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Removal of Ammonia from Aquaculture Wastewater by Down-flow Hanging Sponge System

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ABSTRACT

This study investigates the efficiency of a biological nitrogen removal system for aquaculture effluent treatment of a down-flow hanging sponge (DHS). The experiment has been performed for 212 days. The DHS system had hydraulic retention time (HRT) decrease from 8 hours to 1 hour (8 hours, 5 hours, 3 hours and 1 hour). From the experiment data showed that the amount of ammonia after passing through the system at an HRT 1 hour there was 0.42 mg-N/L. The system provided average removal efficiencies for ammonia and Total nitrogen of 99% and 69%, respectively. The water quality profile results revealed the ammonia, BOD, SS and VSS are most eliminated in the first segment of DHS system. DHS system can perform nitrification reducing ammonia (NH_3) toxicity in aquaculture wastewater. The study confirmed that the DHS system provided nitrification process and the overall DHS system provided high-performance aquaculture effluent treatment system.

Keywords : Down-flow Hanging Sponge; Ammonia removal; Nitrogen removal

INTRODUCTION

The main source of ammonia nitrogen in water from aquaculture comes from the excretion of aquatic organisms and microbial degradation [1]. Ammonia concentrations below 0.05 mg/L can cause respiratory stress to the fish [2]. For this reason, the removal of ammonia from wastewater has become an important part of the overall treatment process.

For aquaculture wastewater treatment, it is necessary to use simple and low cost technology. Sand filters [3], moving bed biofilm reactors [4], chitin and chitosan [5] are typically used to remove ammonia.

The down-flow hanging sponge (DHS) reactor is a type of trickling-filter reactor in which the sponge acts as the filtering media. Sponge is selected because it has higher porosity and larger surface area than other types of media. Many researchers have developed a down-flow hanging sponge (DHS) and up-flow sludge blanket (USB) systems to remove nitrogen from marine fish aquarium [3, 6, 7]. In general, ammonia-contaminated aquaculture wastewater is a remarkable problem in Thailand. Many wastewater treatments are employed and not yet accomplised to remove ammonia. Therefore, appropriate wastewater treatment is required. Among various wastewater treatment, DHS system is an interesting choice for treating ammonia-contaminated aquaculture wastewater because of its removal capability. Additionally, the advantages of this system are not necessary to aerate, small area required, energy saving, low operation and maintainance costs [8].

This research investigates the suitability and performance of DHS system regarding the removal of NH_3, NO_2^-, and NO_3^-. This system is expected to be a promising alternative wastewater treatment to remove ammonia from aquaculture wastewater.

METHODOLOGY

Reactor configurations

Aquaculture wastewater was collected from Faculty of Fisheries, Kasetsart University, Bang Khen Campus. An overview and configuration of the DHS reactor are shown in Figure 1. The DHS module column consists of three identical segments. The reactor had a rectangular-shaped segment of 0.23 m long, 0.23 m wide, and 0.42 m high. The segments were filled with sponge media to a height of 0.35 m. The total volume of sponge media was 29.43 L. The dimensions of the used sponge amounted to 16 mm height and 33 mm diameter.

Operating conditions

The wastewater was fed directly into the first unit using a peristaltic pump via the temporary storage tank. The influent wastewater was distributed from the top of the unit and flowed down through the sponge media by gravity. Each segment had small holes to naturally supply air from the atmosphere and the DHS reactor was operated under ambient temperatures ranging from 27 to 32 °C (average 28.8 °C). During operational period, the hydraulic retention time (HRT) reduced from 8 to 1 hour (HRT 8 h: 70 days, HRT 5 h: 50 days, HRT 3 h: 52 days and HRT 1 h: 37 days).

