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Nitrogen removal from domestic wastewater using two stage tidal flow constructed Wetland

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ABSTRACT

In this study two stage tidal flow constructed wetland (TSTFCW), with three different ratios for Hydraulic Retention Time (HRT) 1:1, 1:2 and 1:3 in Phase-I and 1:1, 2:1 and 3:1 in Phase-II, is used to treat domestic wastewater. To enhance the removal efficiency first stage CW was planted with *Typha sp*. It was demonstrated that the maximum removal efficiencies of BOD_5, COD, TSS, NH_4-N, NO_2-N and TN were 46.09 %, 46.05 %, 77.25 %, 86.40 %, 50.47 % and 82.38 % respectively in Phase-I for 1:3 HRT ratio while maximum removal efficiency of NO_3-N was in Phase-II for 3:1 HRT ratio as 65.25 %. This study shows lower removal efficiency for organic matter removal which may be due to less HRT. The results suggest provision of more duration of HRT to achieve increase in efficiency of organic matter removal under same operating conditions.

Key words : *Two stage tidal flow constructed wetland, Hydraulic retention time, Nitrogen removal, Typha sp.*

Introduction

Conventional wastewater treatment technologies have several shortcomings, because of high construction costs and complex operation, especially for small towns (Liu *et al.,* 2016). Constructed wetland (CW) treatment systems are eco-friendly and sustainable technologies which mimic the function of natural wetland for improving water quality along with cost-effectiveness and simple in operation technology. CWs are equipped with vegetation, this vegetation stores nutrients, provides extra surface area for microbial growth (Butterworth *et al.,* 2016). CW is a complex biological and physical system that alters the chemical nature of contaminants, organic loading and nutrients present in the wastewater (You *et al.,* 2014).

Tidal flow constructed wetland (TFCW) have been proved as an updated version of CW with improvement in treatment efficiency because of an innovative oxygen-intensifying operation (Li *et al.,* 2015). Term "tidal flow" is an operational strategy that allows CWs to be filled with wastewater, reacts with the filter media and roots of vegetation, and then are completely drained out for providing resting of CW bed in cyclic manner (Zhi and Ji, 2014). In short TFCWs follows the cycle of fill, react, drain and rest period in order to provide consequent supply of oxygen and its consumption for improving the system. TFCWs dominates other CWs by providing cyclic input and output of wastewater and promoting transfer of air into CW zone, and developing aerobic and anaerobic conditions one after other by making it efficient for pollutants removal (Ye *et al.,* 2016). In TFCW the variation of magnitude of flow velocity and change in its direction periodically making it more complex than other type of CW (Wu *et al.,* 2012). TFCWs are more efficient in

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nitrogen removaland can be applicable for treatment of domestic wastewater (Austin, 2006).

In domestic wastewater organic matters, nitrogen and suspended solids are the main components (Chan *et al.*, 2008). More and more accumulation of nitrogen in water bodies enhances eutrophication, reduction in the level of dissolved oxygen, and provides nutrients for growth of the plant which can affect the aquatic life (Chavan *et al.*, 2008). Along with this the increase in concentration of nitrogen in drinking water can have adverse effect on human health like blue baby syndrome, cancers of ovary and bladder (Shen *et al.*, 2019). Due to such ill effects it becomes necessary to treat the domestic wastewater.

In CWs, sequential nitrification and denitrification processes play major role in nitrogen removal (Ding *et al.*, 2014). Insufficient oxygen supply restricts nitrogen removal in CWs, therefore TFCWs provide good environmental condition for nitrogen removal by increasing oxygen transport (Zhi and Ji, 2014).

The present study assessed the two stage tidal flow constructed wetland for wastewater treatment. Specifically concentrating on nitrogen removal the objectives established are (i) effect of second stage anaerobic unit on treatment efficiency and (ii) effect of different time ratios of first stage to second stage of wetland.

Material and Methods

Constructed Wetland System

A schematic diagram showing a section of two stage tidal flow constructed wetland (TSTFCW) was used in this study is shown in Fig. 1. Three identical TSTFCW models were manufactured from a sheet metal namely model-A, model-B and model-C. The dimension of first stage reactor was 250mm X 250mm X 600mm (L X B X H) and that for second stage reactor was 300mm X 300mm X 400mm (L X B X H). First stage reactor was packed with two particle sizes: a small size of 3–4 mm (ϕ) for first 300mm height, a medium size of 4–5 mm (ϕ) for remaining 300 mm. Second stage reactor was also packed with two particle sizes: a large size of 5–6 mm (ϕ) for first 200 mm height, an extra-large size of 6–7 mm (ϕ) for remaining 200 mm.

