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Research Article

Ultrashort Hydraulic Retention Time of Aeration and Nonaeration Constructed Wetlands for a Large Volume of Primary-Treated Wastewater from a Medical Rubber Glove Factory

Worasit P. Na-Ayuthaya[1], **Krirk Wongsontam**[1], **Napimporn Sangvichien**[1] **and Panya Khaenamkaew**[2]

[1]*Department of Resources and Environment, Faculty of Science at Sriracha, Kasetsart University, 199 M.6 Sukumvit Rd, Thung Sukla, Sriracha, Chonburi 20230, Thailand*
[2]*Department of Basic Science and Physical Education, Faculty of Science at Sriracha, Kasetsart University, 199 M.6 Sukumvit Rd, Thung Sukla, Sriracha, Chonburi 20230, Thailand*

Correspondence should be addressed to Worasit P. Na-Ayuthaya; pangpakarn@hotmail.com

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A substantial volume of primary-treated wastewater from a medical rubber glove factory caused public freshwater to become sewage. The ultrashort hydraulic retention time in constructed wetlands was urgently employed for wastewater remediation. Pilot-scale, aeration, and nonaeration horizontal surface flow constructed wetlands (HSFCWs) with emergent plants were designed, compared, and optimized. Activated carbon, coconut shells, and oyster shells were subsequently transferred into a plastic basket as a substrate layer, while *Typha angustifolia* L. was used as an emergent plant. The experiments were conducted at a hydraulic retention time of 2, 4, 6, and 8 hr. per effluent recirculation. Sampling data were collected for each of the four effluent recirculations. The removal efficiencies of BOD, COD, FOG, TKN, TSS, TDS, EC, and salinity in the aeration HSFCWs were high—53.25, 67.28, 97.93, 78.93, 95.87, 87.52, 86.36, and 90.38%—at the first effluent recirculation of sampling, respectively, while the removal efficiencies in the nonaeration HSFCWs were also high—55.12, 57.38, 94.62, 83.10, 95.95, 88.09, 89.54, and 93.46%, respectively. Increasing the hydraulic retention time increased removal efficiencies. The removal efficiency of BOD in aerated HSFCWs was higher than in nonaerated HSFCWs in the second effluent recirculation of sampling. This is because the oxygen supplied by aeration in the system increased the organic and inorganic pollutant removal efficiencies. Other pollutants were removed more effectively during the second effluent recirculation. Excluding BOD and COD, Duncan's multiple test revealed that the number of effluent recirculations for removal efficiencies of FOG, TKN, TSS, TDS, EC, and salinity was nonsignificant at the $p \leq 0.001$ level. These findings led to optimization of the medical rubber glove wastewater treatment at an ultrashort hydraulic retention time of 2–4 hr. This process and the control of CWs may be the best industrial wastewater treatment practice and a long-term solution for the industrial sector.

1. Introduction

Medical rubber gloves are in high demand in Thailand due to the rapid emergence of the SARS-CoV-2 virus (COVID-19 disease). The production of medical rubber gloves results in contaminated wastewater and chemical pollutants. The overall production capacity of rubber gloves in Thailand is expected to increase by at least 10 billion, allowing Thailand to have a total production capacity of at least 56 billion latex gloves by the end of 2021 (an increase of 22% from 2020). This is due to the expansion of the production capacity of Thailand's major rubber glove factory. Another factor is the entry of new businesses, both Thai and international, that have heavily invested in the manufacturing of rubber gloves in Thailand [1, 2]. In the case of Shun Thai Rubber Gloves Industry Public Company Limited, approximately 1,000,000 rubber gloves are produced per day (see Table 1), leading to 3,000–3,500 m^3 of wastewater per day generated from this process [3]. The factory follows the requirements of the industrial estate authority of Thailand (Notification of Ministry of Industry No. 2, issued in accordance with the factory act: the characteristics of wastewater discharged from factory), and the wastewater is treated successfully, monitored, and reported before being released into public freshwater. However, in the current scenario, wastewater levels were approximately two times greater than that previously discharged, causing the public freshwater to become sewage. To prevent overloading of the public freshwater, the discharged wastewater requires additional treatment for maintaining ecologically sustainable freshwater and possible reuse. Accordingly, constructed wetlands are an appropriate method for wastewater treatment for the required ecologically sustainable freshwater [4, 5].

