The use of water spinach (*Ipomoea aquatica*) in domestic wastewater treatment

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ABSTRACT

The main objective of this study was to examine the efficacy and capacity of using hydroponic systems in municipal pollutant removal at household scale. Three pilot scaled hydroponic systems [dimension for each system: 4.5 m (L) x Φ 114 mm] were installed to investigate the optimal age of vegetable, planting density and retention time for household wastewater treatment, respectively. Water spinach (*Ipomoea aquatica*) planted in 27 plastic cups throughout 4.5-m-length and 114-mm-diameter uPVC pipes filled with wastewater was employed as the treating agent of pollutants. The averaged influent contained proximately 32.5 mg/L suspended solids (SS), 76.0 mg/L biological oxygen demand (BOD_5), 220.5 mg/L chemical oxygen demand (COD), 26 mg/L NH_4^+, 5.0 mg/L NO_3^-, and 8.5 mg/L PO_4^{3-} at pH 7.3. Results showed that a designed system consisting of 10 plants of 15-day-old water spinach pre-planted in baked clay in each cup was capable of treating 30 L of domestic wastewater meeting the current municipal wastewater discharge standards in Vietnam (column A standards of QCVN 14:2008/BTNMT) after 4 days of wastewater retention time. If operated under conditions of the above parameters, the pilot-plant hydroponic system can achieve the removal of 65% SS, 82% BOD_5, 74% COD, 90% NH_4^+, 30% NO_3^- and 86% PO_4^{3-}. The result of this study has provided an applicable domestic wastewater treatment system eco-friendly and suitable for small and medium household areas.

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1. Introduction

The proportion of domestic wastewater treated is at low levels, and raw wastewater is usually discharged directly to environment in urban areas of Vietnam (MONRE, 2016). Currently, 37 collective wastewater treatment plants have been in operation in urban centers of grade III or higher cities (MONRE, 2016). Wastewater drainage systems, however, have not been completed, causing difficulties in collecting and leading wastewater to treatment plants (MONRE, 2016). Hence, a domestic wastewater treatment plant at household scale is necessary to reduce pollutant loads to environment.

Domestic wastewater can be treated in different ways: mechanically, chemically or biologically (Luong, 2011; Hoang & Tran, 2014). Among biological treatments, the hydroponic system is a potential way for wastewater treatment at household scale because it is easy to establish and requires small space and harvested vegetable can be used as food (VEA, 2010). Hydroponic crops can be almost any type of plants such as vegetables, fruits, flowers, garden trees, herbs, ivy, and perennial that crops are harvested after a short planting period (Lem et al., 1990). It is easy to control various environment parameters as nutrients, pH, temperature, oxygen, etc. (Lem et al., 1990). Wastewater would be used instead of chemical fertilizers for growing vegetables. However, hydroponics has disadvantages such as higher initial costs than planting in soil and diseases could spread to the other plants root easily and are difficult to control in the case of planting with recirculation systems (Lem et al., 1990).

Ipomoea aquatica, or water spinach, is a herbaceous perennial trailing vine (Patnaik, 1976). It has hollow stems that grow floating or prostrate (Patnaik, 1976). The roots from the nodes penetrate the soil or mud, and the leaves are simple and alternate (Patnaik, 1976). This plant species grows well as a crop in regions where the mean temperature is above 25^0C (Patnaik, 1976). Hence, hydroponics in Vietnam is a conducive environment for water spinach to flourish.

Previous studies have demonstrated that planting *Ipomoea aquatica* in fishponds can efficiently remove nutrients and improve water quality (Li & Li, 2009; Dai et al., 2012). Accordingly, the current study expected that water spinach could use the nutrients in domestic wastewater for growing and reducing water pollutant loads. Pilot hydroponic systems with water spinach were established to examine the removal percentages of municipal pollutants in wastewater from an apartment. Moreover, the optimal age of water spinach, planting density and retention time were also determined for household guidelines.

2. Materials and Methods

2.1. Domestic wastewater characteristics

Domestic wastewater was collected from collecting tank of Sunview Apartment, Cay Keo Street, Thu Duc District, HCMC, Vietnam in the morning from January to June 2017 according to TCVN 6663-1:2011 and ISO 5667-1:2006. The wastewater parameters included: water temperature 29^0C, pH 7.3, SS 32.5 ± 1.5 mg/L, BOD_5 76.0 ± 8.0 mg/L, COD 220.5 ± 25.5 mg/L, NH_4^+-N 26.0 ± 4.0 mg/L, NO_3^--N 5.0 ± 1.0 mg/L, and PO_4^{3-} 8.5 ± 1.5 mg/L and did not vary much throughout the experiments. Wastewater was pre-filtered through a kitchen sieve to remove large particles, contained in 30-L plastic buckets and transferred to Environmental Technology Laboratory of Faculty of Environment and Natural Resources, Nong Lam University. The wastewater was then analyzed and employed for the experiments immediately.