Each stage reactors were provided with valves for sampling and draining of wastewater. The filter media were compacted before the start of experiment. *Typha sp.* used for experimentation and were brought from naturally grown wetlands and planted in all constructed wetland reactors.

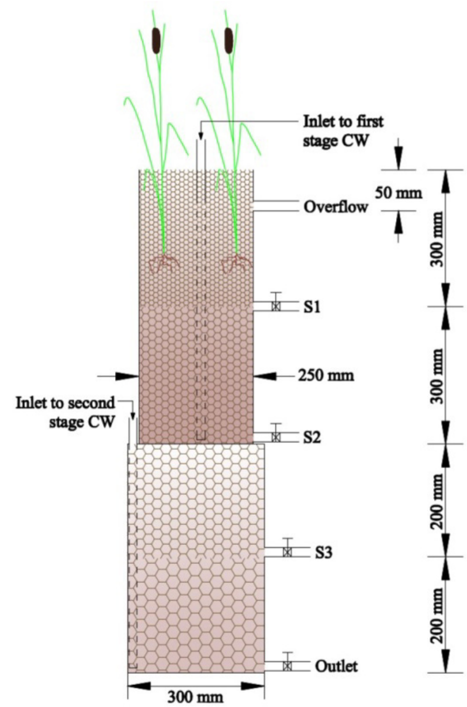

Fig. 1. Two stage tidal flow constructed wetland (S1, S2 and S3 - Sampling points)

Constructed Wetland Operation

The wastewater from feed tank was evenly distributed over the first stage reactor with sequential batch operations. The output from first stage reactor was given to the second stage reactor for purely anaerobic treatment. The water depth in first stage reactor was maintained 50 mm below the level of filter media surface by providing overflow valve to work as a sub-surface flow CW. The three TSTFCWs were operated for 11 months, initial 3 months were considered as acclimation period. For initial 4 months (described as Phase-I) the experiment was conducted with three different ratios for Hydraulic Retention Time (HRT) in first stage reactor to HRT in second stage reactor. The ratio of HRT in first stage to second stage was 1:1; 1:2 and 1:3. Thus making reaction period of 4, 4, 4 hours in first stage reactors and 4, 8, 12 hours in second stage reactors respectively of model-A, B and C. For next 4 months (described as Phase-II) the experiment was conducted with three different ratios for HRT. The ratios were 1:1, 2:1, 3:1 making reaction period of 4, 8, 12 hours in first stage reactors and 4, 4, 4 hours in second stage reactors respectively for model-A, B and C. The characteristics of the wastewater is shown in Table 1.

Water Quality Analysis

The wastewater was analysed for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and total suspended solids (TSS)by standard methods (APHA-AWWA-WEF, 1999). Ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) has been analysed using HANNA COD Photometer and mulitparameter. In this work total nitrogen (TN) was expressed as the sum of NH_4-N, NO_3-N and NO_2-N and organic nitrogen was negligible during the whole experiments (Palmer *et al.,* 2009; Yue *et al.,* 2009).

Analyses of data

The efficiency of the constructed wetland model for removal of various parameters (Table 1) was calculated using the formula below:

$$\text{Removal efficiency (\%)} = \frac{C_{in} - C_{out}}{C_{in}} \times 100$$

in which C_{in} is the inlet concentration of pollutant and C_{out} is the outlet concentration of pollutant for the constructed wetland system.

