EFFECTS OF HYDRAULIC RETENTION TIME ON THE PILOT-SCALE ACTIVATED SLUDGE AND FLOATING AQUATIC MACROPHYTES WETLAND SYSTEM FOR TREATMENT OF CAFETERIA WASTEWATER

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Abstract - Selection of a suitable method for treatment of domestic wastewater depends on its efficiency, simplicity, and cost-effectiveness. This study investigated the effects of hydraulic retention time (HRT) on the treatment efficiency of an activated sludge process (AS) and floating aquatic macrophytes (water hyacinth) constructed wetland (FAMCW) system. Experiments were conducted in pilot-scale reactor under steady-state conditions and varying HRT (6, 12 and 18 h). Total suspended solid (TSS), Biochemical Oxygen Demand (BOD), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N) and ortho–Phosphate (o-PO_4) were measured to evaluate the removal efficiency. The average removal efficiencies were 46.4%, 81.0% and 91.9% of TSS, 49.9% ,79.9% and 95.6% of BOD, 25.2% ,54.6% and 76.14 % of NO_3^--N, 36.7% ,-149.0% and 89.0% of NH_4^+-N and 89.3%, 96.2% and 90.8% of o-PO_4^{3-} under HRT of 6, 12 and 18 h, respectively. The results indicated that average removal efficiencies of BOD, TSS, NO_3-N and NH_4-N increased with an increase in HRT. Average removal efficiency of o-PO_4 in AS was highest at the shortest HRT. Limiting dissolved oxygen level resulted in an increase of NH_4-N concentration in FMACW. Highest and lowest relative growth rates (RGR) of water hyacinth were found in 12h HRT (0.0265 d^{-1}) and 18h HRT (0.0150 d^{-1}), respectively. These findings confirmed hydraulic retention time is a key factor in determining the effectiveness of wastewater treatment in an AS-FAMCW reactor.

Index Terms - Hydraulic Retention Time, Activated Sludge Process, Floating Aquatic Macrophytes Constructed Wetland, Removal Efficiency.

I. INTRODUCTION

Surface water resources in developing countries are under serious threat in terms of both quality and quantity as a result of indiscriminate discharge of polluted effluents from industrial, agricultural, and domestic/sewage activities [1]. In urban areas, public water supply is mainly derived from rivers, streams, wells and lakes for domestic and industrial uses. Almost 80% of the water supplied for domestic use returns as wastewater[2].In most cases, untreated wastewater, when discharged directly into the ground, can become potential pollutant sources of groundwater causing pollution in downstream areas.

In order to treat the large volume of wastewater, secondary conventional treatment based on activated sludge (AS) is commonly used. The activated sludge process (AS) used for wastewater treatment can be divided into two main categories: suspended growth and attached growth processes [3]. Conventional AS is a suspended growth technology comprising an enrichment culture of microbial consortia in order to remove impurities and transform wastewater into environmentally acceptable quality [4]. Treatment by AS consists of an aeration basin in which air or oxygen is forced into wastewater developing biological flocs which degrade organic matter. Conventional AS however do not readily remove total nitrogen and total phosphorus in wastewater. Thus, biological nutrients (NO_3 and PO_4) removal process increase a construction and operation cost [5] of the wastewater treatment. Hence, it is expected that constructed wetland (CW) should enhance the removal of nutrients discharged from the AS.

CWs have been proven to be a suitable wastewater treatment system for developing countries in tropical areas where land is available at low cost and warm temperature is suitable for [6]. CWs are artificial system, designed and constructed to utilize the natural processes of wetland vegetation, soil and their microbial consortium to treat the contaminants in waste streams [7],[8]. The macrophytes grown in CWs can be classified according to their life form such as emergent aquatic, floating-leaved aquatic, freely floating, and submerged aquatic macrophytes [9]. Studies showed that floating macrophytes can be used to remove nutrients from wastewater due to their high growth rates[10]–[12].