Constructed wetlands (CWs) are basic, low-cost wastewater treatment units that apply natural processes to enhance wastewater quality and allow for its reuse [6]. Based on the water flow characteristics, CWs are classified into two types: surface flow or surface free-flow wetlands and subsurface flow. In particular, constructed wetlands with a free-flow water surface (or horizontal flow) allow water to flow aboveground, exposing it to the atmosphere and direct sunlight. Simultaneous physical, chemical, and biological processes filter solids, degrade organics, and remove nutrients from wastewater as it slowly flows through the wetland. Although horizontal flow constructed wetlands (HFCWs) can provide a reliable secondary level of treatment for biological oxygen demand (BOD) and total suspended solids (TSS), they are frequently less effective for nitrogen removal unless a longer hydraulic retention time and adequate oxygenation are provided [7]. Furthermore, wetland plants, such as emergent plants in HSFCWs, are an essential component of the constructed wetland treatment system [8]. They are important in CWs because of their microorganisms that dissolve and remove nutrients and other pollutants. A variety of pollutants, including biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total coliforms, and metals, can be removed from wastewater by using HSFCWs with an emergent plant through microbial degradation, plant uptake, substrate adsorption, filtration by packed media, and biological predation [9, 10]. Wetland performance is frequently measured in terms of pollutant removal efficiency and rate [6, 11]. Several authors have used the model's area and volumetric rate constants to simulate the behavior of the CW hydraulics and describe the removal performance for various pollutants [9,12]. The main treatment mechanisms in constructed wetlands are plant uptake and conversion, together with microbial processes [13]. The effect of aeration time (AT) on the removal efficiency was also reported by Feng and Liu. Under an oxygen-supplying condition, the nitrogen removal efficiency was greatly increased [14]. Hydraulic retention time (HRT) is the most influential factor in CWs systems that affects contact between substrates and microorganisms, favoring higher treatment efficiency [15]. When the HRT is increased, the removal rate of pollutants and the system's output power can be improved, thereby improving the system's power generation performance. In 2015, Yang investigated the system's HRT performance at 6, 12, 18, 24, and 48 hours. It is concluded that as HRT is increased, the time for the constructed wetland-microbial fuel cell (CW-MFC) system to reach a stable output voltage increases, as does the internal resistance. The power density gradually decreases as it grows larger, while the Coulomb efficiency gradually increases [16]. This is because, as the HRT is extended, the matrix intercepts the organic matter in the sewage, the electrogenic bacteria directly utilize the dissolved organic matter in the sewage, and the microorganism biodegrades the organic matter trapped on the substrate, resulting in a higher Coulomb efficiency [17]. Furthermore, Almasi et al. demonstrated that both HRT and AT have a significant influence on the efficiency of a laboratory-scale upflow aerobic/anoxic sequential bioreactor (UAASB) with alternate aeration to remove organic matter, nitrogen components, and phosphorous. When the HRT and AT were 12 h and 60 min, respectively, the optimum operational conditions for maximum pollutant removal rate with more than 75% removal of total COD were achieved [18].

According to our wastewater target treatment, wastewater pollutants were a powder from leaching and nitric acid, sodium hydroxide, and rubber scraps from a washing mold process. The pretreatment was carried out by the factory process. However, large volumes of wastewater generated by factories in a short period of time necessarily require rapid treatment with short-term consumption. As described above, reduced HRT times and aeration are of great interest for large volumes of wastewater discharged into public freshwater. To the best of our knowledge, there has been no report on rapid HRT with an aeration system. A short HRT period, for example, 2 or 4 hr. per effluent recirculation, is highly appealing for resolving the aforementioned wastewater problem.

