Performance evaluation of horizontal flow constructed wetlands as primary and secondary treatment for university campus wastewater

Yee Yong Tan¹, Fu Ee Tang¹, Carrie Lee Ing Ho¹, Madeline Shu Zhen Wong¹
¹Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, Miri 98009, Sarawak, Malaysia

E-mail: tan.yee.yong@curtin.edu.my

Abstract. Horizontal flow constructed wetland (HFCW) is an attractive green technology for wastewater treatment. In the present study, four laboratory-scale HFCWs were constructed to serve as the primary and secondary treatment of university campus wastewater. The effect of hydraulic residence time (HRT) and pre-aeration of influent were investigated. The experimental results demonstrated that the wetland vegetation played an important role in the oxygen restoration and the influence of pre-aeration was minor. In the primary treatment, effective removals of TSS and NH₄-N were observed. However, the treatment of BOD and NO₃-N were insignificant due to the low influent concentrations. As for secondary treatment, the HFCWs effectively reduced the concentrations of BOD, NH₄-N, and NO₃-N in the effluent from the Intermittent Decanted Extended Aeration (IDEA) plant. The effluent quality of all HFCWs complied with the Standard A sewage discharge. Longer HRTs brought a positive effect to the removals of organic matter and nitrogen.

1. Introduction

Constructed wetlands have been well regarded as an attractive alternative for wastewater treatment due to its simple operation and maintenance, excellent energy efficiency, and reasonable construction cost [1]. Horizontal flow constructed wetland (HFCW) is a type of subsurface flow constructed wetland that the influent is fed at one side, and the treatment takes place when it flows horizontally towards the outlet zone. HFCWs have been widely used to treat municipal wastewater, stormwater runoff, agricultural wastewater, and industrial wastewater [2]. However, the application of such treatment technology is uncommon in Sarawak, where only a HFCW serves as a secondary treatment in a 600 population equivalent (PE) wastewater treatment system [3]. There was a pilot-scale HFCW treating greywater discharged from biofilters, but the system has been demolished due to some reasons [4]. The effluent from both HFCWs complied with the Standard A of the Environmental Quality Act (Sewage and Industrial Effluents) 1979, which revealed that HFCW is a feasible wastewater treatment option in Sarawak. Reference [5] indicated that the lack of interest in constructed wetlands in Sarawak was attributed to the insufficient existing system to demonstrate its treatment capability.

HFCW consists of a wetland bed planted with wetland vegetation. The wetland bed, which is also known as substrate, is typically constructed by sand or gravel [2]. Reference [6] emphasized that the selection of substrate materials is based on the permeability and retention capacity for the contaminants. The role of wetland vegetation in HFCW is to support the microbial growth and to release oxygen to the
substrate via the roots-rhizome [7]. Besides, the presence of wetland vegetation brought a positive effect in removing organic matter and nitrogen [8]. As the HFCW is continuously fed, the wetland bed is saturated and the concentration of dissolved oxygen is limited. The suspended solids are removed via filtration and sedimentation and the efficiency is always satisfactory [2,8]. On the other hand, the degradation of organic matter and nitrate is dependent on the anoxic and anaerobic processes [2,9]. In HFCW, the removal of ammonium is less efficient as the occurrence of nitrification is limited by the anoxic and anaerobic condition [8]. As a result, HFCW was typically used as a secondary or tertiary treatment option [1,10]. Artificial aeration was proposed as an operational alternative to enhance the treatment efficiency of organic matter and nitrogen in HFCWs [11]. Reference [8] also emphasized the significance of hydraulic residence time (HRT) in HFCW, in which a longer HRT contributed to better treatment efficiencies.

The main aim of this study was to determine the performance of HFCWs as a primary and secondary treatment system for university campus wastewater. Four laboratory-scale HFCWs were constructed in Curtin University Malaysia to treat raw wastewater and treated wastewater from the existing Intermittent Decanted Extended Aeration (IDEA) treatment plant. The effluents were sampled at regular intervals to assess the influence of HRTs in HFCWs. The effect of pre-aeration of influent on the treatment performance was also investigated. The effluent concentrations from HFCWs were compared to national effluent standard and the effluent from the IDEA plant.