FAMCWs are commonly used for treatment of runoff waters such as urban [13], road and highway [14], airport [15], golf course [16], agriculture [17]. Constructed wetlands are commonly used for secondary treatment in Highlight a section that you

want to designate with a small communities [18]. Study shown that nitrogen removal efficiency of aquatic macrophyte in the order of water hyacinth (Eichhornia crassipes), > water lettuce (Pistia stratiotes) > duckweeds (Lemna minor and Spirodela polyrhiza) during the summer season and phosphorus removal in summer was highest by water hyacinth [19]. Water hyacinth showed high efficiency of nutrient removal capacity due to vegetative reproduction and vigorous growth rate [20]. Relative growth rate (RGR) is a prominent indicator of plant strategy with respect to productivity as related to environmental stress and disturbance regimes [21]. RGR is measured based on dry-mass basis including roots.

Hydraulic retention time (HRT) is an important parameter in wastewater treatment, which directly affects the design, operational/investment cost and energy requirements. HRT would also boost removal efficiency of BOD and chemical oxygen demand (COD) [22]. Removal rate of BOD and COD was ascending with an increase of HRT on hospital and dairy-industry wastewater treatment [23]-[24].

In this study, pilot-scale reactor was developed with the combination of AS and FAMCW systems in series. Fabricated reactor was then used to determine the optimized HRT on treated cafeteria wastewater based on pollutant removal efficiency and relative growth rate of water hyacinth. Materials and Methods

A. Experimental setup

Pilot-scale AS- FAMCW was established and maintained in a greenhouse facility. Fig. 1 shows the schematic diagram of the pilot scale reactor used in this study. The aeration tank, settling tank and FAMCW were made of plastic with a capacity of 5.3, 6.0 and 47.6 L, respectively. PVC pipes were used to connect the system. An air pump and a set of diffusion aerators were used to aerate the aeration tank. Peristaltic pump was used to automatically supply wastewater to the reactor from the feed tank and sludge was 100% recycled. Aerobically digested sludge obtained from a CMU Wastewater Treatment Plant was used as inoculum and wastewater generate from cafeteria was used to feed the reactor. Water hyacinth collected from CMU reservoir was grown for two weeks in a plastic bowl at greenhouse. The whole plants were directly transferred to the reactor. Sixty percent of the water surface was covered by water hyacinth initially and maintained throughout the experiment.

B. Operation, Sampling and Analysis

The reactor was operated under the hydraulic loading rates of 14.72, 7.36, and 4.91 mL/min to acquire the 6, 12 and 18 h of HRT respectively. Peristaltic pump was weekly calibrated to ensure the constant flow rate and relatively constant concentration of anti-foaming agent was mixed with raw wastewater (10-20 ppm). Dissolved oxygen concentration in aeration rank was maintained within a range of 2-3 mg/L. 500 mL of water samples were collected from the inlet (SP1), outlet of the AS (SP2) and outlet of FAMCW (SP3) (Fig 1). Water samples were collected at every three days until reactor reach steady-state condition.

Collected samples were measured for physical parameters such as T, EC and pH, TDS and analyzed for BOD, TSS, NO_3-N, NH_4-N and o-PO_4 using standard methods [25]. Fresh and dry weights of the water hyacinth were determined according to standard protocol[26].

C. Pollutant Removal Efficiency

The removal of TDS, BOD, TSS, NO_3-N, NH_4-N and o-PO_4 in the AS-FWSCW system refers to the difference between the influent (C_{in}) and effluent (C_{out}) concentrations of wastewater. Thus, the removal efficiency (R_r) of is expressed by (1):

