



## A RESEARCH ON THE PERFORMANCE OF DOWN-FLOW HANGING SPONGE (DHS) REACTOR IN TREATING DOMESTIC WASTEWATER

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Received: 12 November 2017; Accepted for publication: 31 May 2018

**Abstract.** The aim of this study was to evaluate the performance of a down-flow hanging sponge (DHS) system in treating domestic wastewater. A pilot-scale of DHS system with a capacity of 60 L was designed and fabricated from polyvinyl chloride (PVC). The dimensions of DHS system are 1.5 m in height and square surface with 0.2 m in width, consists of three identical segments connected vertically in series. Each segment was filled by polyurethane sphere containing sponge. The total area of sponge and polyurethane sphere was  $3,300 \text{ m}^2 \text{ m}^{-3}$ , density at  $150 \text{ kg m}^{-3}$ , void ratio at 90 %. DHS system was operated at ambient temperature within 82 days and stepwise increased of organic f rate from 0.5 to 1 and 1.5  $\text{kg COD m}^{-3} \text{ d}^{-1}$ . The results showed that this system performed well throughout the operational period and achieve the maximum removal of COD, BOD<sub>5</sub>, NH<sub>4</sub><sup>+</sup>-N, and TN as 80 %, 83 %, 65 % and 60 %. The effluent of wastewater from DHS system achieved the requirement for National technical regulation on domestic wastewater of Vietnam type B QCVN 14:2008/BTNMT. In conclusion, the performance of DHS system indicated a high potential for application in removing organic matter and converting nitrogen ammonia to nitrogen nitrate, however it did not perform well for the removal of total nitrogen, it is necessary to study further by providing an anoxic zone in the system to enhance the treatment of nutrient in wastewater.

**Keywords:** Down-flow Hanging Sponge (DHS) system; domestic wastewater; organic loading rate; removal efficiency.

**Classification numbers:** 3.7.2; 3.4.2.

### 1. INTRODUCTION

Viet Nam is a developing country; where urbanization and industrialization have made significant increasing of national economic and living standard for residents. Going together with these processes the environmental impact has become more and more serious, and one of

these issues is the aquatic pollution by domestic wastewater. Therefore, many municipal wastewater treatment plants have been established and operated throughout the country [1].

Biological treatment is one of the most important steps for treatment of wastewater in which microorganisms convert the organic matters and nutrients to biomass or other simple products. In environmental engineering, microorganisms in biological treatment can be performed in suspended growth such as activated sludge process, oxidation ditch or in attached growth (biofilm) such as trickling filter, rotating biological contactor. In an attached growth process, a biofilm consisting of microorganisms attach and cover the support packing materials which may be rock, plastic or other materials [2]. Nowadays, attached growth process has been applied more commonly in the worldwide. The principal advantages of aerobic attached growth processes compare to activated sludge process are as follows: less energy required, simple operation and maintenance, good sludge properties, and easy to recover from shock toxic load. One of the most biofilm systems commonly used in wastewater treatment is the Down-flow Hanging Sponge (DHS) reactor. DHS reactors offer several advantages compared to other systems such as high organic loading rate, high removal efficiency, high biomass concentration, long sludge residence time (SRT), and short HRT [3-5]. There have been many authors investigated about DHS reactor in treating different types of wastewater. Mahmoud and colleagues [5] used a hybrid up-flow anaerobic sludge blanket (HUASB) reactor followed by a down-flow hanging sponge reactor to treat municipal wastewater. The result showed that this system could achieve the removal values of  $\text{COD}_{\text{total}}$ ,  $\text{COD}_{\text{soluble}}$ ,  $\text{BOD}_{5\text{total}}$ , TSS and TN of  $90 \pm 4$ ,  $78 \pm 8$ ,  $95 \pm 2$ ,  $96 \pm 5$  and  $72 \pm 8$  %, respectively. The authors also found out the DHS model performs well for organic matter and nitrogen removal at high OLR up to  $4.8 \text{ kg COD m}^{-3}\text{d}^{-1}$ . Tawfik et al. [6] investigated the effect of retention time, sponge pore size, and sponge bulk volume on the removal of fecal coliform through down-flow hanging sponge system treating UASB reactor effluent, and they found out that significant improvement in the removal rate of fecal coliform was achieved when increasing the retention time from 1.0 to 6.0 h, sponge bulk volume from 12.9 to 51.6 l, and decreasing sponge pore size from 1.92 to 0.56 mm [6]. Fleifle et al. [7], studied on modelling and profile analysis of a down-flow hanging sponge system treating agricultural drainage water with HRT of 2 h and OLR of  $3 \text{ kg COD m}^{-3}\text{d}^{-1}$ . The research showed that the average removal efficiencies parameters as of 83.7 % ( $\text{COD}_{\text{total}}$ ), 88.6 % ( $\text{COD}_{\text{soluble}}$ ), 66.7 % (TKj-N), 85.0 % ( $\text{NH}_4\text{-N}$ ), and 88.9 % TSS [7]. In another study, DHS model was applied to treat low strength sewage at HRT of 1.5 hours. This reactor could achieve the removal efficiency of TSS, BOD and Coliform at 90 %; 85 %; 98 %, respectively without external aeration energy [8]. Nomoto and colleagues [9] investigated the characteristics of DO, organic matter, and ammonium profile for practical-scale DHS (four layers) reactor under the range of organic load as  $3.21 - 7.89 \text{ kg COD m}^{-3}\text{d}^{-1}$ . They found out that about a half of the COD was removed by the first layer. After that, organic removal was followed the first order reaction equation from the second to the fourth layers. The ammonia nitrogen removal ratio improved when the HRT was extended. The removal efficiency had closed relationship with DO concentration in layers [9].