2. Materials and Methods

2.1. Laboratory-scale HFCWs

Four laboratory-scale HFCWs were constructed in plastic containers that were 0.70 m long, 0.40 m wide, and 0.33 m high. The surface area and depth of the laboratory-scale HFCWs were 0.28 m² and 0.23 m, respectively. The sand was used as the main substrate materials in the HFCWs. The effective size and uniformity coefficient of the sand were determined using sieve analysis, which was 0.16 mm and 1.74 respectively. Constant head permeability test was adopted to measure the hydraulic conductivity of the sand, where an average value of 0.09 mm/s was obtained. The average porosity of the sand was 46%. 4.75 mm-gravel was used in the inlet and outlet zone of the HFCWs, where the main function was to uniformly distribute the influent wastewater and collect the treated wastewater. The substrate profile of the HFCW was 0.10 m inlet zone (4.75 mm-gravel), 0.50 m treatment zone (sand), and 0.10 m outlet zone (4.75 mm-gravel). The top surface of the substrate was covered with a 20 mm thick gravel layer to prevent the sand erosion, and thus the total depth of the substrate was increased to 0.25 m. Six common reeds (Phragmites karka) were planted in each HFCW. The bottom slope of the HFCW was set as 1°. Prior to the commencement of experiments, each HFCW were acclimatized with wastewater up to eight weeks. Figure 1 illustrates the schematic representation of the laboratory-scale HFCW.
2.2. Operation and analytical analysis of HFCWs

The laboratory-scale HFCWs were operated from May 2018 to August 2018. Two HFCWs were fed with raw wastewater, which was identified as primary treatment. Another two HFCWs were fed with treated wastewater from the IDEA plant located in Curtin University Malaysia, which were known as secondary treatment. To study the effect of pre-aeration on the treatment performance, one of each primary and secondary HFCW was fed with influent that was aerated until the dissolved oxygen (DO) reached saturation. Table 1 summarises the descriptions of each HFCW in this study. Three litters of influent were fed in each system, and the effluents were sampled every 12-hour until 60 hours. The experiments were repeated for four times in each HFCW. The parameters used to evaluate the performance included dissolved oxygen (DO), total suspended solids (TSS), 5-day biochemical oxygen demand (BOD₅), ammonium (NH₄-N) and nitrate (NO₃-N). DO, BOD₅, NH₄-N, NO₃-N were measured using Hach HQ40D Portable Multi Meter with IntelliCAL™ probes, while Hach DR2800 Spectrophotometer was used to determine the concentration of TSS.

Table 1: Descriptions of HFCWs

| HFCW | Influent                          | Aeration of Influent |
|------|-----------------------------------|----------------------|
| PN   | Raw Wastewater (Primary)          | No                   |
| PA   | Raw Wastewater (Primary)          | Yes                  |
| SN   | Treated Wastewater (Secondary)    | No                   |
| SA   | Treated Wastewater (Secondary)    | Yes                  |

3. Results and Discussion

The results of the influent and effluent of each HFCW are presented in Table 2 to Table 5. According to Table 2 and Table 3, it was observed that the quality of raw wastewater was highly variable. The concentrations of DO fluctuated between 0.55 mg/L and 2.6 mg/L and TSS concentrations were within a range of 89 mg/L to 112 mg/L. The BOD₅ was unexpectedly low in raw wastewater, in which only two samples showed a concentration above 1 mg/L. The concentrations of NH₄-N were typically high, which ranged from 22.70 mg/L to 117 mg/L. In contrast, the concentrations of NO₃-N were mostly below 0.7 mg/L. According to Table 4 and Table 5, the wastewater was aerated in the IDEA plant, where the DO concentrations were above 4.3 mg/L in all cases. The concentrations of TSS and NH₄-N were significantly reduced after the treatment, where the TSS concentrations were within a range of 30 mg/L to 33 mg/L and NH₄-N concentrations were below 51 mg/L. However, it was observed that the concentrations of BOD₅ and NO₃-N increased in the IDEA plant. The BOD₅ concentrations fluctuated between 4.49 mg/L and 7.33 mg/L, while the NO₃-N concentrations were mostly higher than 1 mg/L.