$$R_r = \frac{C_{in} - C_{out}}{C_{in}} \quad (1)$$

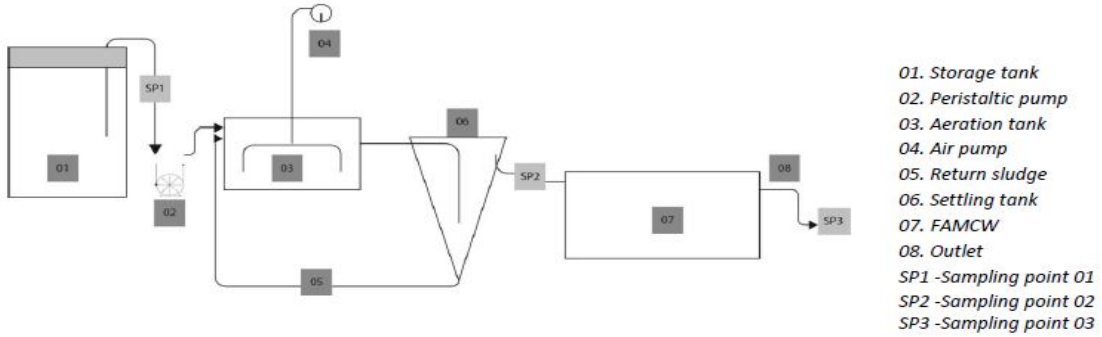


Fig. 1. Schematic diagram of the pilot scale reactor

A. Relative growth rate

After steady-state condition of the reactor was attained, plants were harvested and dried at 60 °C to constant weight. The fresh (FW) to dry weight (DW) ratio was calculated and the relative growth rate (RGR, d^{-1}) was calculated by (2) [27]:

$$RGR = \frac{\ln(W_2/W_1)}{t_2 - t_1} \quad (2)$$

where W_1 and W_2 are the initial and final DW (g), and t_1 and t_2 are the initial time of reactor and final harvesting time of reactor (days) respectively.

B. Statistical Analysis

All the statistical analyses were performed with the R statistical software version 3.3.1. All variables were tested for normal distribution and variance homogeneity, using the Kruskal-Wallis [28] nonparametric statistical test followed by Dunn's [29] multiple comparison test when assumptions on the normal distribution and variance did not meet. When necessary, logarithmic transformations were used to achieve normal distributions. All statistical tests were performed considering a 5% significance level. The p-values was adjusted using Benjamini-Hochberg method[30].

II. RESULTS AND DISCUSSION

A. Effect of Hrt on BOD Removal

The BOD removal efficiency under different HRTs are shown in Fig. 2. The average BOD removal efficiency of AS-FAMCW at 6, 12 and 18 h HRTs were 46.4±27.3, 81.0±64.1, and 91.9±10.7 % respectively. Average BOD removal efficiencies were 31.0±57.2, 49.5±47.5, and 42.7±16.5 % for FAMCW and 23.7±14.3, 48.3±102.9, and 88.3±21.6 % for AS in 6, 12 and 18 h HRTs, respectively (Table I). The average BOD removal efficiency in the case for 18-h HRT was significantly higher than that 6-h HRT case in both overall reactor and AS alone ($p<0.05$). There was no significant difference between the operation at 12- and 6-h HRTs and 18- and 12-h HRTs ($p > 0.05$).

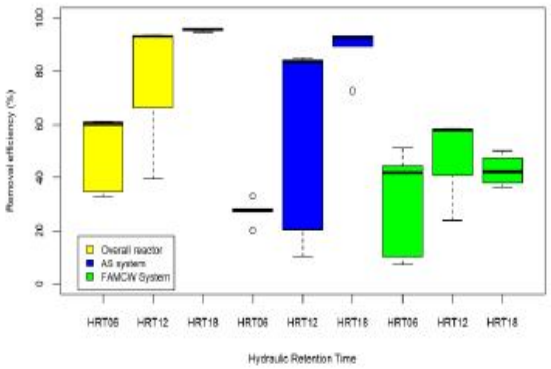


Fig. 2. BOD removal efficiencies of AS-FAMCW

It was also observed that the greatest portion of the BOD was removed in 18-h HRT AS (88.3%) while FAMCW removed BOD only 42.7%. Higher HRTs provide sufficient time for microorganisms to degrade organic matter in wastewater than lower HRTs. Previous studies illustrated that some bacteria were washed out of upflow anaerobic sludge blanket reactor while the HRT was less than 12 h, and the BOD removal efficiency decreased with the decrease in HRT [31]. It is clear that the shorter HRTs operated the lower removal efficiencies of BOD achieved.

B. Effect of HRT on TSS removal

Total suspended solid is the dry-weight of particles trapped by a filter. The TSS removal efficiency under different HRTs are shown in Fig. 3. Average TSS removal efficiencies at overall reactor were 46.4±27.3, 81.0±64.1, and 91.9±10.7 % (Table I) in 6-, 12-, and 18-h HRTs, respectively. Average TSS removal efficiency for 18-h HRT (91.9%) was significantly higher ($p = 0.007$) than 6-h HRT (46.4%) in AS-FAMCW. The TSS removal efficiency 18-h HRT was significantly higher ($p = 0.021$) than that 6-h HRT case in AS. There was no significant difference in TSS removal efficiency between 12- and 6-h HRTs ($p > 0.05$) and 18- and 12-h HRTs ($p > 0.05$). 18-h HRT condition provides plenty of time for particles to settle down in secondary clarifier and FAMCW. This finding supports higher TSS removal efficiencies in higher HRTs.