In Viet Nam, there were several preliminary researches about the DHS model for wastewater treatment in laboratory scale. However, there have been no many applications and publications about this field. This study aims to investigate the performance of DHS reactor treating domestic wastewater in different organic loading rate.

## 2. MATERIALS AND METHODS

## 2.1. Reactors and operations

In this study, a pilot-scale of down-flow hanging sponge system with a capacity of 60 L was designed and fabricated from polyvinyl chloride (PVC). The dimensions of DHS system are 1.5 m in height and 0.2 m in width of the internal surface. The schematic diagram of the experimental set up is presented in Fig.1. The DHS module column consists of three identical segments connected vertically in series. Air windows were located between segments for air diffusion. Each segment was filled with sponge to reach volume as 6 L (representing 30 % (v/v) of the segment volume). The polyurethane Bio-Bact spheres with 36 mm diameter were used for attached material. Sponge was located at the core of the polyurethane sphere for avoiding clogging and enhancing air diffusion in to the sponge. The total area of sponge and polyurethane sphere had specific surface area of  $3,300 \text{ m}^2\text{m}^{-3}$ , density of  $150 \text{ kg m}^{-3}$ , void ratio of 90 %. The reactor was operated at ambient temperature.

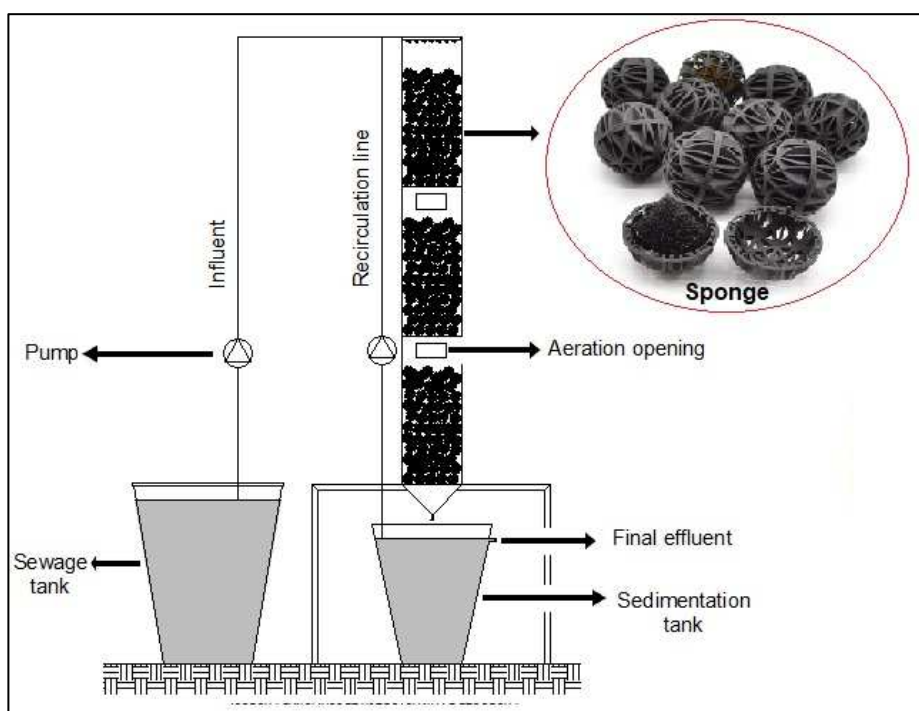


Figure 1. Schematic diagram of the experimental DHS system.

## 2.2. Wastewater source

In this investigation, wastewater was collected from storage tank of domestic wastewater from Co May dormitory, Nong Lam University – Hochiminh City. In order to maintain the equitable of water quality, wastewater was pumped to a stored tank every day at 8 am before feeding to the DHS system. The characteristics of the wastewater are presented in Table 1.

*Table 1. Characteristics of the dormitory wastewater used in the experiment.*

Parameter	Unit	Range
pH	-	7.3 ± 0.3
TSS	mg/L	18 ± 10
BOD <sub>5</sub>	mg/L	154 ± 20
COD	mg/L	234 ± 10
DO	mg/L	0.4 ± 0.1
NH <sub>4</sub> <sup>+</sup> -N	mg/L	40 ± 20
NO <sub>3</sub> <sup>-</sup> -N	mg/L	0.17 ± 0.07
N Total	mg/L	45 ± 10
P Total	mg/L	6.7 ± 2
Alkalinity	mgCaCO <sub>3</sub> /L	320 ± 2

