NO_3-N inlet (mg L^{-1})	94.49^{a}	63.59^{b}	43.81^{c}	27.72^{d}	75.61^{a}	64.53^{a}	40.83^{b}	35.25^{b}	98.12^{a}	83.42^{a}	54.53^{b}	35.90^{c}
NO_3-N outlet (mg L^{-1})	94.85^{a}	63.80^{b}	43.95^{c}	27.80^{d}	68.09^{a}	57.75^{a}	35.95^{b}	30.48^{b}	98.42^{a}	83.69^{a}	54.69^{b}	36.00^{c}
Production per pass (mg L^{-1})	0.364^{a}	0.208^{b}	0.138^{c}	0.078^{d}	0.300^{a}	0.258^{a}	0.150^{b}	0.122^{b}	0.306^{a}	0.270^{a}	0.158^{b}	0.100^{c}
Vol. production rate (g m^{-3} d^{-1})	$1,006.39^{a}$	575.07^{b}	381.54^{c}	215.65^{d}	829.44^{a}	714.24^{a}	414.72^{b}	337.92^{b}	846.72^{a}	748.80^{a}	437.76^{b}	276.48^{c}
Areal prod. rate (mg m^{-2} d^{-1})	306.17^{a}	174.95^{b}	116.07^{c}	65.60^{d}	252.34^{a}	217.29^{a}	126.17^{b}	102.80^{b}	257.59^{a}	227.80^{a}	133.17^{b}	84.11^{c}
Production efficiency (%)	0.38^{a}	0.32^{b}	$0.31^{b,c}$	0.28^{c}	0.44^{a}	0.43^{a}	0.41^{a}	0.39^{a}	0.31^{a}	0.30^{a}	0.28^{a}	0.27^{a}

Values in same treatment and same row with different letters are significantly different ($p<0.05$)