3.1. Dissolved oxygen (DO)

Figure 2 and Figure 3 illustrate the influent and effluent DO concentrations from HFCWs as primary and secondary treatment. It was observed that the pre-aeration of influent had an insignificant effect on the effluent DO concentrations from HFCWs. On the other hand, the effluent DO concentrations were greatly influenced by the wetland vegetation. As the HFCWs were fed at 6.30 pm, the wetland vegetation underwent respiration only during night time and it resulted in lower effluent DO concentrations in the first 12-hour of treatment. The only exception was HFCW PN. During the daytime, the oxygen was released from the photosynthesis of wetland vegetation, which substantially increased the DO concentrations in all HFCWs at the 24-hour HRT. A similar pattern was recorded in the following 36 hours. This observation demonstrated that the well-developed root-rhizome of the common reeds (as shown in Figure 4) effectively supplement oxygen in the primary and secondary HFCWs. This finding agreed with reference [7] and reference [12]. It also explained that the rise in DO concentrations in HFCW PN in the first 12-hour was due to the high initial oxygen content in the wetland bed.
Table 2: Results of influent and effluent of HFCW PN

| Samples   | 1      | 2      | 3      | 4      |
|-----------|--------|--------|--------|--------|
|           | DO (mg/L) |       |        |        |
| Influent  | 0.55   | 1.44   | 2.59   | 1.37   |
| 12 hours  | 2.38   | 2.34   | 1.96   | 2.4    |
| 24 hours  | 6.01   | 6.06   | 6.97   | 7.69   |
| 36 hours  | 2.59   | 2.32   | 3.38   | 4.75   |
| 48 hours  | 7.46   | 7.89   | 8.09   | 9.09   |
| 60 hours  | 3.7    | 3.32   | 3.84   | 4.78   |
|           | TSS (mg/L) |       |        |        |
| Influent  | 112    | 100    | - (a)  | 89     |
| 12 hours  | 34     | 31     | - (a)  | 32     |
| 24 hours  | 32     | 31     | - (a)  | 30     |
| 36 hours  | 33     | 28     | - (a)  | 29     |
| 48 hours  | 33     | 32     | - (a)  | 29     |
| 60 hours  | 31     | 34     | - (a)  | 30     |
|           | BOD₅ (mg/L) |       |        |        |
| Influent  | 0.82   | 6.71   | 0.51   | 0.29   |
| 12 hours  | 2.57   | 1.05   | 1.38   | 1.28   |
| 24 hours  | 1.37   | 0.82   | 1.74   | 1.89   |
| 36 hours  | 1.33   | 1.18   | 1.27   | 1.35   |
| 48 hours  | 0.73   | 0.69   | 0.74   | 0.88   |
| 60 hours  | 2.2    | 1.43   | 0.98   | 1.06   |
|           | NH₄-N (mg/L) |       |        |        |
| Influent  | 117    | 95.5   | 24.8   | 30.3   |
| 12 hours  | 6.81   | 2.14   | 1.63   | 1.2    |
| 24 hours  | 5.1    | 1.36   | 0.611  | 1.08   |
| 36 hours  | 1.2    | 0.618  | 1.26   | 0.672  |
| 48 hours  | 2.31   | 2.89   | 1.32   | 1.32   |
| 60 hours  | 1.61   | 1.12   | 0.683  | 0.875  |
|           | NO₃-N (mg/L) |       |        |        |
| Influent  | 0.312  | 0.25   | 12.5   | 0.632  |
| 12 hours  | 0.375  | 0.369  | 0.398  | 0.802  |
| 24 hours  | 0.406  | 0.484  | 0.409  | 0.402  |
| 36 hours  | 0.478  | 0.381  | 0.447  | 0.366  |
| 48 hours  | 0.352  | 0.716  | 0.446  | 0.439  |
| 60 hours  | 0.424  | 0.561  | 0.414  | 0.417  |