2.2. Conditions of water spinach

Prior to the experimetns, water spinach was grown hydroponically in baked clay at Institute of Biotechnology and Environment (IBE), Nong Lam University. Water spinach seeds were provided by Phu Nong Seeds Company.

2.3. Experiments

2.3.1. Hydroponic systems

Three pilot scaled experiments consisting hydroponic systems [dimension for each system: 4.5 m (L) x Φ 114 mm] were installed with water spinach to investigate the optimal age of vegetable, planting density and hydraulic retention time (HRT) for household wastewater treatment, respectively (Figure 1). Water spinach (*Ipomoea aquatica*) planted in 27 plastic cups throughout 4.5-m-length and 114-mm-diameter uPVC pipes filled with wastewater was employed as the treating agent of pollutants. A similar designed pipe without water spinach was used to make the control.

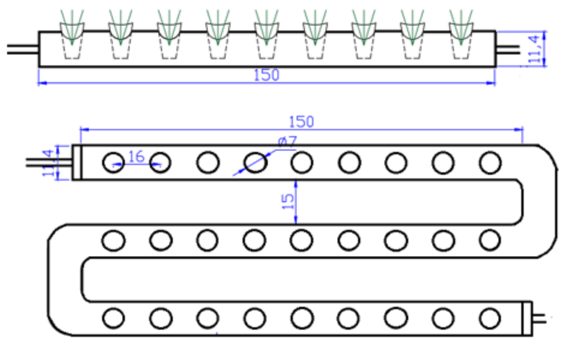

Figure 1. Hydroponic pilot (sizes in cm).

The pre-experiments were executed to choose ranges of vegetables' optimal age (10, 15 and 20 days old), optimal planting density (5, 10 and 15 plants per cup) and optimal retention time (2, 4 and 6 days).

2.3.2. Determination of the optimal age of vegetables

After 10, 15, and 20 days pre-planted in baked clay at IBE, water spinach was transferred to three hydroponic systems, respectively in 27 plastic cups. Each cup contained 10 plants. The control system was made without vegetables. Thirty liters of domestic wastewater were added to each hydroponic systems with HRT = 4 days. Treated wastewater was collected after HRT to analyze

SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations remaining.

2.3.3. Determination of the optimal planting density

Fifteen-day-old water spinach was planted in 27 plastic cups with 3 different densities of 5, 10 and 15 plants per cup throughout the pipes, respectively. The control system was made without vegetables. Thirty liters of domestic wastewater was added to each hydroponic systems with HRT = 4 days. Treated wastewater was collected after HRT to determine SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentration residues.

2.3.4. Investigate the optimal retention time

Thirty liters of domestic wastewater was added to each hydroponic systems. Fifteen-day-old water spinach was removed from baked clay and put in 27 lastic cups with the density of 10 plants/cup. There were 3 hydroponic systems with 3 different HRTs of 2, 4, and 6 days, respectively. A control system was made without vegetables. Treated wastewater was collected after HRT to analyze SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations remaining.

2.4. Water analysis

The concentrations of SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} and pH of the wastewater out of the hydroponic systems were checked after hydraulic retention time. The water sample was collected stochastically from three locations of each hydroponic system from 8 AM to 9 AM with 100 mL per model.

Chemical oxygen demand was analyzed according to SMEWW 5220 D (2012). BOD_5 was analyzed according to TCVN 6001-1:2008 and ISO 5815-1:2003. NH_4^- (LoD = 0.2 mg/L, LoQ = 0.5 mg/L), NO_3^- (LoD = 4 mg/L, LoQ = 10 mg/L) and PO_4^{3-} (LoD = 0.04 mg/L, LoQ = 0.1 mg/L) concentrations were determined by Sera Test Kits (Germany). In addition, the samples have concentrations of NO_3^- less than 20 mg/L were determined by Tropic Marin Test Kits (Germany) with LoD = 0.5 mg/L and LoQ = 1.5 mg/L. pH was measured by LAQUAtwin portable pH meter (HORIBA Scientific, Japan). Temperature was measured by mercury thermometer. Each measurement was made 3 times.