The objective of this research is to evaluate the removal performances and treatment efficiency of aeration and nonaeration HSFCW systems by the ultrashort HRT per effluent recirculation approach. A hydraulic loading rate (HLR) was constantly adjusted to find the most optimal operating and design parameters.

2. Materials and Methods

2.1. Source of Wastewater, HSFCWs with Emergent Plant Design, and Sampling Period. The primary-treated wastewater in this study was supplied from Shun Thai Rubber Gloves Industry Public Co. Ltd., Rayong Province (12°47′08″ N, 101°29′10″ E). The experiment was conducted in a series of pilot-scale HSFCWs units located at Kasetsart University campus, Sriracha, Chonburi, Thailand (13°07′32″ N, 100°55′04″ E). Each HSFCWs unit with an emergent plant species was composed of a substrate layer and plants on the top of the unit, which was placed into a cement pipe chimney with a radius of 0.5 m and height of 0.9 m (Figure 1). The HSFCWs units were constructed from a plastic basket with a radius of 0.4 m and a height of 0.6 m, for an effective volume

Table 1: The productivity of medical rubber gloves and its correlated wastewater per month in the years 2019, 2020, and 2021.

Rubber gloves (million/month)				Wastewater (m^3/month)			
Month	2019	2020	2021	Month	2019	2020	2021
January	55	61	87	January	79,000	81,000	100,000
February	64	70	75	February	89,000	77,000	100,000
March	71	75	87	March	93,000	81,000	98,000
April	51	76	80	April	72,000	78,000	99,000
May	66	82	80	May	91,000	96,000	111,000
June	63	79	78	June	85,000	70,000	105,300
July	66	83	86	July	69,000	77,000	109,700
August	38	70	71	August	51,000	77,000	97,600
September	40	81	76	September	56,000	80,000	90,300
October	51	81		October	70,000	79,000	
November	60	78		November	80,000	81,000	
December	65	83		December	79,000	80,000	

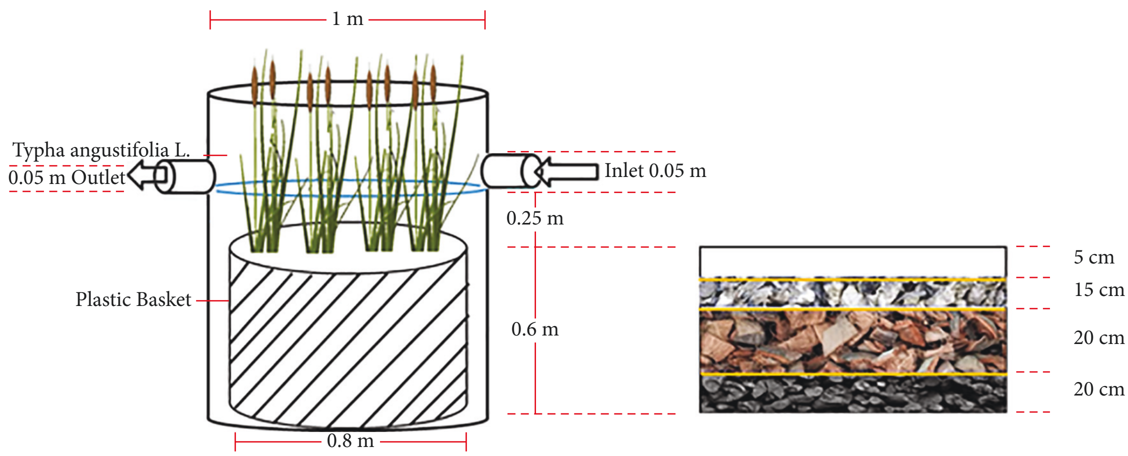

Figure 1: Schematic diagram of pilot-scale HSFCWs planted with emergent *Typha angustifolia* L.