(a) Equipment was unavailable
Table 3: Results of influent and effluent of HFCW PA

| Samples   | Experiments | 1   | 2   | 3   | 4   |
|-----------|-------------|-----|-----|-----|-----|
| **DO (mg/L)** |             |     |     |     |     |
| Influent  |             | 7.44| 7.29| 7.50| 7.04|
| 12 hours  |             | 2.22| 1.26| 1.33| 1.64|
| 24 hours  |             | 5.84| 5.47| 5.74| 5.34|
| 36 hours  |             | 2.77| 2.23| 3.34| 3.06|
| 48 hours  |             | 7.28| 7.18| 8.58| 7.25|
| 60 hours  |             | 4.37| 3.66| 4.89| 3.89|
| **TSS (mg/L)** |         |     |     |     |     |
| Influent  |             | 108 | 112 | - (a)| 116 |
| 12 hours  |             | 36  | 34  | - (a)| 37  |
| 24 hours  |             | 31  | 34  | - (a)| 30  |
| 36 hours  |             | 31  | 31  | - (a)| 31  |
| 48 hours  |             | 32  | 30  | - (a)| 29  |
| 60 hours  |             | 37  | 34  | - (a)| 32  |
| **BOD₅ (mg/L)** |         |     |     |     |     |
| Influent  |             | 0.39| 3.68| 0.54| 0.12|
| 12 hours  |             | 2.30| 0.99| 1.37| 1.14|
| 24 hours  |             | 1.66| 0.71| 0.35| 0.70|
| 36 hours  |             | 1.12| 0.66| 0.16| 0.17|
| 48 hours  |             | 0.94| 0.35| 0.51| 0.44|
| 60 hours  |             | 0.62| 0.46| 0.61| 0.53|
| **NH₄-N (mg/L)** |       |     |     |     |     |
| Influent  |             | 115 | 75.90| 22.70| 32.60|
| 12 hours  |             | 3.41| 2.53| 0.893| 0.838|
| 24 hours  |             | 2.75| 1.45| 0.113| 0.51|
| 36 hours  |             | 0.418| 0.607| 0.303| 0.334|
| 48 hours  |             | 1.13| 0.868| 0.283| 0.298|
| 60 hours  |             | 0.716| 0.441| 0.194| 0.184|
| **NO₃-N (mg/L)** |       |     |     |     |     |
| Influent  |             | 0.394| 0.476| 17.10| 0.624|
| 12 hours  |             | 0.427| 0.218| 0.313| 0.838|
| 24 hours  |             | 0.453| 0.256| 0.404| 0.510|
| 36 hours  |             | 0.522| 0.283| 0.435| 0.334|
| 48 hours  |             | 0.444| 0.875| 0.454| 0.298|
| 60 hours  |             | 0.479| 0.706| 0.446| 0.184|

(a) Equipment was unavailable
Table 4: Results of influent and effluent of HFCW SN