3. Results

3.1. Optimal age of water spinach

After 4 days, SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations of wastewater in the hydroponic systems containing 10, 15, and 20-day-old water spinach were 13.0 ± 1.5, 15.0 ± 2.0, 61.0 ± 5.0, 4.0 ± 1.0, 3.0 ± 0.5 and 2.0 ± 0.5 mg/L; 11.8 ± 1.3, 13.5 ± 2.5, 57.5 ± 5.5, 2.5 ± 0.5, 3.5 ± 0.5 and 1.2 ± 0.2 mg/L; and 16.0 ± 1.0, 15.5 ± 2.0, 67.5 ± 6.5, 3.5 ± 0.5, 4.0 ± 1.0 and 2.5 ± 0.5 mg/L, respectively (Figure 2). The pH values ranged from 7.9 to 8.1 in the three systems. As a result, the efficiency of the system with 15-day-old water spinach was greater than that of the other systems. Therefore, 15-day-old water spinach was employed for the next experiments.

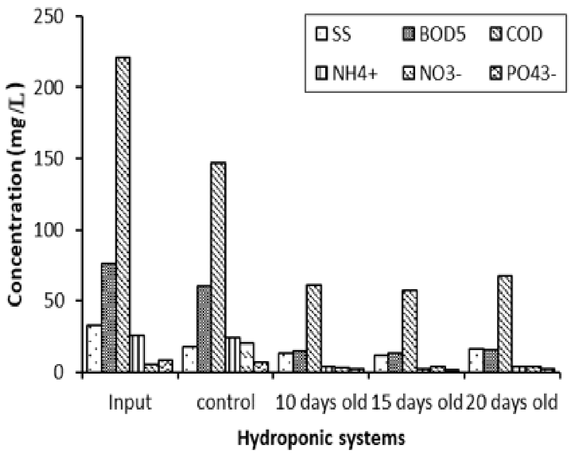

Figure 2. Treated wastewater parameters in hydroponics with different initial ages of water spinach.

3.2. Optimal planting density

After 4 days, treated SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} values of hydroponic systems with 5 plants/cup, 10 plants/cup, and 15 plants/cup were 15.0 ± 1.5, 16.0 ± 2.0, 68.0 ± 7.0, 3.0 ± 0.5, 4.0 ± 0.5 and 1.5 ± 0.5 mg/L; 11.0 ± 1.0, 14.0 ± 2.0, 55.0 ± 5.0, 2.5 ± 0.5, 3.0 ± 1.0 and 1.2 ± 0.2 mg/L; 10.0 ± 1.0, 14.0 ± 2.0, 57.5 ± 5.5, 2.5 ± 0.5, 3.5 ± 1.0 and 1.4 ± 0.2 mg/L, respectively (Figure 3). The pH values ranged from 7.5 to 8.0. Consequently, the optimal density was 10 plants each cup and used in the last experiment.

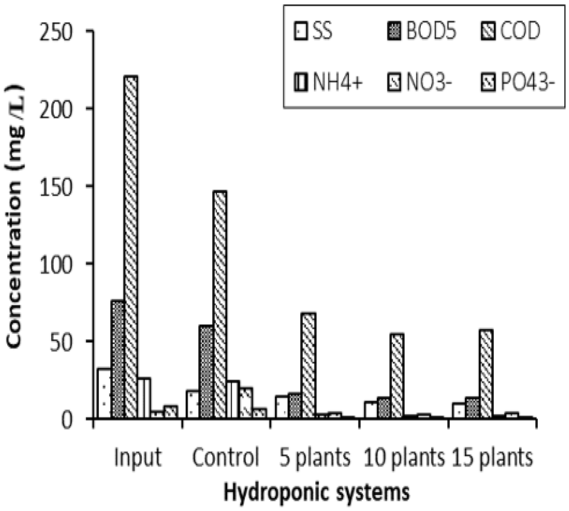

Figure 3. Treated wastewater parameters in hydroponics with different planting densities.