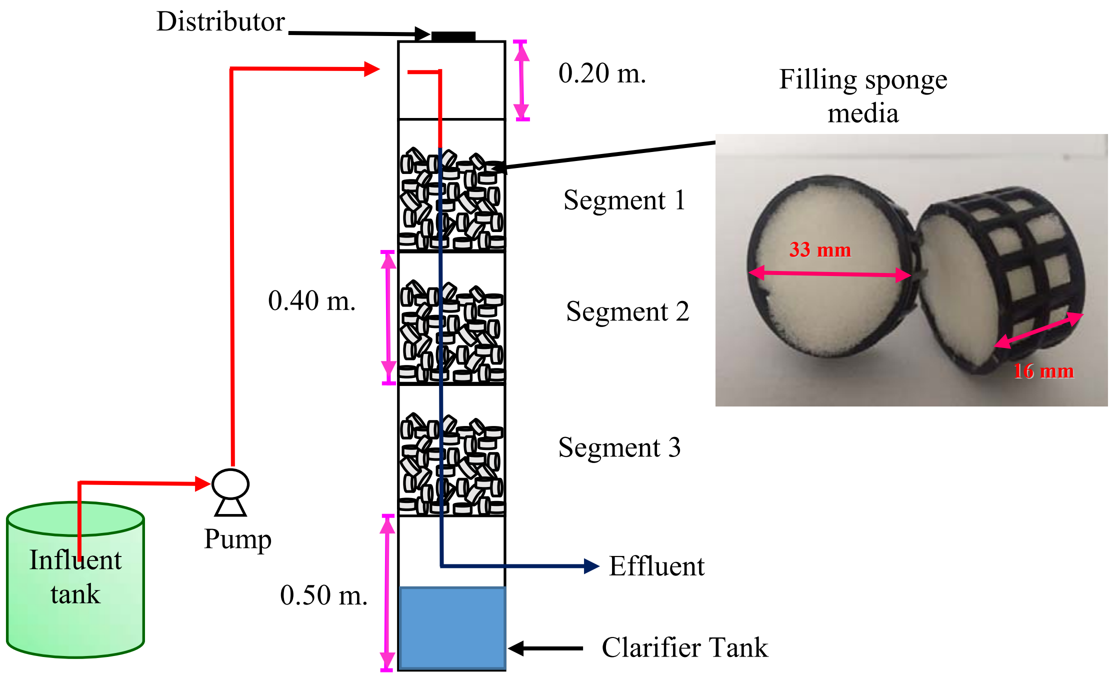

Figure 1 Schematic diagram of the DHS reactor

Water quality analysis

From aquaculture wastewater characteristics analysis, the ammonia component was 0.1 mg-N/L. Therefore, ammonium carbonate $(NH_4)_2CO_3$ was added to the influent in order to control ammonia concentration. The average ammonia, nitrate and total nitrogen concentration in the influent was 11.7 mg-N/L, 1.72 mg-N/L and 19 mg-N/L, respectively. The average temperature was 28.8 °C, dissolved oxygen was 2.7 mg/L, pH 8.1, oxidation-reduction potential concentration was -8.5 mV and conductivity concentration was 567 µs/cm.

Wastewater samples were collected two times a week for complete analysis. Temperature, Dissolved oxygen (DO), pH, Conductivity and the oxidation–reduction potential (ORP) were measured. The performances of the DHS reactors were evaluated by analyzing the following parameters; ammonia, nitrate, and total nitrogen. Each sample was filtered through a glass fiber filter (GB-140, 0.4 µm; Advantec, Tokyo, Japan) before the nitrogen analyses. Nitrogen compounds were analyzed using a HACH water quality analyzer (DR-1900, HACH, US).

Oxygen Uptake Rate (OUR)

Oxygen uptake rate experiments were conducted to determine the sludge activity, about twenty pieces of sponge media were randomly selected from each of segment. The attached sludge was collected from the sponge media by squeezing and washing with distilled water some pasts of them were measured for sludge concentration. The remains sludge samples were washed by aerated dilution water including reagents for BOD measurement (three times higher concentration) followed by overnight aeration for determination of the specific oxygen uptake rate. For the OUR test, a DO meter was inserted into the BOD bottles. The DO was every 1 minute. All experiments were conducted at 30 ± 1 °C. The calculation of endogenous respiration rate is slope from linear relation from DO (mg/L) and time (min) divided by of sludge concentration (g VSS/L sponge). The endogenous respiration rate was then measured without any substrates. Next, the activity of heterotrophic bacteria using 3,000 mg COD/L sodium acetate (CH_3COONa) and autotrophic bacteria using 200 mg-N/L ammonium chloride (NH_4Cl).