Results and Discussion

BOD_5 and COD Removal

The variation in concentration of BOD_5 and COD at inlet, outlet and in between sampling points S1, S2,S3 is shown in Fig. 2 and 3 respectively for Phase-I and Phase-II with varying HRT ratios. As shown in Fig. 2 and 3 average concentration in the final effluent is remained below 102 mg/L (minimum concentration of 90 mg/L) for BOD_5 in Phase-I of HRT ratio 1:3 (total 16 hours) and average concentration in the final effluent is remained below 152 mg/L (minimum concentration of 132 mg/L) for COD in Phase-I of HRT ratio 1:3.Average Removal efficiency at outlet for the same is 46.09% and 46.05% respectively for BOD_5 and COD. The removal efficiency of BOD_5 is improved from 21.35% in Phase-I of HRT ratio 1:1 (total 8 hours) to 46.09% in Phase-I of HRT ratio 1:3 also the removal efficiency for COD is improved from 25.20 mg/L in Phase-I of HRT ratio 1:1 (total 8 hours) to 46.05% in Phase-I of HRT ratio 1:3.These removal efficiencies and effluent concentration of BOD_5 and COD are achieved just in 16 hours of operation of CW model. The removal efficiencies and outlet concentration of BOD_5 and CODwas not that much good because of less retention time in constructed wetland reactors (Lavrova and Koumanova, 2010). It was observed that the 16 hours of duration is not sufficient for removal of BOD_5 and COD, so it can be suggested that this time and HRT ratio should be increase for more

Table 1. Characteristics of influent wastewater (mean ± SD, n=10)

Parameter	Influent (mg/L)	
	First 4 months	Next 4 months
BOD_5	188.47±18.52	182.18±22.58
COD	281.91±23.14	273.72±28.40
TSS	378±71.15	376±54.41
NH_4-N	68.5±8.63	68.52±6.28
NO_3-N	9.05±2.57	9.55±2.16
NO_2-N	2.41±0.87	2.79±0.88
TN	79.96±10.14	80.86±7.85

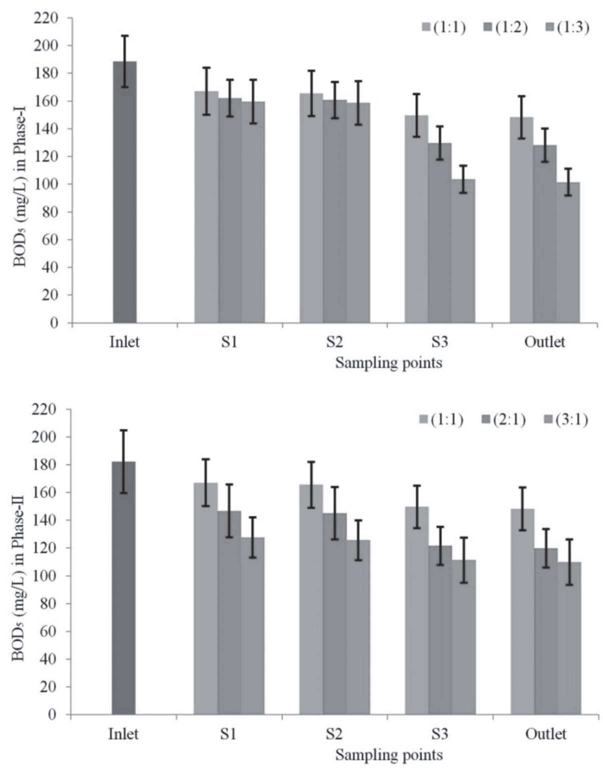

Fig. 2. BOD_5 values (error bars show the standard deviation, n = 10) with its treatment efficiencies at different sampling points and at different time ratio of HRT

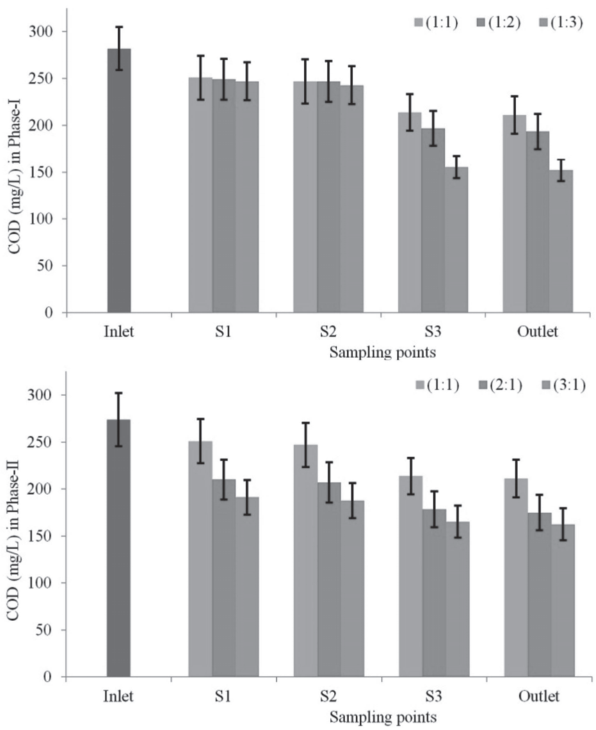

Fig. 3. COD values (error bars show the standard deviation, $n = 10$) with its treatment efficiencies at different sampling points and at different time ratio of HRT