### 2.3. Biofilm forming and reactor operation

Activated sludge from the secondary sedimentation tank was used to form biofilm of DHS system. The activated sludge contained mix liquor suspended solid (MLSS) at 30,000 mg L<sup>-1</sup>, this sludge was diluted with wastewater to achieve a sludge solution which had MLSS at 3000 mg L<sup>-1</sup>. This sludge solution was pumped and recycled continuously to the materials of DHS system for three days to create the biofilm on the sponge and spheres. In the next step, dormitory sewage was injected at low concentration within 20 days for acclimation. After that, the reactor was started to operate at the first phase.

Wastewater was injected into the top of the DHS model and passed through a distributor and flowed into the segments by gravity and collected at sedimentation tank. The circular ratio was 1:1. Three phases of experiment were operated in this study corresponding to three levels of organic loading rate, each level of organic loading rate levels was operated in 20-30 days duration. The detail information of operational conditions is showed in Table 2.

*Table 2. The detail information of operational conditions.*

Condition	Acclimation	Phase 1	Phase 2	Phase 3
Temperature, T (°C)	28 ± 2	28 ± 2	28 ± 2	28 ± 2
Flow rate, Q (m <sup>3</sup> /day), (*): Q <sub>total</sub> = Q <sub>circulation</sub> + Q <sub>in</sub>	0.015 (0.03*)	0.038 (0.076*)	0.075 (0.15*)	0.,113 (0.226*)
Hydraulic retention time, HRT (h)	14	6	3	2
Organic loading rate, OLR (kg COD m <sup>-3</sup> d <sup>-1</sup> )	0.2	0.5	1	1.5

## 2.4. Sampling and analytical methods

The DHS reactor was operated within 110 days in which the sampling time was 81 days for three level of organic loading rate. Influent and effluent samples were taken three times per week at the same moment of the day and analyzed such parameter pH, DO, BOD<sub>5</sub>, COD, NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>-N, TN, TP to determine the treatment efficiency of the DHS system. Samples were taken during the operational period. Such parameters COD, NO<sub>3</sub><sup>-</sup>-N, NH<sub>4</sub><sup>+</sup>-N, TN, TP were analyzed in the laboratory according to APHA [10]. Biological oxygen demand BOD<sub>5</sub> was analyzed by BOD-OxiDirect (AL606). Other parameters such as DO, pH, and turbidity were directly tested by a Multi Parameter Water Quality Meter, WQC-22A (Japan).