RESULTS AND DISCUSSION

Process performance

The performance of the DHS reactor was evaluated continuously for 212 days. The reactor was operated at a HRT of 8 hours for 70 days (phase-1), 5 hours for 50 days (phase-2), 3 hours for 52 days (phase-3), and 1 hour for 37 days (phase-4). Figure 2 shows the concentrations of ammonia nitrate and total nitrogen.

Nitrogen removal efficiency was measured and monitored twice a week in terms of ammonia (NH_4), nitrate (NO_3^-), and Total nitrogen. The DHS reactors performed with concurrent organics and NH_4 removal, even though no mechanical aeration was installed. The DHS reactor produced a relatively high DO concentration in the effluents even at an HRT of 1 hour. The high DO concentration is crucial to achieving sufficient efficiency for nitrification [7]. The oxygen supply function of the DHS reactor which usually occurs via natural dissolution of the oxygen into the wastewater when it flows down the sponge media.

The average ammonia influent concentration was 11.7 mg-N/L and effluent concentration was 0.12±0.04 mg-N/L, 0.11±0.11 mg-N/L, 0.11±0.07 mg-N/L and 0.42±0.27 mg-N/L (Table 1) for phase-1, phase-2, phase-3 and phase-4, respectively. The amount of NO_3^- produced was 4.2±1.39 mg-N/L 3.4±1.07 mg-N/L, 3.0±1.17 mg-N/L and 6.9±2.10 mg-N/L for phase-1, phase-2, phase-3 and phase-4 respectively. From previous experiments investigating the use of DHS reactors to treat aquaculture system. Ammonia concentrations effluent was 1.62 mg-N/L [9].