| Samples   | DO (mg/L) | TSS (mg/L) | BOD$_5$ (mg/L) | NH$_4$$^+$-N (mg/L) | NO$_3$-N (mg/L) |
|-----------|-----------|------------|----------------|---------------------|-----------------|
|           | 1         | 2          | 3              | 4                   |                 |
| Influent  | 5.6       | 5.33       | 5.16           | 4.34                |                 |
| 12 hours  | 2.96      | 2.29       | 1.92           | 2.01                |                 |
| 24 hours  | 7.58      | 7.24       | 6.59           | 6.76                |                 |
| 36 hours  | 3.94      | 3.96       | 3.21           | 3.37                |                 |
| 48 hours  | 7.91      | 7.94       | 8.42           | 7.54                |                 |
| 60 hours  | 4.53      | 4.26       | 3.89           | 3.28                |                 |
| Influent  | 30        | 33         | - (a)          | 31                  |                 |
| 12 hours  | 33        | 30         | - (a)          | 39                  |                 |
| 24 hours  | 31        | 32         | - (a)          | 30                  |                 |
| 36 hours  | 30        | 32         | - (a)          | 33                  |                 |
| 48 hours  | 30        | 30         | - (a)          | 31                  |                 |
| 60 hours  | 30        | 33         | - (a)          | 30                  |                 |
| Influent  | 5.91      | 6.14       | 5.10           | 4.49                |                 |
| 12 hours  | 0.6       | 0.05       | 1.11           | 1.37                |                 |
| 24 hours  | 1.6       | 0.23       | 1.15           | 1.4                 |                 |
| 36 hours  | 0.43      | 0.31       | 1.03           | 0.94                |                 |
| 48 hours  | 0.7       | 0.19       | 0.36           | 0.85                |                 |
| 60 hours  | 0.1       | 0.35       | 0.41           | 0.45                |                 |
| Influent  | 50.6      | 32.3       | 8.92           | 15.80               |                 |
| 12 hours  | 1.12      | 0.388      | 0.306          | 0.325               |                 |
| 24 hours  | 0.906     | 0.204      | 0.268          | 0.248               |                 |
| 36 hours  | 0.239     | 0.0599     | 0.0822         | 0.177               |                 |
| 48 hours  | 0.57      | 0.636      | 0.116          | 0.251               |                 |
| 60 hours  | 0.299     | 0.146      | 0.0147         | 0.047               |                 |
| Influent  | 0.787     | 1.28       | 15.3           | 1.00                |                 |
| 12 hours  | 0.436     | 0.202      | 0.286          | 0.504               |                 |
| 24 hours  | 0.243     | 0.232      | 0.28           | 0.261               |                 |
| 36 hours  | 0.244     | 0.136      | 0.287          | 0.236               |                 |
| 48 hours  | 0.213     | 0.372      | 0.335          | 0.269               |                 |
| 60 hours  | 0.58      | 0.33       | 0.346          | 0.318               |                 |

(a) Equipment was unavailable
Table 5: Results of influent and effluent of HFCW SA

| Samples | Experiments | 1 | 2 | 3 | 4 |
|---------|-------------|---|---|---|---|
| Influent| DO (mg/L)   | 7.47 | 7.32 | 7.33 | 7.05 |
|         |             | 3.25 | 2.37 | 2.17 | 2.08 |
| 12 hours|             | 6.70 | 6.83 | 6.04 | 4.67 |
| 24 hours|             | 4.09 | 4.16 | 3.51 | 2.25 |
| 36 hours|             | 7.53 | 7.65 | 7.71 | 5.45 |
| 48 hours|             | 4.93 | 4.17 | 4.09 | 3.05 |
| 60 hours|             |     |     |     |     |
| TSS (mg/L)| Influent   | 33 | 32 | - (a) | 32 |
|         | 12 hours   | 31 | 31 | - (a) | 33 |
|         | 24 hours   | 29 | 34 | - (a) | 32 |
|         | 36 hours   | 32 | 34 | - (a) | 33 |
|         | 48 hours   | 31 | 35 | - (a) | 32 |
|         | 60 hours   | 31 | 34 | - (a) | 34 |
| BOD₅ (mg/L)| Influent   | 6.34 | 7.33 | 6.54 | 6.03 |
|         | 12 hours   | 1.22 | 0.91 | 1.44 | 1.26 |
|         | 24 hours   | 0.67 | 0.51 | 0.78 | 0.64 |
|         | 36 hours   | 0.45 | 0.36 | 0.88 | 0.48 |
|         | 48 hours   | 0.65 | 0.49 | 0.75 | 0.62 |
|         | 60 hours   | 0.38 | 0.82 | 1.3  | 1.17 |
| NH₄-N (mg/L)| Influent   | 43.7 | 21.4 | 8.68 | 16.8 |
|         | 12 hours   | 0.859 | 0.392 | 0.291 | 1.444 |
|         | 24 hours   | 0.744 | 0.267 | 0.219 | 0.456 |
|         | 36 hours   | 0.204 | 0.119 | 0.111 | 0.351 |
|         | 48 hours   | 0.652 | 0.315 | 0.0886 | 0.312 |
|         | 60 hours   | 0.376 | 0.18 | 0.0604 | 0.172 |
| NO₃-N (mg/L)| Influent   | 0.881 | 1.21 | 17.8 | 1.11 |
|         | 12 hours   | 0.836 | 0.354 | 0.331 | 0.597 |
|         | 24 hours   | 0.396 | 0.197 | 0.295 | 0.329 |
|         | 36 hours   | 0.313 | 0.212 | 0.31 | 0.251 |
|         | 48 hours   | 0.294 | 0.401 | 0.36 | 0.319 |
|         | 60 hours   | 0.347 | 0.387 | 0.365 | 0.312 |