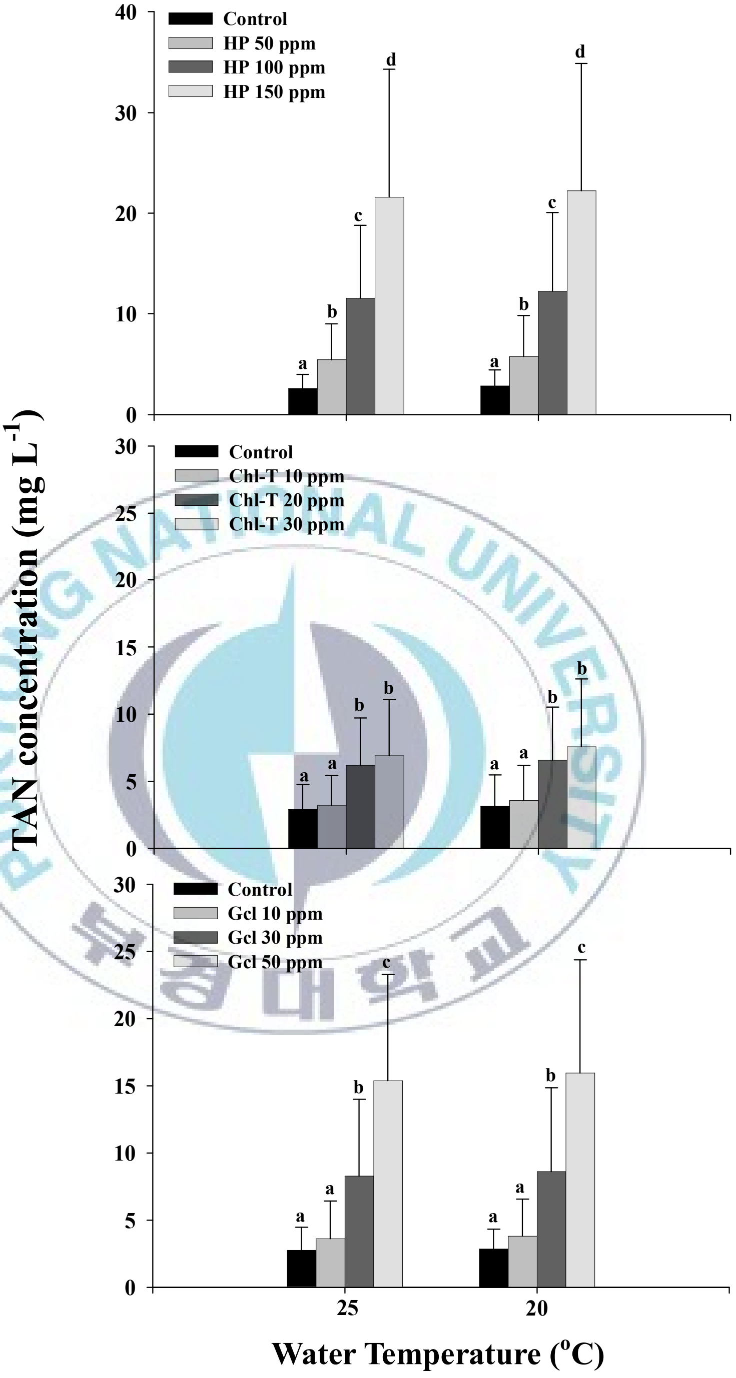

Fig. 3.18. TAN concentration in the short period observation at 25, 20 and 15°C of water temperature in seawater