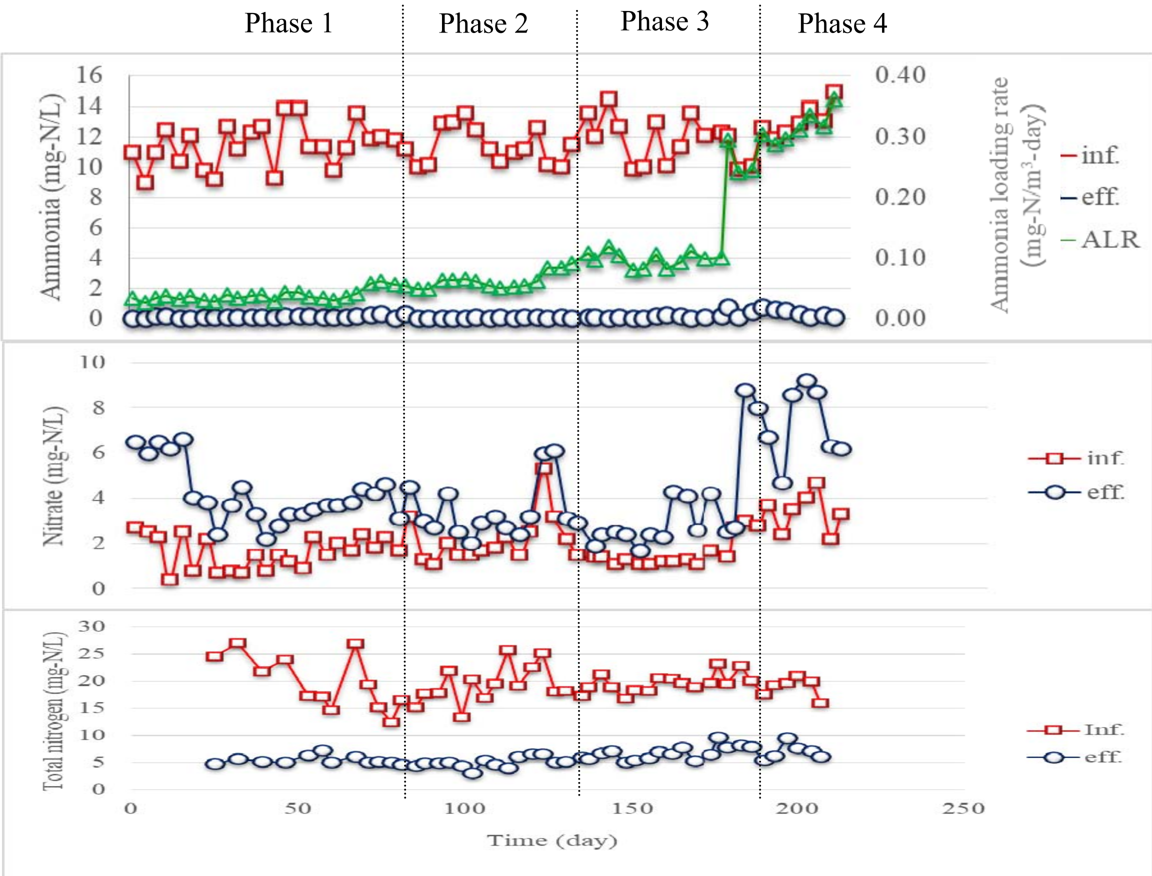

Figure 2 Ammonia (mg/L), Ammonia loading rate (mg-N/m^3-day), Nitrate (mg/L) and Total nitrogen (mg/L) versus time

Table 1 Summary of effluent quality in the system.

Parameters	HRT 8		HRT 5		HRT 3		HRT 1	
	influent	effluent	influent	effluent	influent	Effluent	influent	Effluent
Ammonia (mg/L)	11.43±1.53	0.12±0.04	11.7±1.08	0.11±0.11	11.79±1.52	0.11±0.07	12.37±1.5	0.42±0.27
Nitrate (mg/L)	1.57±0.75	4.21±1.38	2.1±1.03	3.41±1.07	1.48±0.56	3.03±1.17	3.23±0.77	6.99±2.10
Total Nitrogen (mg/L)	18.21±4.75	5.63±0.85	19.32±3.55	4.85±0.84	19.84±2.03	6.1±0.85	19.47±2.17	7.55±1.38
ALR (mg-N/m^3-day)	0.04±0.00		0.06±0.01		0. 10±0.01		0.30±0.00	
% remove Ammonia (%)	99 ±0.33		99 ±0.09		99 ±0.6		97 ±2.24	
Total Nitrogen (%)	73 ±8.6		72 ±6.6		68 ±3.62		62 ±4.92	

The ammonia loading rate was 0.04±0.00 mg-N/m^3-day, 0.06±0.01 mg-N/m^3-day, 0.10±0.01 mg-N/m^3-day and 0.30±0.00 mg-N/m^3-day at HRT of 8 hours, 5 hours, 3 hours and 1 hour, respectively. Ammonia removal efficiency of the DHS system remains constant although the ammonia loading rate increase. The previous experiments investigating the use of DHS system to treating agricultural drainage water. The ammonia loading rate was 0.03 mg-N/m^3-day at HRT 2 hours [10].

In addition, the average NH_4 removal efficiency of 99% and total nitrogen removal efficiencies of 69% was observed in the DHS reactor. The proficient ability of DHS system to remove nitrogen compounds within target water quality throughout the study suggested that the DHS system was stable for long-term operation.

Water quality profiles

The water quality was determined at different height of the DHS reactor to evaluate the reactor performance. The samples were observed on day 65 at a HRT of 8 hours, on day 118 at a HRT of 5 hours, on day 175 at a HRT of 3 hours and on day 211 at a HRT of 1 hour. The results of nitrogen removal (figure 3) occurred majority took place in the upper portion (from the inlet to 0.4 m). The DO concentration sharply increased in the upper portion and remained constant in the lower portion. These results indicate that there was better nitrification efficiency in these portions.

Wastewater from aquaculture consists of ammonia and organic nitrogen compounds. From the experiment showed that volume of ammonia before entering the system was 11.7 mg-N / L. Ammonia was decreased after passing the first segment of system. The ammonia was almost completely removed, with only 0.1 mg/L, 0.1 mg/L, 0.1 mg/L and 0.4 mg/L remaining in the final effluent at HRT of 8 hours, 5 hours, 3 hours and 1 hour, respectively (removal efficiency of ammonia was 99%).