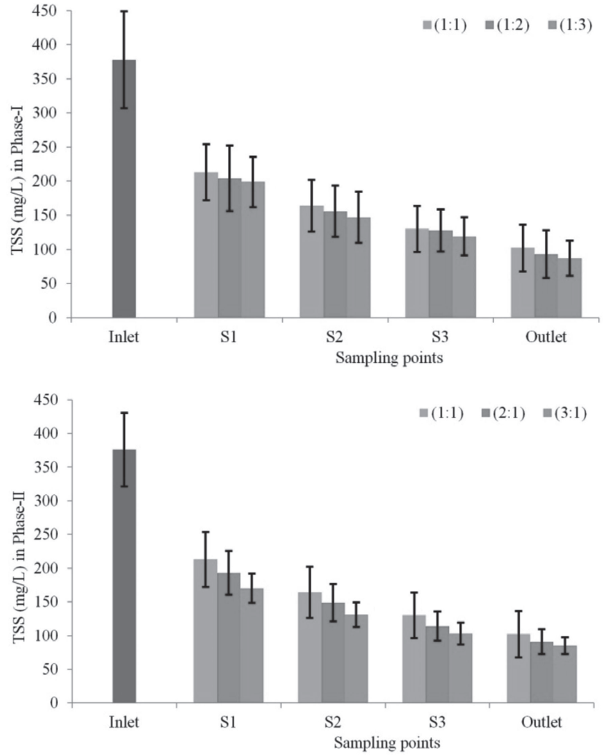

Fig. 4. TSS values (error bars show the standard deviation, $n = 10$) with its treatment efficiencies at different sampling points and at different time ratio of HRT

removal of BOD_5 and COD. Akinbile *et al.* (2016) also suggested that longer the operating time more will be reduction in BOD_5 and COD levels.

Removal of Total Suspended Solids

The influent concentration of TSS throughout the experiment was 378±71.15 mg/L and 376±54.40 mg/L in Phase-I and Phase-II respectively shown in Fig. 4. Both phases show higher removal of suspended solids with the average removal efficiency ranging from 73.56% to 77.25%. This removal of TSS is achieved by filter media of varying size provided inside the CW also the denser root of the planted bed enhanced the removal efficiency.

During the whole experiment there was no significant difference between average removal of TSS, in terms of percentage removal in Phase-I maximum removal efficiency was 77.25% for HRT time ratio 1:3 and Phase-II maximum removal efficiency was 77.20% for HRT time ratio 3:1. Value of TSS in both cases was less than 90 mg/L.

Vegetation provided in CW system plays very important role in removal of solids, also the mechanism between plant root and microorganisms enhances reduction in COD and solid content by offering bio polishing treatment to wastewater (Yusoff *et al.*, 2019).

Removal of Nitrogen

Nitrogenous substances NH_4-N, NO_3-N, NO_2-N and TN were detected in the influent samples, with the average concentrations as 68.5±8.63 mg/L, 9.05±2.57 mg/L, 2.41±0.87 mg/L, 79.96±10.14 mg/L for Phase-I and 68.52±6.28 mg/L, 9.55±2.16 mg/L, 2.79±0.88 mg/L, 80.86±7.85 mg/L for Phase-II respectively. The CWs reactors showed variable removal efficiency for NH_4-N, NO_3-N, NO_2-N and TN for various HRT time ratios. The maximum removal efficiency achieved for NH_4-N was 86.40 % in Phase-I with HRT time ratio 1:3, for NO_3-N was 65.25 % in Phase-II with HRT time ratio 3:1, for NO_2-N was 50.47% in Phase-I with HRT time ratio 1:3 and for TN was 82.38 % in Phase-I with HRT time ratio 1:3.