## 3. RESULTS AND DISCUSSION

### 3.1. pH and dissolved oxygen (DO)

The pH values of influent wastewater were stable at 7.0 - 7.5 throughout experiment without adjustment. The effluents samples had pH values in the range of 6.9 - 7.3 in the operational periods (data not shown). These ranges of pH were suitable as the condition of pH for the growth of microorganisms [2]. Therefore, the pH value in the present study was achieved as the optimum level for performance of biological treatment.

DO concentration of influent and effluent is shown in Fig. 2. It is clear to see that DO was low in the influent (0.6 – 1 mg/L) and it increased up to 1.2 – 2.5 mg/L in the effluent, these values of DO could indicate the oxidation condition of DHS reactor. This increase in the DO concentration can be explained by diffusion of oxygen from the atmosphere to the DHS reactor segments flowing through the reactor, and also the circular flow (1:1) could supply more DO for the system. Therefore, the DHS system did not require any external aeration which can save energy and devices required for aeration. This trend of DO is similar to the result of the previous study [11]. However, the DO concentration of the effluent in this study was lower than that DO concentration found out by other studies [8, 12].

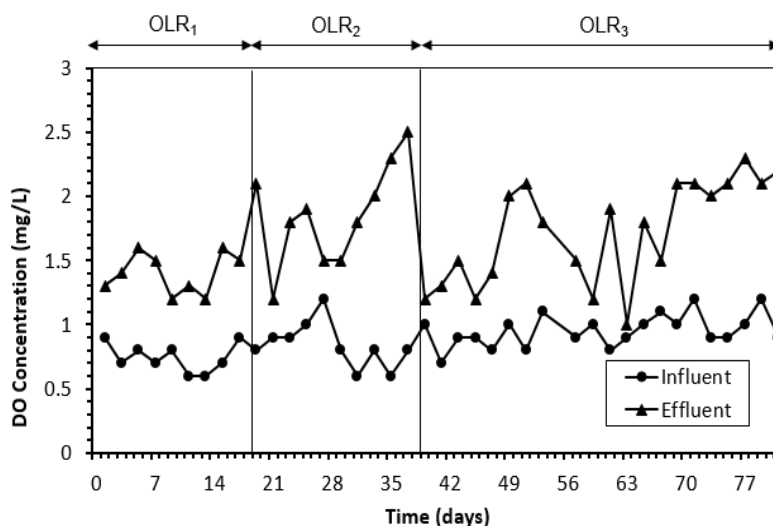


Figure 2. Dissolved oxygen profile during the time course.

### 3.2. Chemical oxygen demand (COD) removal

The profile of COD influent, effluent and removal efficiency are illustrated in Figure 3. It is shown that the influent COD was variable with an average at about 280 mg/L. The COD values of effluent were stable at about 70 mg/L except some samples was higher in the duration of day 46-45 of the time course because of highly fluctuation of the influent. The removal efficiency was low in the early stage of the start at getting increased after that, the COD removal efficiency achieved 80 % on the ninth day of first level organic loading rate. In stage 2, OLR was increased to 1 kg COD m<sup>-3</sup> day<sup>-1</sup>, the removal of COD was stable at around 80 %. In the third stage, the system was operated at OLR 1.5 kg COD m<sup>-3</sup> day<sup>-1</sup>, the COD removal efficiency was decreased and fluctuated at about 70 %. Perhaps, the lower removal efficiency in stage 3 was due to the higher organic loading rate and unstable of the influent COD. The COD removal of DHS model was discussed in previous study. Araki and colleagues used a system of UASB followed by a DHS model to treat municipal sewage, their system could achieve 94% of COD removal in with the removal of DHS model was 71 % [13]. In another study, Mahmoud et al. operated a DHS system to treat UASB effluent at OLR of 3.2 kg COD m<sup>-3</sup> day<sup>-1</sup>, this experiment showed that the removal of carbonaceous organic matter in terms of COD was 61 ± 12 % [5]. A research of modelling and profile analysis of a down-flow hanging sponge system treating agricultural drainage water at OLR as 3 kg COD m<sup>-3</sup> day<sup>-1</sup>, the result of model showed average removal efficiencies of COD was as of 83.7 % [11]. It could be recognized that similar removal efficiencies were achieved in this study and those of previous studies. However, previous study confirmed that the combination of anaerobic-aerobic systems could achieve higher removal efficiency in comparison with the single aerobic one [14].