At an HRT of only 1 hour, the first segment completed nitrification as well as organic removal. Owing to nitrate was detected in the effluent. This was likely due to the high DO concentration in the effluent. The nitrification occurred within the system which caused ammonium are transformed to nitrate. In the part of nitrite were very low which almost equaled to zero. Additionally, the total nitrogen was reduced from 23.57 to 9 mg-N/L in the DHS reactor due to ammonia has changed to nitrite, nitrate, nitrogen gas, and some ammonia evaporates into the air. Overall, these findings imply that nitrification occurred in the DHS reactor.

The results presented figure 4 shows that most of BOD concentration sharply decreased in the 1^{st} segment and continuously decreasing in the 3^{st} segment. The BOD removal for wastewater before entering the system were 30.2, 30.8, 30.3 and 33 mg/L and after passing through the system BOD concentration was 1.2 mg/L, 3.5mg/L, 2.6 mg/L and 2 mg/L in the final effluent at HRT of 8 hours, 5 hours, 3 hours and 1 hour, respectively. The system has removal efficiency of BOD up to 90%. From the result, that system has a high BOD removal resulting in good denitrification process. Although, BOD values had been being low, but can still work in the denitrification process. Because in the system there are bacteria that cause the denitrification process.

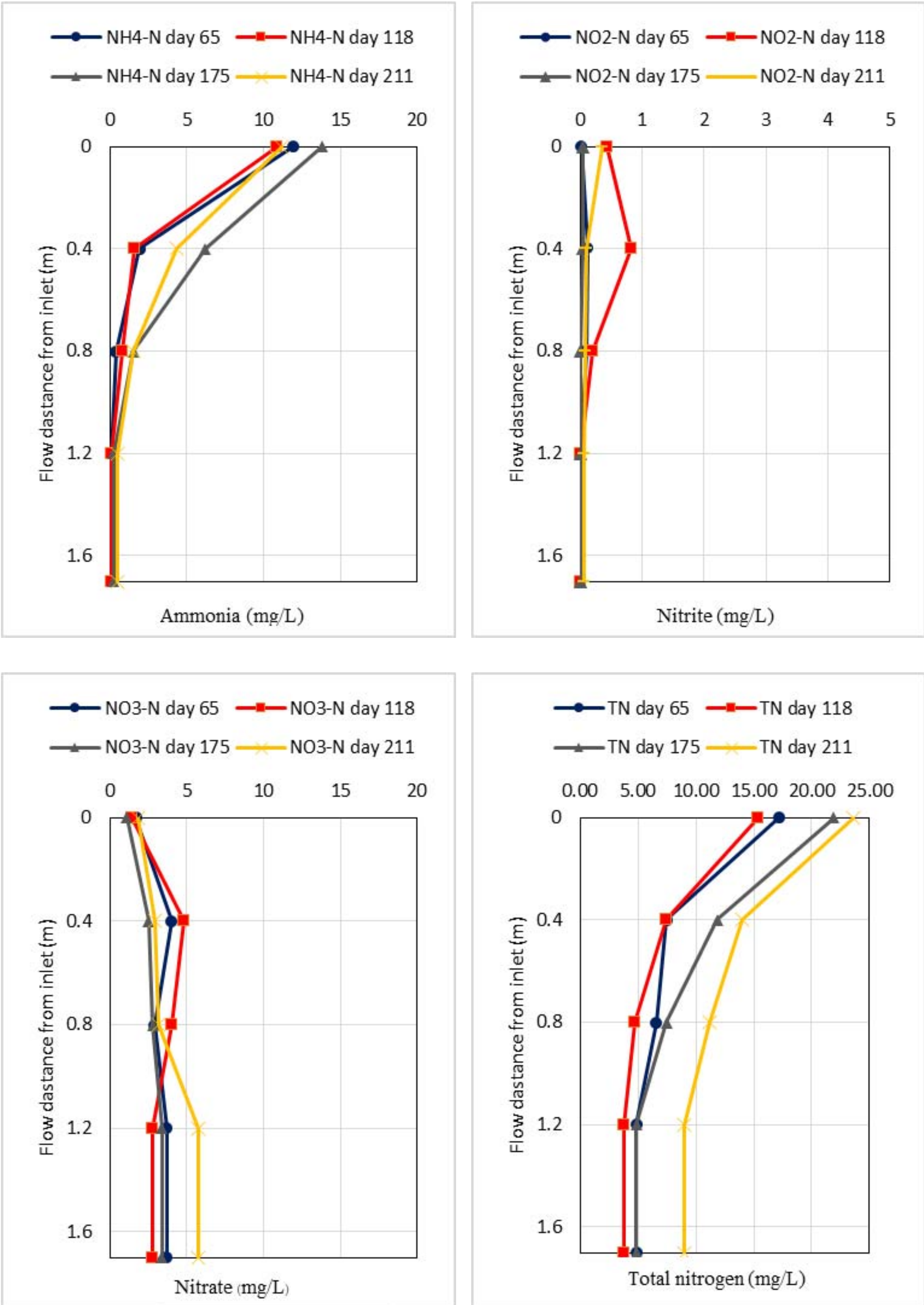

Figure 3 Water profiles in DHS reactor for ammonia, nitrite, nitrate and total nitrogen

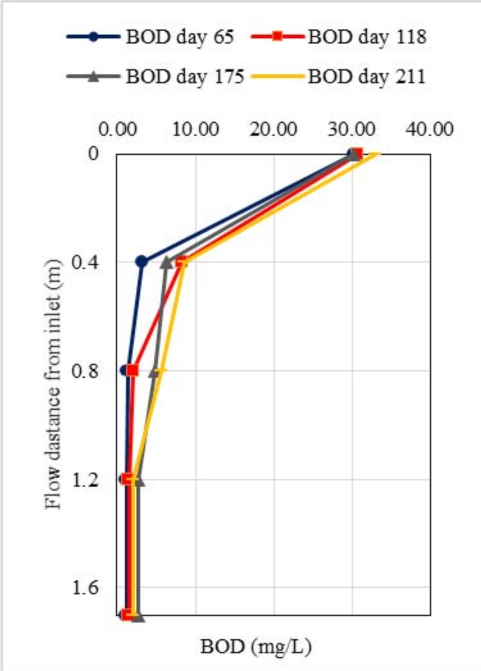

Figure 4 Water profiles in DHS reactor for BOD

The suspended solids and volatile suspended solids was determined at different heights in the DHS reactor to evaluate the reactor performance (Figure 5).