In Phase-II with HRT time ratio 3:1 NO_3-N removal was maximum i.e. 65.25 % with effluent value 3.29±0.69 mg/L but in Phase-I with HRT time ratio 1:3 the removal efficiency was 60.12 % with effluent value 3.60±1.02 mg/L. Both the outlet values are under the Indian effluent discharge standards. From this study for maximum removal of nitrogen content operation strategy of Phase-I with HRT ratio 1:3 can be provided for TSTFCW.

It can be seen that the removal efficiency increases with increase in HRT of second stage of CW. Chen *et al.* (2017) observed that the two stage CW gives higher removal of nitrogen content which provides aerobic and anaerobic conditions for nitrification and denitrification while single stage CWs is incapable to remove more amount of nitrogen content. Ding *et al.* (2012) also stated that for achieving higher nitrogen removal the availability of oxygen was the major problem for denitrification. More anaerobic condition in CW suppresses the growth of ammonia-oxidizing bacteria and conducive to the development of denitrifying bacteria (Chen *et al.*, 2017). In this study first stage CW is providing aerobic condition in reactor by oxygen transport through plant root and second stage CW is completely anaerobic and thus giving higher removal efficiency. This study also demonstrates that maximum duration of anaerobic condition gives more nitrogen removal, thus it is recommended to provide longer anaerobic condition and shorter aerobic condition to get better nitrogen removal efficiency. Plant root plays important role for nitrogen removal, more the root size maximum is the nitrogen removal.

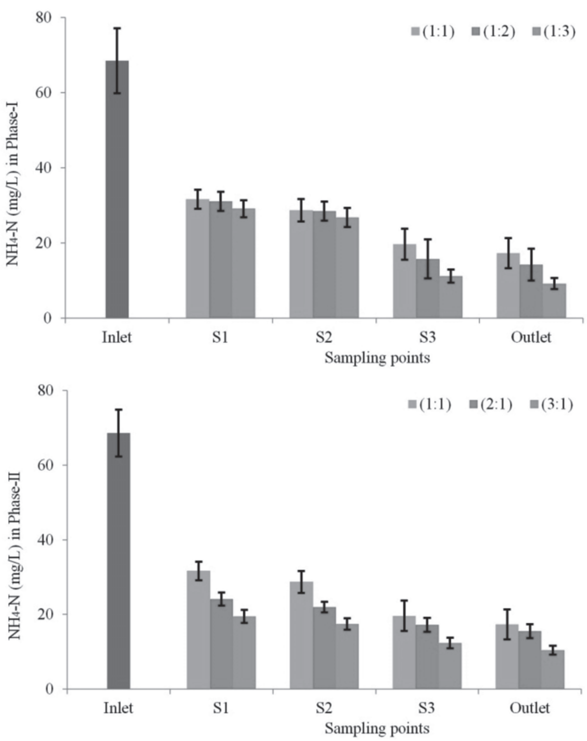

Fig. 5. NH_4-N values (error bars show the standard deviation, n = 10) with its treatment efficiencies at different sampling points and at different time ratio of HRT

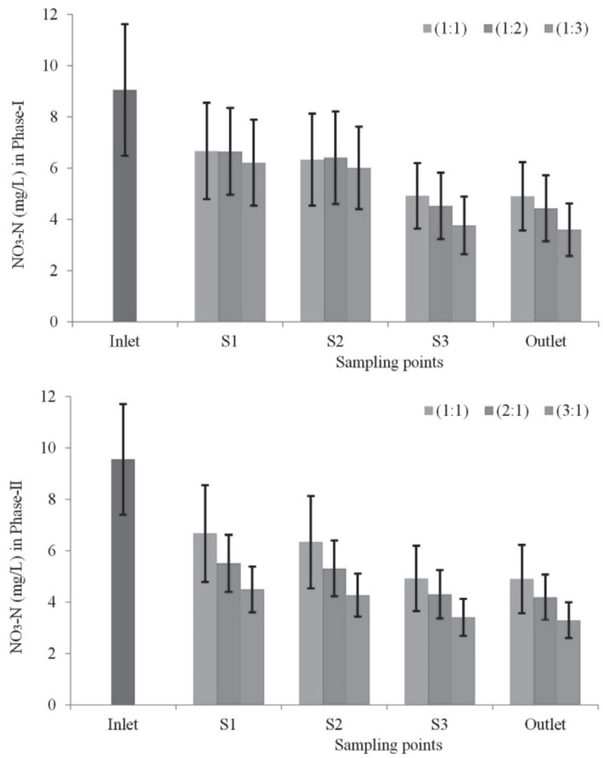

Fig. 6. NO_3-N values (error bars show the standard deviation, n = 10) with its treatment efficiencies at different sampling points and at different time ratio of HRT

In CWs, filtration and adsorption are the most efficient physical processes for denitrification. Degraded organic matter and dead plants tissues provides electron for denitrification (Gajewska *et al.*, 2015). In a CW, more amount of NH_4-N removal occurs through microbial action than the direct absorption by plants, which makes CW very complex system of simultaneous physical, chemical and biological actions (Abbasi *et al.*, 2017).