(a) Equipment was unavailable
Figure 2: Influent and effluent DO concentration of HFCW PN and PA

Figure 3: Influent and effluent DO concentration of HFCW SN and SA

Figure 4: Roots-rhizome of common reeds in HFCWs
3.2. *Total suspended solids (TSS)*

Figure 5 and Figure 6 illustrate the influent and effluent TSS concentrations from HFCWs as primary and secondary treatment. As the removal of TSS was dependent on filtration and sedimentation process [10], the effect of pre-aeration was insignificant to the treatment performance. According to Figure 5, the effluent TSS concentrations were within a range of 30 to 40 mg/L and were independent of influent concentrations and HRTs. The overall removal efficiencies of TSS in HFCW PN and PA were between 68 and 73%. As for secondary treatment, no TSS removal was observed in SN and SA as the influent TSS concentrations were typically low. These observations showed that no further TSS removal was achieved in the HFCWs when the TSS concentration was around 30 mg/L. The removal efficiencies and effluent TSS concentrations were similar to reference [8] but were lower than reference [1] and reference [4]. Since the accumulation of solids and debris, as well as the continuous growth of microorganisms and root-rhizomes, were beneficial to the TSS removals, the treatment capacity of HFCWs could be higher in the process of time [8].

![Figure 5: Influent and effluent TSS concentration of HFCW PN and PA](image)

![Figure 6: Influent and effluent TSS concentration of HFCW SN and SA](image)

3.3. *Biological Oxygen Demand (BOD)*

Figure 7 and Figure 8 illustrate the influent and effluent BOD\(_5\) concentrations from HFCWs as primary and secondary treatment. In HFCW PA and PN, only the third run of experiments demonstrated BOD\(_5\) removals in the first 12-hour. This was due to the low BOD\(_5\) concentrations in raw wastewater, and thus the removal efficiencies of BOD in HFCWs as primary treatment were unable to be identified. The
organic matter released from the vegetal debris and microorganism in HFCWs contributed to higher BOD₅ concentrations in effluent [10].

As for secondary treatment, the BOD removals were observed in both HFCW SN and SA. The mean removal efficiencies of BOD in HFCW SN and SA in the first 12-hour of treatment were 84.19% and 81.36%, respectively. This finding indicated that the effect of pre-aeration of influent was insignificant compared to the influence of wetland vegetation. It is also observed that a longer HRT resulted in a lower BOD₅ concentration. In HFCW SA, the removal efficiency increased to 90% after 24-hour HRT, while HFCW SN achieved 93% at 60th hour. Similar observations were reported in reference [8]. The overall removal efficiencies of BOD₅ in HFCW SN and SA were higher than the data reported in the literature [1,8]. The well-developed roots-rhizome of common reeds maintained high oxygen content and supported the biofilm growth in HFCWs, which stimulated the aerobic degradation of organic matter and guaranteed a desirable treatment performance [8,11,12].

3.4. Ammonium (NH₄-N)

Figure 9 and Figure 10 illustrate the influent and effluent NH₄-N concentrations from HFCWs as primary and secondary treatment. According to Figure 9, the mean removal efficiencies of NH₄-N in HFCW PN and PA in the first 12-hour were 95.35% and 96.80%, respectively. The removal efficiencies and effluent
concentrations were much lower compared to the literature [1,2,8,11]. In HFCW, the treatment capacity of NH$_4$-N was limited by the DO concentrations, in which nitrification was less efficient under anoxic and anaerobic condition [9]. However, the DO concentrations were found to be high in the proposed HFCWs due to the presence of wetland vegetation, and thus the nitrification process acted an important role in removing NH$_4$-N. In addition, the influent concentrations of BOD were low, and thus the oxygen content did not pose as a limiting factor in the nitrification process. The adsorption and vegetation uptake also played important roles in NH$_4$-N removal. Reference [13] reported that the adsorption capacity of fine gravel for NH$_4$-N was more than 750 mg/kg. Reference [6] also indicated that the nitrogen uptake capability of common reeds was up to 2500 kg/ha/yr. Accordingly, the proposed HFCWs demonstrated excellent treatment capacity for NH$_4$-N. Similar to BOD, a longer HRT also contributed to a lower NH$_4$-N concentration. The removal efficiencies of NH$_4$-N achieved 97.96% and 99.34% in HFCW PN and PA, respectively. The removal efficiencies and effluent concentrations of HFCW SN and SA were highly similar to HFCW PN and PA.