3.3. Optimal retention time

After HRT = 2 days, SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations of wastewater in the experimental hydroponic system were 19.5 ± 1.5, 53.0 ± 6.0, 97.0 ± 15.0, 3.0 ± 0.5, 4.0 ± 1.0 & 2.0 ± 0.5 mg/L, respectively (Figure 4a) and pH was 7.5 ± 0.1 while those of the control system were 24.0 ± 1.0, 68.0 ± 8.0, 160.0 ± 20.0, 24.0 ± 4.0, 5.0 ± 1.0 and 7.5 ± 0.5 mg/L, respectively (Figure 4b) and pH was 7.1 ± 0.2. After HRT = 4 days, SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations of wastewater in the experimental hydroponic system were 11.5 ± 1.5, 13.5 ± 5.5, 57.0 ± 8.0, 2.5 ± 0.5, 3.5 ± 0.5 and 1.2 ± 0.3 mg/L respectively (Figure 4a) and pH was 7.8 ± 0.1 while those of the control system were 18.0 ± 1.5, 60.0 ± 6.0, 146.5 ± 18.0, 24.0 ± 4.0, 20.0 ± 2.0 and 7.0 ± 0.5 mg/L respectively (Figure 4b) and pH was 6.8 ± 0.1. These parameters met the current municipal wastewater discharge standards in Vietnam (column A standards of QCVN 14:2008/BTNMT).

After HRT = 6 days, SS, BOD_5, COD, NH_4^-, NO_3^-, and PO_4^{3-} concentrations of wastewater in the experimental hydroponic system were 3.5 ± 0.5, 6.0 ± 1.0, 36.0 ± 7.0, 2.5 ± 0.5, 3.0 ± 0.5 and 1.2 ± 0.5 mg/L respectively (Figure 4a) and pH was 8.1 ± 0.1 while those of the control system were 7.0 ± 1.0, 52.0 ± 6.0, 112.0 ± 15.0, 22.0 ± 4.0, 25.0 ± 3.0 and 7.0 ± 1.0 mg/L respectively (Figure 4b) and pH was 6.5 ± 0.1.

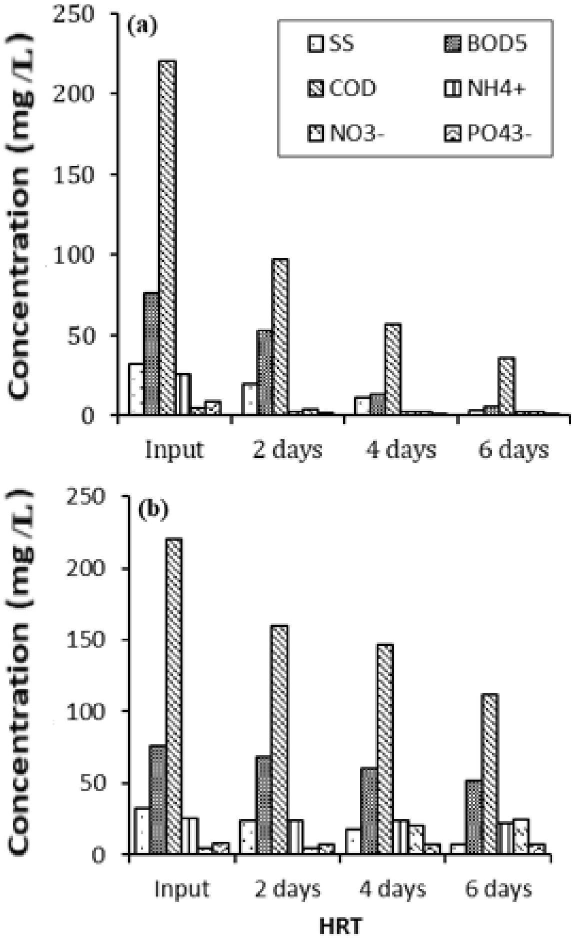

Figure 4. Treated wastewater parameters in (a) hydroponics with different HRTs and (b) the control system.

4. Discussion

4.1. Hydroponics with water spinach

In general, a hydroponic system consisting of 10 plants of 15-day-old water spinach pre-planted in baked clay in each cup could process 30 L of domestic wastewater to meet the current municipal wastewater discharge standards in Vietnam (column A standards of QCVN 14:2008/BTNMT) at a HRT of 4 days.

4.1.1. pH

pH of the wastewater out of the hydroponic systems increased slightly from 7.3 to over 7.5 in all experiments. That was because the water spinach in the hydroponic systems absorbed

$CO2$ for photosynthesis, so the pH of water was increased. $CO2$ in the water reacts with water to produce H+ and bicarbonate to decrease pH of water according to the mechanism: : $CO_2 + H_2O \leftrightarrows H_2CO_3 \leftrightarrows H^+ + HCO_3^-$ (Kanabkaew & Puetpaiboon, 2004). Because CO_2 for photosynthesis of aquatic plants is absorbed faster than the amount of CO_2 generated from the respiratory process of the quatic plants, plants must take CO_2 from the metabolism of HCO_3^- ($2HCO_3^- \rightarrow CO_2 + CO_3^{2-} + H_2O$) (Kanabkaew & Puetpaiboon, 2004). Therefore, the pH of water increases.