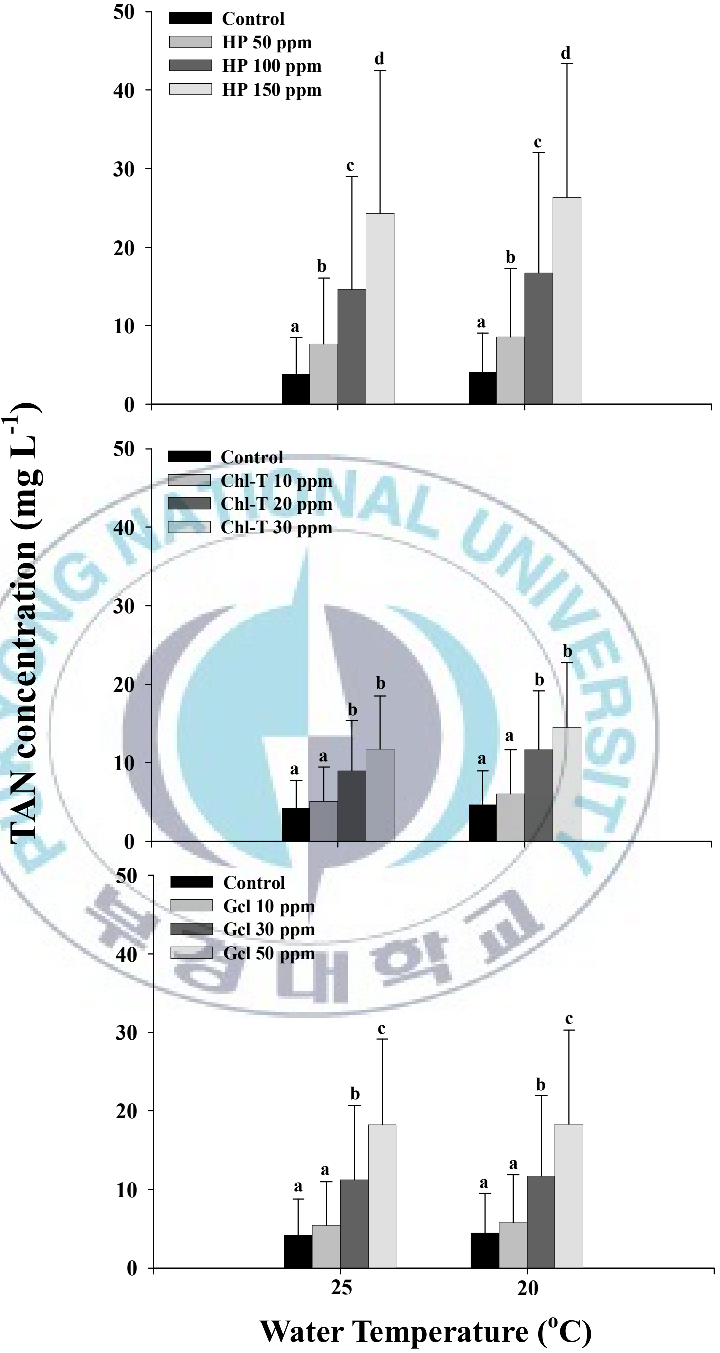

Fig. 3.19. TAN concentration in the short period observation at 25, 20 and 15°C of water temperature in seawater

IV. Discussions

The values of water temperatures, pH, dissolve oxygen and salinity in all system and treatments were in the compatible range for nitrification as mentioned by Wheaton et al. (1994).

According to this experiment, the nitrification efficiency at higher water temperature showed higher TAN removal rate. However, in the control of this experiment, the removal rates was less significant than van't Hoff-Arrhenius equation as also shown by Kim et al., (2008), Zhu and Chen (2002) and Zhang et al., (2009). Zhang et al., (2009) investigated the differences in TAN removal rates between 26°C and 15°C of water temperature and found that the difference of about 18.3%, whereas in this experiment showed about 16.67% between 25°C and 15°C of water temperature.

The volumetric rates of TAN by control were ranged at 138.24 – 414.72 g TAN m^{-3} d^{-1} and comparable to the result by Greiner and Timmons (1998) showed 84 – 480 g TAN m^{-3} d^{-1} and by Harwanto (2009) showed between 193.1 and 536.84 g TAN m^{-3} d^{-1}. Furthermore, the removal rate of TAN in the control of this experiment showed higher rate than the result by treatments and was found not significantly different in the 10 ppm of chloramine-T and guaiacol in the freshwater and seawater treatment. The result was confirmed by Liu et al., (2005) who reported nitrifying bacteria are highly sensitive to toxic compound and inhibit ammonia-oxidizing process.

This experiment also indicated the nitrification efficiency in seawater is lower than in freshwater in all treatments on the same water temperature as mentioned also by Carrol (2003), Harwanto and Jo (2007) and Losordo (2005). For instance, in the long period observation in the freshwater at 25°C, the volumetric removal rate of TAN in the control, 50, 100 and 150 ppm were 283.06, 230.40, 177.74 and 131.66 g TAN m^{-3} d^{-1}, respectively. Whereas the same experiments in the seawater showed lower rates of 237.31, 180.86, 132.48 and 102.53 g TAN m^{-3} d^{-1}, respectively. The result was also found in the 20°C and 15°C of water temperature.

The NO_2-N and NO_3-N concentration in the treatments were significantly different in comparison to the control except in the 10 ppm of chloramine-T and guaiacol as also mentioned by Moller et al., (2009). This may result from that nitrite-oxidizing bacteria were inhibited by chemotherapeutants. Thereafter, related to NO_2-N concentration in the treatments, Kim et al. (2008) and Zhang et al. (2009) explained the higher water temperature may result in higher NO_2-N removal rate. This result also confirmed that experiment was carried out at 25°C of water temperature always showed higher NO_2-N removal rate than those to 20°C and 15°C. This inclination also found in the same comparison for the treatment of 20°C to 15°C of water temperature.