![Figure 9: Influent and effluent NH$_4$-N concentration of HFCW PN and PA](image)

![Figure 10: Influent and effluent NH$_4$-N concentration of HFCW SN and SA](image)

3.5. Nitrate (NO$_3$-N)

Figure 11 and Figure 12 illustrate the influent and effluent NO$_3$-N concentrations from HFCWs as primary and secondary treatment. HFCW was well recognized as a treatment option that is favourable for denitrification and has excellent treatment capacity for NO$_3$-N [6]. However, the removals of NO$_3$-
N were insignificant in HFCW PN and PA due to the low influent concentrations. Only the third run of experiments demonstrated remarkable NO$_3$-N removal. The slight increase in the effluent concentrations of NO$_2$-N in the first 12-hour was attributed to the occurrence of nitrification in HFCWs, where NO$_3$-N was released from the degradation of NH$_4$-N. Based on the removal efficiencies of NH$_4$-N in HFCW PN and PA, the effluent concentrations of NO$_3$-N were expected to be much higher. Accordingly, the low NO$_3$-N concentrations in the effluent implied that denitrification and vegetation uptake removed a certain amount of NO$_3$-N in HFCWs. On the other hand, the HFCW SN and SA showed reasonable treatment for NO$_3$-N, which achieved mean removal efficiencies 69.13% and 55.05%, respectively, in the first 12-hour HRT. A longer HRT was advantageous to the denitrification, where the removal efficiencies reached the maximum at 36$^{th}$ hour in both HFCWs. The removal efficiencies and effluent concentrations of NO$_3$-N in HFCW SA and SN were comparable to reference [1] and reference [4]. The effect of pre-aeration of influent was not observed in the removal of NO$_3$-N in all HFCWs.

![Figure 11: Influent and effluent NO$_3$-N concentration of HFCW PN and PA](image1)

![Figure 12: Influent and effluent NO$_3$-N concentration of HFCW SN and SA](image2)

### 3.6. Primary treatment and secondary treatment

In order to assess the feasibility of HFCW as a primary treatment option for university campus wastewater, the effluent quality of HFCW PN and PA were compared to the effluents from the existing IDEA plant. In addition to this, the effluent quality of HFCW SN and SA were compared to the performance of IDEA plant to evaluate the treatment efficiencies as a secondary treatment. The present
study revealed that the influence of pre-aeration of influent was minor to the treatment performance of HFCWs, and thus the effluent quality of HFCW PN and PA were highly similar. Therefore, the effluent concentrations of HFCW PN and PA at each HRT (i.e., 12-hour, 24-hour, 36-hour, 48-hour, and 60-hour) were averaged to determine the mean effluent concentrations of each quality parameters. As significant treatment efficiencies were obtained in the first 12-hour, the 12-hour HRT was adopted in the analysis. A similar approach was carried out for HFCW SN and SA. Figure 13 presents the comparisons of the effluent quality from HFCWs, IDEA plant, and the acceptable conditions of sewage discharge of standard A in *Environmental Quality (Sewage) Regulations 2009*. The mean effluent concentration of DO from IDEA plant was higher than HFCWs, but the oxygen released from the photosynthesis of wetland vegetation substantially increased the DO content in the next 12 hours. The TSS concentrations from HFCW were slightly higher than the effluent from IDEA plant, but both systems fulfilled the requirement of Standard A sewage discharge (50 mg/L). The effluent BOD$_5$ and NO$_3$-N concentrations from both HFCWs and IDEA plant complied with the standard (20 mg/L and 10 mg/L, respectively), but the treatment performance of HFCWs were found to be better than the IDEA plant. The mean effluent concentration of NH$_4$-N from the IDEA plant was two times higher than the standard (5 mg/L), while the NH$_4$-N concentrations discharged from the HFCWs were below the limit. As for secondary treatment, Figure 14 demonstrated that the HFCWs improved the quality of the effluent from the IDEA plant, where the concentrations of BOD$_5$, NH$_4$-N, and NO$_3$-N were significantly reduced. However, no further removal of TSS was observed in HFCWs. The experimental results revealed that HFCW is a feasible option for the primary and secondary treatment of university campus wastewater.