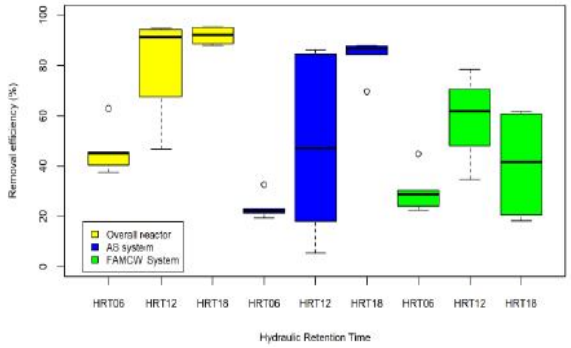


Fig.3.TSS removal efficiencies of AS-FAMCW

C. Effect of HRT on NO_3-N removal

Biological nitrogen removal is typically achieved by autotrophic nitrification under aerobic conditions followed by heterotrophic denitrification under anoxic conditions [3],[32]. The NO_3-N removal efficiency under different HRTs are shown in Fig. 4. Average NO_3-N removal efficiency in AS-FAMCW system experienced a proportional increase as the HRT increased, which were 25.2±42.8, 54.6±50.5, and 76.1±18.1 % for 6-, 12- and 18-h HRTs, respectively. Similar trend was found in AS, which were 18.3±30.5, 36.8±67.7, and 58.9±1.4 % for 6-, 12- and 18-h HRTs, respectively whereas FAMCW has removal efficiency of 9.2±21.8, 19.0±45.9, and 42.1±43.5 % for 6-, 12- and 18-h HRTs, respectively. Average NO_3-N removal efficiency in AS-FAMCW system for 6-h HRT was significantly lower ($p =0.008$) than that 18-h HRT. Moreover, average NO_3-N removal efficiency for 6-h HRT was significantly lower ($p =0.008$) than 18-h HRT case in AS system.

Parameter	Overall efficiency (%)			AS efficiency (%)			FAMCW efficiency (%)		
	HRT 06	HRT 12	HRT 18	HRT 06	HRT 12	HRT 18	HRT 06	HRT 12	HRT 18
TSS	46.4±27.3	81.0±64.1	91.9±10.7	23.7±14.3	48.3±102.9	88.3±21.6	30.2±24.6	59.2±50.1	40.7±64.8
BOD	49.9±40.9	79.9±75.0	95.6±1.7	27.2±12.9	56.7±105.4	88.3±24.8	31.0±57.2	49.5±47.5	42.7±16.5
NO_3-N	25.2±42.8	54.6±50.5	76.1±18.1	18.3±30.5	36.8±67.7	58.9±1.4	9.2±21.8	19.0±45.9	42.1±43.5
NH_4-N	36.7±7.7	-149.0±658.9	89.0±22.2	86.7±33.8	-18.5±254.7	72.6±28.4	-668.7±1316.2	-173.4±328.8	56.5±47.6
o-PO_4	89.3±13.4	96.2±21.2	90.8±23.4	76.3±32.7	66.0±37.4	46.3±19.3	53.8±14.9	90.9±50.7	83.9±41.2

Table I Average [± (S.D.)($t_{\alpha/2v}$)] pollutant removal efficiency of the reactor at different HRTs

Similar result was found in the FAMCW, average NO_3-N removal efficiency for 6-h HRT was significantly lower (p =0.022) than that 18-h HRT. Furthermore, average NO_3-N removal efficiency for 18-h HRT was significantly higher ($p<0.05$) than that for 6-h HRT in AS system. No significantly difference in removal efficiency was observed between HRT of 12 and 18 h ($p > 0.05$) except in 6- and 12-h HRT AS system and HRT of 06 and 12h ($p > 0.05$).

Results indicated that higher HRTs enhanced the NO_3-N removal efficiency than lower HRTs. This is probably because insufficient nitrification occurred in lower HRT due to short retention time for growth of nitrifying bacteria. However, when the influent NO_3-N concentration was too high, the impact of HRT on denitrification was weakened [33].