From the result profile considering slope of the graph, that suspended solids are most eliminated in the 1st segment reactor. The DHS reactor maintained a low sludge concentration in the sponge media, having enough space to accumulate suspended solids in the wastewater.

The suspended solids was almost completely removed, with only 9.67 mg/L, 3.5 mg/L, 3.75 mg/L and 3 mg/L remaining in the final effluent at HRT of 8 hours, 5 hours, 3 hours and 1 hour, respectively.

The volatile suspended solids was almost completely removed with only 5.34 mg/L, 3.3 mg/L, 3.2 mg/L and 1.03 mg/L remaining in the final effluent at HRT of 8 hours, 5 hours, 3 hours and 1 hour, respectively. The upper portion of the reactor was mostly responsible for removing solids and organic matter, the middle portion was mostly responsible for removing residual and soluble organic matter [11].

The DHS wastewater treatment system was effective remove suspended solids. It was caused by the sponge media because there are a lot of space on the surface of the sponge. The effluent had a low amount of suspended solids. The sponge does not clog due to microorganisms that help decompose organic matter at the surface of sponge [12].

Oxygen Uptake Rate (OUR)

The oxygen uptake rate was determined for retained sludge along the reactor height on day 119 (Table 2). In aerobic process, process required oxygen for their respiration digestion of organic matter. Carbon dioxide was a product from bacterial consumed. When organic matter from wastewater was lacked, some bacteria were died and then bacteria will consume dead bacteria as food.