Conclusion

In this study removal efficiency of nitrogen content is at satisfactory level in Phase-I for 1:3 HRT ratios.Nevertheless, lower organic matter removal

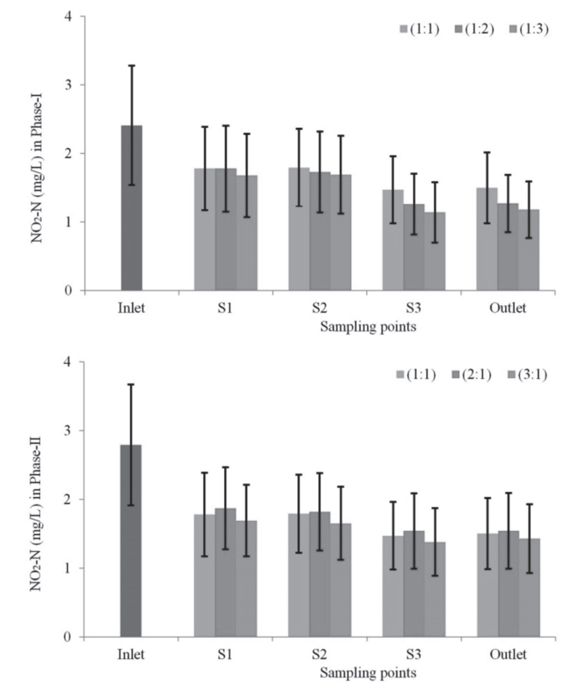

Fig. 7. NO_2-N values (error bars show the standard deviation, n = 10) with its treatment efficiencies at different sampling points and at different time ratio of HRT

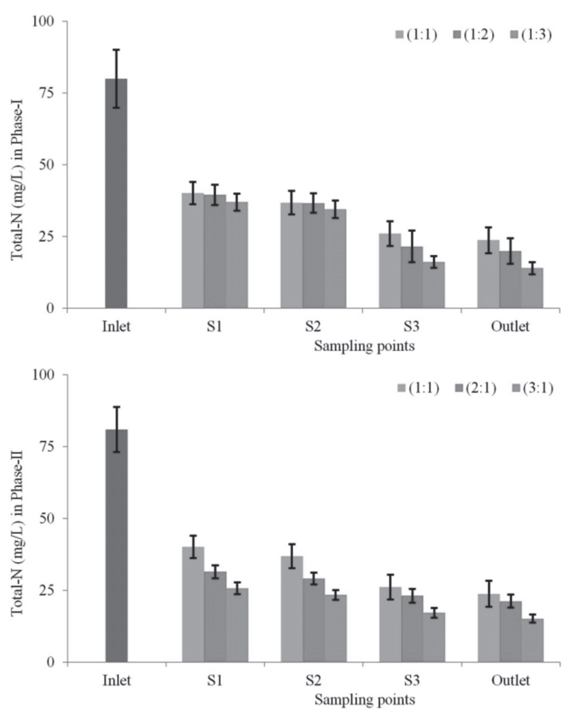

Fig. 8. TN values (error bars show the standard deviation, n = 10) with its treatment efficiencies at different sampling points and at different time ratio of HRT

efficiencies (46.09% for BOD_5 and 46.05% for COD) were detected in Phase-I for 1:3 HRT ratios which was seen as maximum removal efficiency throughout the study. The poor organic matter removal in thiswork could be attributed to less time provided for treatment in organic matter removal. Meanwhile TSS removal was 77.25% in Phase-I for 1:3 HRT ratios which was shown good removal efficiency in very short duration of time. In summary, the results revealed that the provision of second stage CW shown improved nitrogen content removal efficiency but for increase in organic matter removal efficiency more HRT (double and more) should be provided.

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