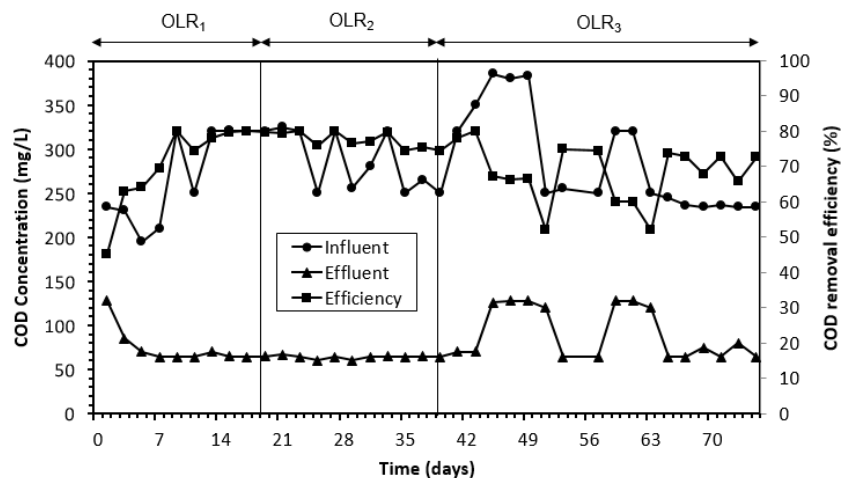
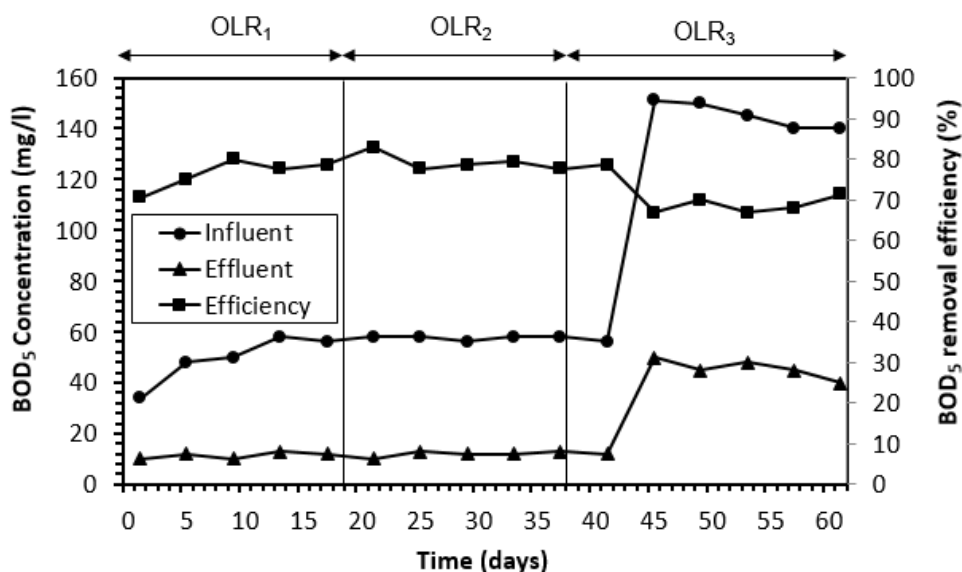


Figure 3. Profile of COD in the influent and the effluent of DHS system during the time course.