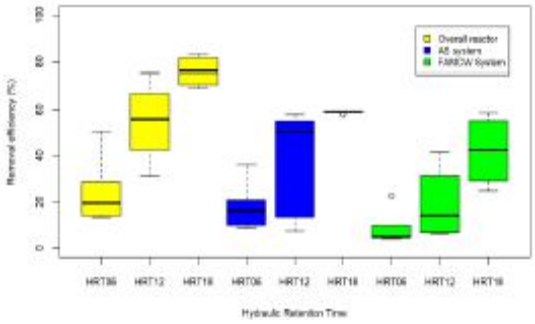


Fig. 5. NO_3-N removal efficiencies of AS-FAMCW

A. Effect of HRT on NH_4-N removal

NH_4-N is a significant contaminant which contain in many type of wastewater and excessive discharge NH_4-N lead eutrophication in water bodies [33]. Average NH_4-N removal efficiency under different HRTs are shown in Fig. 5. The average NH_4-N removal efficiencies at the HRT of 18 h (89.0±22.2 and 56.5±47.6%) were significantly higher ($p<0.05$) than that at the HRT of 6 h (36.7±7.7, -668.7±1316.2%) in overall reactor and FAMCW respectively, and furthermore, the NH_4-N removal efficiency at the HRT of 18 h was significantly higher ($p<0.05$) than that at the HRT of 12 h in overall reactor. There was no significant difference between the operation for 6- and 12-h HRTs ($p > 0.05$) and 18- and 12-h HRTs ($p > 0.05$).

Limited amounts of dissolved oxygen (<2 mg/L) inhibit nitrification and cause nitrite accumulation or nitrous and nitric oxide production [34]. FAMCW recorded higher NH_4-N concentration than in the AS system in 6- and 12-h HRTs due to the dissolve oxygen shortage. Expanding of FAMCW surface area or use of aeration can enhance ammonia nitrogen removal in constructed wetlands [35].

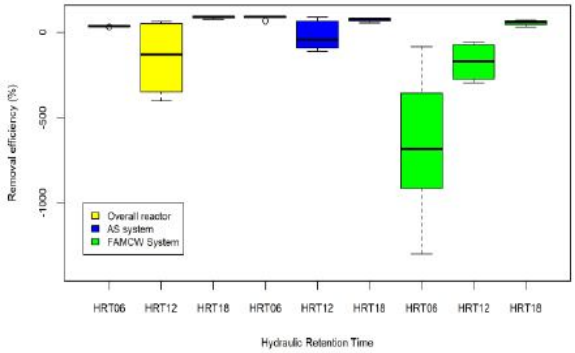


Fig.4. NH_4-N removal efficiencies of AS-FAMCW

B. Effect of HRT on o-PO_4 removal

Phosphorous is one of the major nutrients contributing in the increased eutrophication of lakes and natural waters [36]. The o-PO_4 removal efficiencies under different HRTs are shown in Fig. 6. Average o-PO_4 removal efficiency for 6-, 12- and 18-h HRTs in AS-FAMCW system in series were 89.3±13.4, 96.2±21.2, and 90.8±23.4% (Table I) respectively. Almost similar removal efficiencies recorded in each HRT. o-PO_4 removal efficiency of the 6-h HRT FMACW was significantly higher ($p=0.011$) than 12-h HRT. There was no significant difference ($p >0.05$) between 12- and 6-h HRT AS and AS-FAMCW systems.

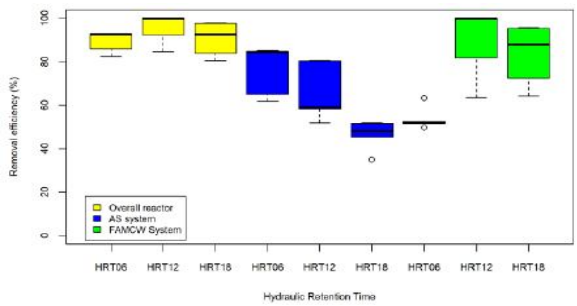


Fig. 6. o-PO_4 removal efficiencies of AS-FAMCW

Higher HRTs provide sufficient time to uptake the o-PO_4 in effluent at FAMCW. Average o-PO_4 removal efficiency of 6-h HRT AS system was significantly higher than 18-h HRT condition ($p = 0.003$). Lopez et al. [37] found that longer HRT (greater than 12 h)

affected intracellular carbon storage polymers and caused a reduction in the rate of aerobic phosphorus removal and conclude that lower HRTs enhance the o-PO_4 removal efficiency in AS. However, there was no significant difference between 12- and 6-h HRTs ($p > 0.05$) and 18- and 12-h HRTs ($p > 0.05$) in AS-FAMCW because FAMCW was removed almost all remain o-PO_4 in effluent.