4.1.2. SS removal

The SS concentration decreased from 32.5 ± 1.5 mg/L to 11.8 ± 1.3 mg/L (Figure 4a), which means 65% of SS was removed from the wastewater. The removal of SS may be due to sedimentation or/and breakdown of microorganisms and plants.

4.1.3. COD and BOD_5 removal

Previous research has show that COD and BOD5 can be assimilated by plants (Vymazal & Kropfelova, 2009). The microbes around the roots can also contribute to the purification. The flourishing roots can provide a comfortable environment for microbes. Thus, the organic matter can be removed effectively. The concentrations of COD and BOD_5 decreased from 220.5 ± 25.5 mg/L to 57.5 ± 5.5 mg/L and from 76.0 ± 8.0 mg/L to 13.5 ± 2.5 mg/L, respectively (Figure 4a). 74% of the COD and 82% of the BOD_5 were removed from the wastewater. The efficiency of removal at different HRTs was quite difference. The efficiency of short HRT (2 days) was lower than that of middle HRT (4 days) (Figure 4). This could be because the plants needed a period of time to adapt to the new environment. When the roots grew flourishing, the plants could purify the water by assimilation of organic matters and nutrients.

4.1.4. Nitrogen removal

The concentrations of $NH_4^+$and NO_3^- in wastewater decreased from 26.0 ± 4.0 mg/L to 2.5 ± 0.5 mg/L and from 5.0 ± 1.0 mg/L to 3.5 ± 0.5 mg/L, respectively (Figure 4a). 90% of the NH_4^+-N and 30% of the NO_3^--N were removed from the wastewater. The nitrogen in wastewater existed in the form of organic nitrogen, NH_4^+-N and NO_3^--N. In the current study, the removal of odd nitrogen in wastewater relied on the assimilation of these compounds by water spinach in hydroponic systems. Firstly, NH_4^+ was converted to NO_3^- and a portion of NO_3^- would then be denitrificated to N2 by microorganisms. Another NO_3^- portion was absorbed by water spinach via roots for growing. However, which process contributed more to the NO_3^- removal was not clarified. In other words, NO_3^- could be assimilated by plants or sent back to the atmosphere by the effect of denitrifying microorganisms (Xu et al., 1999).

4.1.5. Phosphorus removal

Phosphorus is the essential nutrient for plant growth. It can be assimilated by plants and be converted into various kinds of organic matter of plants (Gu et al., 2008). Water spinach, therefore, could assimilate PO_4^{3-} in wastewater and make a reduction from 8.5 ± 1.5 mg/L to 1.2 ± 0.2 mg/L. Eighty six percent of PO_4^{3-} were removed from the wastewater.

4.2. Control system

On one hand, after HRT we observed moss stricking on the inner surface of pipes in the control system. On the other hand, SS created a visible layer of sediment on the inner surface. Moreover, activities of microorganisms could also break organic matters down in wastewater. Consequently, SS, BOD_5 and COD decreased (Figure 4b). Level of pH declined from 7.3 to 6.5. That was probably because NH_4^+ was nitrificated to NO_3^- as evidenced by decreasing NH_4^+ and increasing NO_3^- concentrations at the end of the experiment.

4.3. Suggested household hydroponic system

A family with 4 people release approximately 400 L of wastewater a day (MONRE, 2016). A tank of 1600 L is needed to store wastewater in 4 days. According to the design in this study, 240 m of Φ14-mm uPVC pipe are enough to treat the total amount of wastewater in 4 days. Pipes can be arranged as in Figure 1 or in tower shapes to save space. Total pipe investment costs VND 18,163,200.

5. Conclusions

The averaged influent contained proximately 220.5 mg/L chemical oxygen demand (COD), 76.0 mg/L biological oxygen demand (BOD5), 32.5 mg/L suspended solids (SS), 26 mg/L NH4+, 5.0 mg/L NO_3^-, and 8.5 PO_4^{3-} at pH 7.3. The designed system consisting of 10 plants of 15-day-old water spinach pre-planted in baked clay in each cup was capable of treating 30 L of domestic wastewater meeting the current municipal wastewater discharge standards in Vietnam (column A standards of QCVN 14:2008/BTNMT) after 4 days of wastewater retention time. If operated under conditions of the above parameters, the pilot-plant hydroponic system can achieve the removal of 74% COD, 82% BOD_5, 64% SS, 90% NH_4^+, 30% NO_3^- and 86% PO_4^{3-}. The result of this study has provided an applicable domestic wastewater treatment system eco-friendly and suitable for small and medium household areas.

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