### 3.3. Biological oxygen demand (BOD) removal

Figure 4 shows the influent, effluent and removal efficiency of biological oxygen demand during the time course. The BOD profile of the influent was low in the first stage the second stage at about 30 – 60 mg/L, from the day 42 to 60 of the operational period BOD was increased significantly to 140 – 140 mg/L. The removal efficiency of BOD<sub>5</sub> was 73 % at the start and getting increased and stable quickly. In the level 2 of organic loading rate, the reactor performed stably at BOD<sub>5</sub> removal at about 80 %. In the level 3 of organic loading rate the BOD removal

efficiency was decreased but still maintained stable condition until the end of the experiment. Higher removal efficiencies were achieved in this research than those reported in previous



studies by Mahmoud et al. [5] as  $67 \pm 9\%$  and Tandukar et al. [4].

Figure 4. Profile of BOD in the influent and the effluent of DHS system during the time course.

### 3.4. Nitrogen-ammonium ( $\text{NH}_4^+\text{-N}$ ) and nitrate nitrogen ( $\text{NO}_3^-\text{-N}$ ) removal

Figure 5 illustrates the results of  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$  profiles during the time course. It is easy to see that the removal of  $\text{NH}_4^+\text{-N}$  was stable throughout the experimental period (Fig. 5a). The DHS  $\text{NH}_4^+\text{-N}$  removal efficiency shows that the system is capable of good  $\text{NH}_4^+\text{-N}$  removal with average removal rate of 62 % with the removal efficiency of ammonia was around 63 % during the operation of first and the second stages. In stage 3,  $\text{N-NH}_4^+$  increased in the influent together with the increase of OLR resulting slightly decreased of  $\text{N-NH}_4^+$  removal efficiency at about 60 % during this time. This result indicated that the nitrification process was happened well in DHS model. In a previous study, Cetin and colleagues operated aerobic sequencing batch reactors to treat domestic wastewater and achieved the  $\text{NH}_4^+\text{-N}$  removal efficiency of 60 % [15], that our present study was quite similar with. Nitrification process performs in aerobic condition in two steps. The first step happens in the presence of *Nitrosomonas spp* genus, in which  $\text{NH}_4^+$  is oxidized into  $\text{NO}_2^-$  by following the equation:  $\text{NH}_4^+ + 1.5 \text{O}_2 \Rightarrow \text{NO}_2^- + 2\text{H}^+ + 2\text{H}_2\text{O}$ ; after that nitrite-oxidizing bacteria (*Nitrobacter spp*) oxidize nitrite to nitrate according to equation  $\text{NO}_2^- + 0.5 \text{O}_2 \Rightarrow \text{NO}_3^-$ . The evidence of nitrification process in DHS system is indicated more in the change of nitrate concentration in the influent and effluent (Fig. 5b). It is interesting to see that the nitrate concentration in the influent was inconsiderable but it was increased up to 7-10 mg/L in the effluent. This result confirms that the operational conditions of the experiment could provide good condition of oxidation condition for nitrification of ammonia containing in the influent. The conversion of nitrogen-ammonia to nitrogen-nitrate in this aerobic process can give chances for different groups of microorganisms to grow and further treatment of nitrogen especially the denitrification in anoxic condition for enhancement of nitrogen removal.