Parameter	Comparison	p value		
		AS	FAMCW	Overall
BOD	HRT06 - HRT12	0.524	0.105	0.063
	HRT06 - HRT18	0.032*	0.701	0.020*
	HRT12 - HRT18	0.084	0.153	0.525
TSS	HRT06 - HRT12	0.479	0.262	0.22
	HRT06 - HRT18	0.021*	0.679	0.007*
	HRT12 - HRT18	0.071	0.328	0.126
NO_3-N	HRT06 - HRT12	0.524	0.292	0.122
	HRT06 - HRT18	0.008*	0.022*	0.008*
	HRT12 - HRT18	0.029*	0.184	0.237
NH_4-N	HRT06 - HRT12	0.032*	0.227	1.000
	HRT06 - HRT18	0.206	0.007*	0.038*
	HRT12 - HRT18	0.288	0.126	0.027*
o-PO_4	HRT06 - HRT12	0.229	0.011*	0.282
	HRT06 - HRT18	0.003*	0.051	0.743
	HRT12 - HRT18	0.060	0.465	0.301

*statistically significantly difference in 95% confidence level

Table II. Paired comparison of HRT in each treatment step

C. Relative growth rate of water hyacinth

The water hyacinth is a perennial, mat forming, floating aquatic plant of wide distribution in tropical, subtropical, and warm temperate regions throughout the world [38]. It grows rapidly in polluted waters making it an ideal candidate for large-scale application for nutrient removal and water purification [39].

Relative growth rates (RGR) of the water hyacinth in different HRTs (Fig. 7.) were 0.0168, 0.0265, and 0.0150 d^{-1} in HRTs of 06, 12, and 18 h in for 6-, 12- and 18-h HRTs, respectively. 18-h HRT had the highest removal efficiency and had low growth rates for Eichhornia sp. Advantage of HRT of 18 was the decreased harvesting times during operation due to the low growth rate of Eichhornia sp.

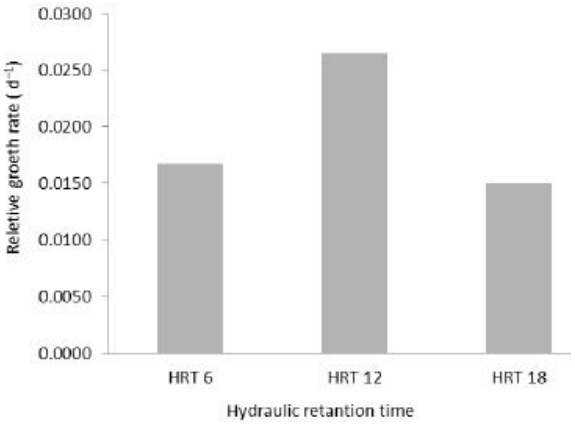


Fig. 7. Relative growth rate of water hyacinth

CONCLUSIONS

The average removal efficiencies of BOD, TSS, NO_3-N and NH_4-N in AS-FAMCW system in series increased with an increase in HRT. Average removal efficiency of o-PO_4^{3-} in AS was highest at the shortest HRT. Limited amounts of dissolved oxygen level triggered an increase of NH_4-N concentration in FMACW. Maximum relative growth rate (RGR) of water hyacinth was found in 12-h HRT while lowest RGR was obtained in 18-h HRT. The 18-h HRT case illustrated highest removal efficiency and had low growth rates for Eichhornia sp.

The results confirm that hydraulic retention time is a key factor in determining the effectiveness of wastewater purification in an AS-FAMCW system in series. Moreover, 12- and 18-h HRTs have been found to be optimum to treat the cafeteria wastewater effectively. Hence, we envisaged that similar strategies can be implemented in other sources of wastewater.

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