![Figure 13: Performance of HFCWs as primary treatment](image1)

![Figure 14: Performance of HFCWs as secondary treatment](image2)
4. Conclusion
This study demonstrated that the proposed HFCW is a feasible option for the primary and secondary treatment of university campus wastewater. The oxygen dynamics in HFCWs were governed by the wetland vegetation, and the pre-aeration of influent had a minor effect on the treatment performance. The removals of TSS and NH$_4$-N were excellent in the primary treatment, but the treatment capacity of BOD and NO$_3$-N were unable to be identified due to the low influent concentrations. As for secondary treatment, the concentrations of BOD, NH$_4$-N, and NO$_3$-N were significantly reduced. However, no further removal of TSS was observed. Additionally, longer HRTs contributed to higher removal efficiencies of BOD, NH$_4$-N, and NO$_3$-N.

References
[1] Thalla A K, Devatha C P, Anagh K and Sony E 2019 Performance evaluation of horizontal and vertical flow constructed wetlands a tertiary treatment option for secondary effluents Appl Water Sci 9 pp 147
[2] Vymazal J 2010 Constructed Wetlands for Wastewater Treatment Water 2(3), pp 530-549
[3] Sewerage Services Department Sarawak 2016 Sewage Treatment Plant at Taman Boulder Built Kuching
[4] Ling T Y, Apun K and Zainuddin S R 2009 Performance of a pilot-scale biofilters and constructed wetland with Ornamental plants in greywater treatment World Applied Science Journal 6(11) pp 1555-1562
[5] Tan Y Y, Tang F E and Ho C L I 2019 Constructed Wetlands: Sustainable Solution to Managing Domestic Wastewater in the Rural Areas of Sarawak IOP Conf. Series: Materials Science and Engineering 495 pp 012063
[6] Kumar S and Dutta V 2019 Constructed wetland microcosms as sustainable technology for domestic wastewater treatment: an overview Environmental Science and Pollution Research 26(12) pp 11662-11673
[7] Vymazal J 2011 Plants used in constructed wetlands with horizontal subsurface flow: a review Hydrobiologia 674(1) pp 133-156
[8] Papaevangelou V, Gikas G D and Tsihrintzis V A 2016 Effect of operational and design parameters on performance of pilot-scale horizontal subsurface flow constructed wetlands treating university campus wastewater Environmental Science and Pollution Research 23(19) pp 19504-19519
[9] Vymazal J 2007 Removal of nutrients in various types of constructed wetlands Science of the total environment 380(1-3) pp 48-65
[10] Dotro G, Langergraber G, Molle P, Nivala J, Puigagut J, Stein O and Von Sperling M 2017 Treatment wetlands (Vol. 7) London UK: IWA publishing
[11] Zhang L Y, Zhang L, Liu Y D, Shen Y W, Liu H, and Xiong Y 2010 Effect of limited artificial aeration on constructed wetland treatment of domestic wastewater Desalination 250(3) pp 915-920
[12] Rehman F, Pervaz A, Khattak B N and Ahmad R 2017 Constructed wetlands: perspectives of the oxygen released in the rhizosphere of macrophytes CLEAN–Soil, Air, Water 45(1) pp 1600054
[13] Zhu W L, Cui L H, Ouyang Y, Long C F and Tang X D 2011 Kinetic Adsorption of Ammonium Nitrogen by Substrate Materials for Constructed Wetlands Pedosphere 21(4) pp 454-463

Acknowledgement
The authors would like to acknowledge Faculty of Engineering and Science, Curtin University Malaysia for supporting this study.