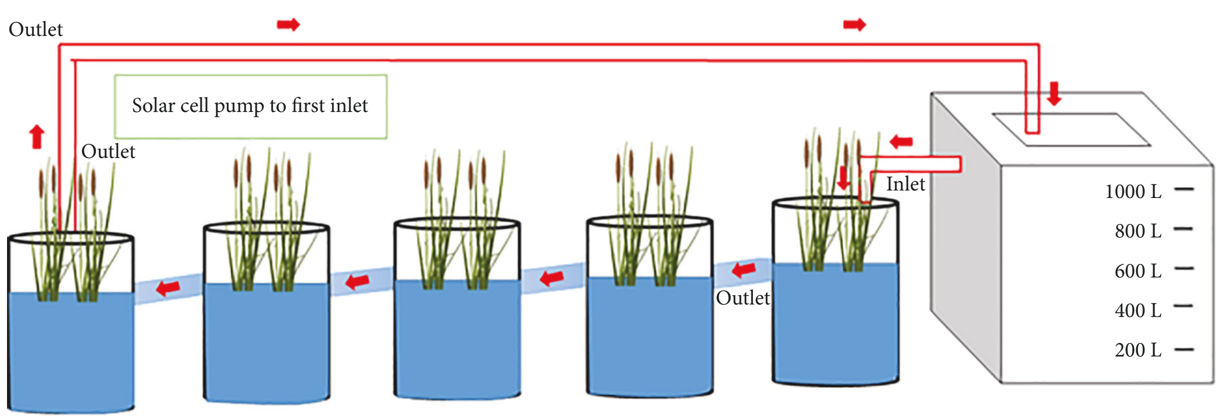

Figure 2: The series of HSFCWs with emergent plant units.

of 0.030 m^3. Activated carbon, coconut shell, and oyster shell were subsequently placed into the plastic basket as a substrate layer, while *Typha angustifolia* L. was used in this experiment as an emergent species at a rate of four plants per unit. Five HSFCWs units were arranged in a series pattern as shown in Figure 2.

The HSFCWs with an emergent plant system (hereafter called HSFCWs system) were fed by primary-treated wastewater at an HLR of 254.80 l per hour by a water pump. For comparison, an aquarium air pump was used to supply oxygen to the system at a rate of 1.00 m^3 per hour (Figure 2). This system was named the aeration HSFCWs system. The inlet wastewater was retained in the system for 2 hr. (known as ultrashort HRT). The treated wastewater was then collected (as samples) at an HRT of 2 hr. Selected samples were then refrigerated at 4°C for temporary storage until further

Table 2: The parameters and corresponded method/equipment used in the analysis.

Parameters	Method/equipment
Acidity-alkaline (pH)	Electrometric method
Biological oxygen demand (BOD)	Azide modification at 20°C, 5 days
Chemical oxygen demand (COD)	Potassium dichromate digestion
Total Kjeldahl nitrogen in water and plants (TKN)	Kjeldahl method
Fat, oil, and grease (FOG)	Extraction by organic solvent
Total suspended solids (TSS)	Total suspended solids dried at 103–105°C
Total dissolved solids (TDS)	Total dissolved solids dried at 103–105°C
Salinity	
Electric conductivity (EC)	Multifunctional water quality, tester GI9909
Temperature	

analysis. The samples were measured by the corresponding method described in Table 2. The outlet-treated wastewater was returned to the first unit's inlet via the solar cell pump to compare the effect of HRTs. HRTs were performed at 4, 6, and 8 hr. corresponding to the second, third, and fourth effluent recirculations, respectively. In addition, at each HRT effluent recirculation, samples were collected and measured.