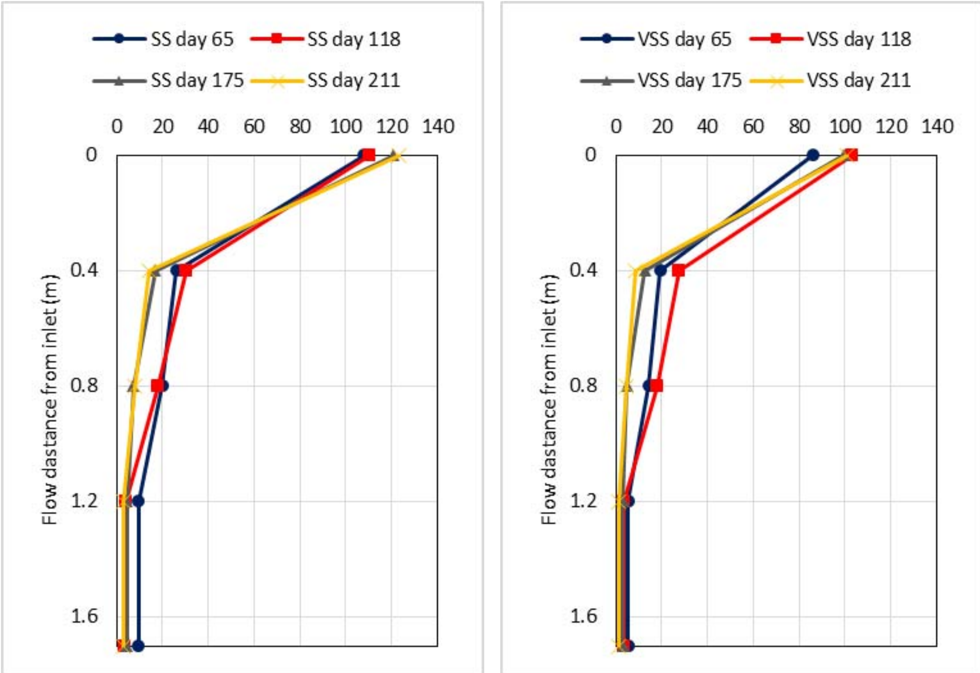

Figure 5 Water profiles in DHS reactor for SS and VSS

Table 2 OUR of the retained sludge in the DHS reactor

Segment	Specific oxygen uptake rate ($g\ O_2$/g VSS day)		
	Endogenous	Heterotrophic	Autotrophic
1	0.0553	0.0722	0.0552
2	0.0617	0.0803	0.0666
3	0.0298	0.0229	0.0232

The measurement and utilization of the oxygen uptake rate (OUR) is very important in biological wastewater treatment process. The oxygen uptake rate was related to the removal characteristics of organic compounds and nitrogen in the DHS reactor. The result showed the heterotrophic respiration amounted 0.0722 g O_2/(g VSS day) in the first segment to 0.0803 g O_2/(g VSS day) in the second segment and 0.0229 g O_2/(g VSS day) in the third segment. These results show the good capability to eliminate organic matter of bacteria in the system. The compared with the previous experiment the heterotrophic respiration decreased from 0.0560 g O_2/(g VSS day) in the first segment to 0.0150 g O_2/(g VSS day) in the fifth segment [11].

The autotrophic respiration (nitrification) of the 1st segment, 2nd segment and 3rd segment was 0.0552, 0.0666 and 0.0232 g O_2/(g VSS day) respectively. These results showed lower autotrophic respiration than the previous study [11] because of low organic compounds in the DHS reactor.

CONCLUSIONS

Down-flow Hanging Sponge Reactor is suitable technology to remove ammonia from aquaculture wastewater because the reactor can remove up to 99% of ammonia. In addition, the sponge media can also cause natural aeration, without cost of filling excess air. The treated water can be safely reused in aquaculture and be able to discharge the natural water resource. Down-flow Hanging Sponge Reactor is an interesting technology of agricultural wastewater treatment.

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