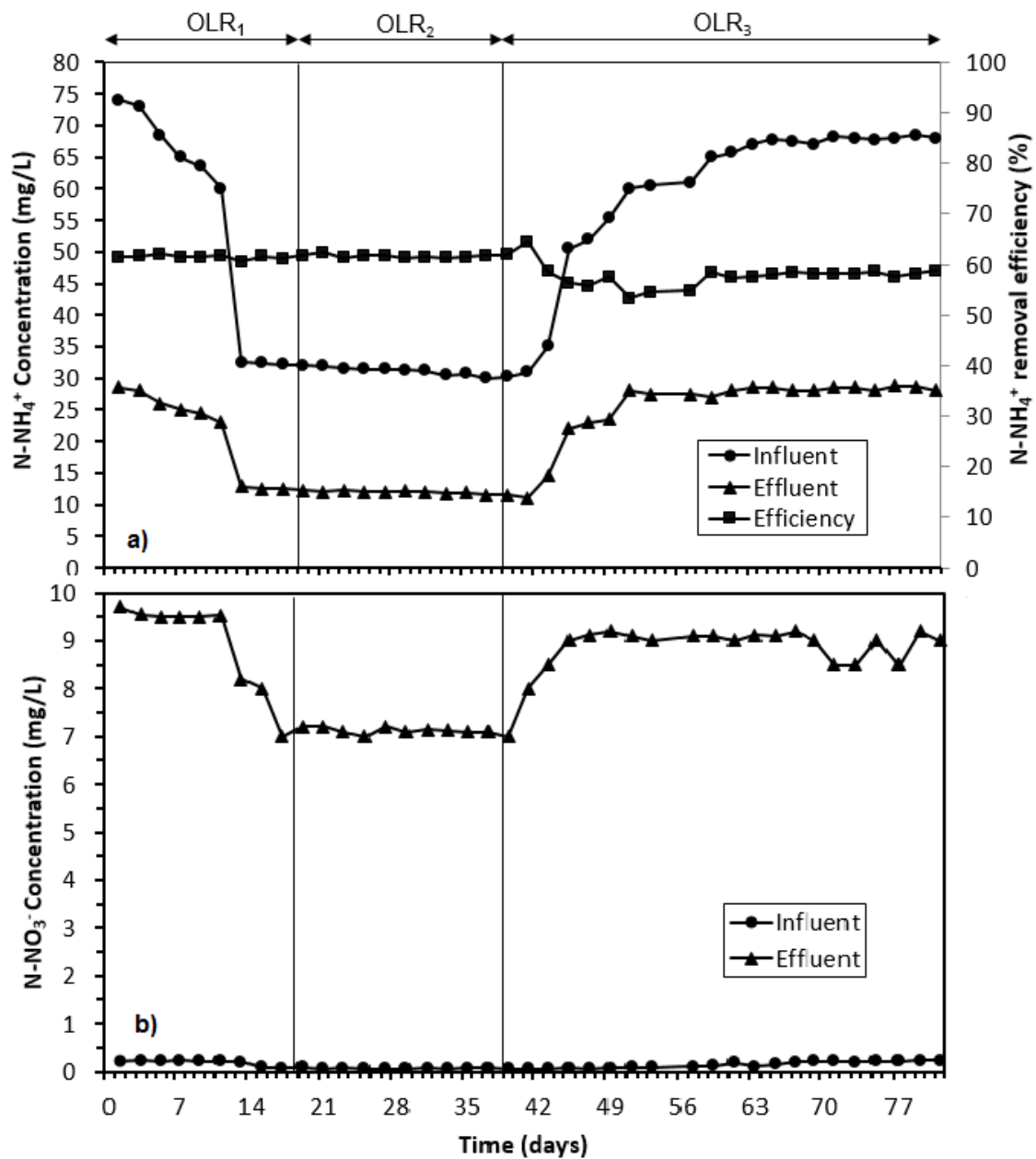


Figure 5. Profile of NH<sub>4</sub><sup>+</sup>-N (a) and NO<sub>3</sub><sup>-</sup>-N (b) in the influent and the effluent of DHS system during the time course.