Hydrogen peroxide was investigated for its effect on nitrification efficiency in the recirculating system. Schwartz et al. (2000) mentioned that 100 ppm treatment caused almost total impairment of nitrification efficiency and the ambient ammonia removal was reduced by 84% and the challenged ammonia removal rate by 57% after 24 h. Moller et al. (2009) also confirmed that the decreasing of nitrification efficiency in the biofilter was about 85% when they used 100 ppm HP and prolonged HP exposure resulted in decreased ammonia oxidizing process in the biofilter. Both studies reported that the increasing of nitrification efficiency capacity occurred at the day 8th for about 20% and 65% at the day 10th. The impairment of nitrification efficiency by hydrogen peroxide also had been reported by Noble and Summerfelt (1996) upon tested 100 ppm HP treatment. In this experiment, hydrogen peroxide (HP) impaired efficiency not only for short period but also for the long period processes. In the short period observation of freshwater and seawater experiments, 50 ppm HP showed impairment of nitrification efficiency by 12 – 27% as compared to the nitrification efficiency of the control (no HP concentration). Furthermore, the impairing were increased following by 100 and 150 ppm of HP treatment up to the level of 37 – 49% and 62 – 74%, respectively. Long period observation showed 16 – 27% in the 50 ppm and 34 – 49% and 47 – 59% in the 100 and 150 ppm of HP treatment, respectively. This experiment also showed that the stabilized period was found in the range of days between 12th and 24th.

Effect of chloramine-T in the biofilter was carried out by Schwartz et al. (2000) used 9 and 12 ppm. They reported after the 9 ppm of single chloramine-T static bath treatment, ambient ammonia removal increased by 20% and challenged ammonia removal was decreased by 5%. The ambient ammonia removal was decreased by 10% and the challenged ammonia removal was decreased by 9% upon single 9 ppm chloramine-T in recycle bath treatment. Upon multiple 12 ppm of chloramine-T static bath treatments there was only a slight decrease in ambient ammonia removal while the challenged ammonia removal was decreased by 8%. Noble and Summerfelt (1996) reported contrary result showing that treatment with 12 ppm of chloramine-T had no effect on biofilters at the Glenwood State Fish Hatchery, Utah, USA. However, in this experiment in the freshwater and seawater showed that 10, 20 and 30 ppm chloramine-T treatment impaired the nitrification efficiency of biofilter by 3 – 6%, 28 – 37% and 38 – 41% in the short period of 24 h observation, while in the long period showed 5 – 7%, 17 – 27% and 23 – 40%, respectively.

There is no specific reference that explained about the effect of guaiacol in the nitrification efficiency of the biofilters. However, this experiment in the freshwater and seawater showed that in the short period observation, the 10, 30 and 50 ppm guaiacol treatment impaired nitrification efficiency of the biofilter by 7 –14%, 30 – 43% and 68 – 75%, respectively. Thereafter, in the long period observation of these treatments resulted 6 – 12%, 26 – 37% and 50 – 60%, respectively.

V. Conclusions

1. In the short period observation, the 50, 100 and 150 ppm of hydrogen peroxide (HP) showed impairment of nitrification efficiency significantly in the biofilters by the range at 12 – 27% in the 50 ppm, 37 – 49% in the 100 ppm and 62 – 74% in the 150 ppm. In the long period observation, these treatments showed impairment on nitrification efficiency of the biofilters by 16 – 27%, 34 – 49% and 47 – 59%, respectively.
2. The 10 ppm of chloramine-T had no significant effect on nitrification efficiency of the biofilters, whereas the 20 ppm and 30 ppm of chloramine-T impaired by 28 – 37% and 38 – 41% in the short period (24 h) observations. In the long period observation, these two concentrations indicated impairing by 17 – 27% and 23 – 40%, respectively.
3. The 10 ppm of guaiacol showed no significant effect on nitrification efficiency of the biofilter in the short period and long period observations, while in the short period (24 h), the 30 and 50 ppm showed impairment by 30 – 43% and 68 – 75%, respectively. Furthermore, in the long period observation showed impairment by 26 – 37% and 50 – 60%, respectively.
4. Consideration should be given on water temperature while giving these chemotherapeutants in the recirculating aquaculture system.
5. Further researches are needed related to chemotherapeutants concentrations, exposure time, ammonia loading rate, biofilter media and water temperature especially on larger scale of recirculating aquaculture system.

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