### 3.5. Total nitrogen (TN) removal

Figure 6 shows the total nitrogen concentration in the influent and effluent were high in the first and the third stages and the removal efficiency in this period was about 50 %. In contrast, in the second stage of the experiment, influent TN was lower than the other stages, the removal efficiency in this stage was about 58-60 %. The total nitrogen concentration in Fleifle et al. modeled a DHS system for treating agricultural drainage, which showed that this model can remove total nitrogen at 65.57 %. during the time course [11]. It was discussed above about the



good conversion of ammonia to nitrate in nitrification resulted increasing of nitrate concentration in the effluent. Abualhail and colleagues investigated organic and nutrient removal by using the anaerobic–anoxic/oxic (A2O) and indicated that this system could achieve 76.45 % of total nitrogen removal [16]. However, the total nitrogen removal in this study was not high. From this result, it can be seen that the DHS system could perform well in the nitrification process but the total nitrogen was not further treated. It means, there was not available of anoxic condition for the denitrification in the reactor thus nitrate was not converted to nitrogen gas. The total nitrogen that removed from the system can be attributed to the assimilation of microorganisms to produce new cells.

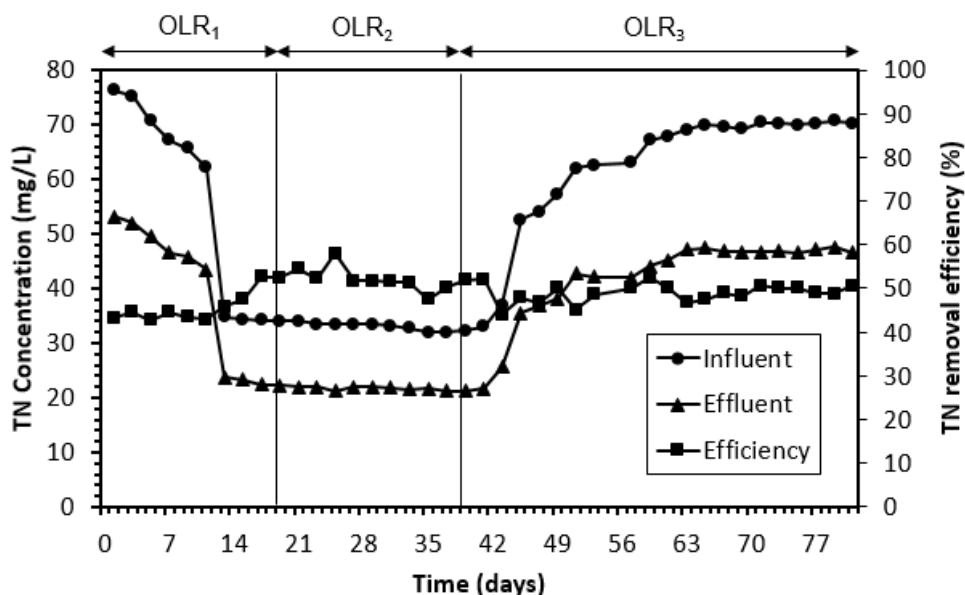


Figure 6. Profile of total nitrogen (TN) in the influent and the effluent of DHS system during the time course.

#### 4. CONCLUSION

In this work, the lab scale of down-flow hanging sponge (DHS) system in treating domestic wastewater was investigated. The available results showed that DHS system performed well throughout the operational period and achieve the maximum removal of COD, BOD<sub>5</sub>, NH<sub>4</sub><sup>+</sup>-N, and TN as 80 %, 83 %, 65 % and 60 %. The residual concentrations of COD, BOD<sub>5</sub>, NH<sub>4</sub><sup>+</sup>-N, and TN in the effluent of both treatment system were in compliance with national standards regulating discharge of treated domestic wastewater into received sources (National technical regulation on domestic wastewater, type B, QCVN 14:2008/BTNMT). In conclusion, down-flow hanging sponge system can show a good performance for removing of organic matters and converting nitrogen ammonia to nitrogen nitrate in domestic wastewater. However, in order to expand application of this model, it is necessary to study further by providing an anoxic zone in the system to enhance the treatment of nutrient in wastewater. In addition, it needs to investigate further for other types of wastewater and experimental conditions of DHS system.

**Acknowledgements.** The authors are profoundly grateful and deeply appreciative of Vietnam Ministry of Natural Resource and Environment for financial support; Hochiminh City University of Natural resource

and Environment, Nong Lam University – Hochiminh City for accommodation of the experimental facilities, and Ms. Tran Thi Tri for assistance in the experimental procedures and data analysis.

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