2.2. Sample Analysis Methods and Calculations. The primary-treated wastewater was subjected to physicochemical and biological analysis. All the analyses were carried out according to the standard method stipulated by the American Public Health Association (APHA) for the examination of water and wastewater [19]. The parameters, corresponding methods, and equipment are shown in Table 2. Each parameter was measured four times ($n = 4$). The average and standard deviations are presented. The impact of various operating conditions on the performance of HSFCWs was assessed using percent removal as described by Abdelhakeem et al. [11]. The removal efficiency (%R) was calculated as follows:

$$\%R = \frac{C_{in} - C_{out}}{C_{in}} \times 100, \tag{1}$$

where C_{in} is the inflow concentration and C_{out} is the outflow concentration.

All experimental data were expressed as an average of four measurements with a standard deviation of one. Multifactor analysis of variance (ANOVA) was used to compare the removal efficiencies of aeration and nonaeration HSFCWs system. When a significant difference between treatments was observed in the ANOVA procedure, multiple comparisons were made using Duncan's multiple range test for differences between means. A significance level of $p < 0.05$ was used in all statistical analyses. The statistical tests were carried out using the IBM® SPSS® statistics software (IBM Singapore Pte Ltd., The IBM Place, Singapore; Part No. D0EJNLL).

3. Results and Discussion

The characteristics of the wastewater before passing through the HSFCWs system are shown in Table 3. The average values of BOD, COD FOG, TKN, TSS, TDS, EC, and salinity are lower than the limit prescribed by the Notification of Ministry of Industry No. 2 requirements [20]. These values were used as initial values for the removal efficiency calculation.

Table 3: Characterization of medical rubber glove factory primary-treated wastewater before incoming the HSFCWs systems.

Parameters	Average	Standard deviation (SD)
pH	8.75	0.01
BOD (mg.l^{-1})	4.55	0.18
COD (mg.l^{-1})	152.75	3.30
FOG (mg.l^{-1})	1.33	0.17
TKN (mg.l^{-1})	0.13	0.02
TSS (mg.l^{-1})	126.00	0.82
TDS (mg.l^{-1})	1,394.50	28.11
EC (μS.cm^{-1})	2,691.25	53.25
Salinity (ppt)	651.00	1.15
Temperature (°C)	29.47	0.05

3.1. The Pollutant Concentration is Dependent on Hydraulic Retention Time. The medical rubber glove wastewater was fed into the nonaeration and aeration HSFCWs system. Tables 4 and 5 show the average value of pollutant concentration measured at different hydraulic retention times. Pollutant levels decrease as HRT increases from the first effluent recirculation (2 hr.) to the fourth effluent recirculation (8 hr.). This result confirms that the HSFCWs system can effectively decrease the pollutants in wastewater. In the present study, the average pH and temperature values during the sampling periods were measured as a function of time. Without pH adjustment, the pH of the aerated HSFCWs system decreased slightly from 8.75 to 7.76, 7.64, 7.52, and 7.37. The pH of the HSFCWs system may change due to aerator oxygen supply, an imbalance in cation and anion uptake, respiration of CO_2 secreted organic acids from roots, and microbial activity [21]. The capacity of water to retain oxygen is determined by temperature; as the temperature rises, dissolved oxygen (DO) decreases. The first effluent recirculation temperature was 30.45°C, with a slight decrement of 29.63°C in the fourth effluent recirculation for aerated HSFCWs, and it was further reduced to 29.60°C in the nonaerated HSFCWs system. Coldwater has a higher concentration of dissolved oxygen. This trend is similar to those reported in the literature [22,23]. The main target

Table 4: The average concentrations of pollutants in the wastewater after passing through the nonaeration HSFCWs system.

HRT/effluent recirculation	1st (2 hr.)		2nd (4 hr.)		3rd (6 hr.)		4th (8 hr.)	
Parameters	Average	SD	Average	SD	Average	SD	Average	SD
pH	7.76	0.02	7.64	0.02	7.52	0.01	7.37	0.01
BOD (mg.l^{-1})	2.04	0.02	2.56	0.01	3.12	0.05	3.88	0.24
COD (mg.l^{-1})	65.00	5.77	55.00	5.77	37.50	5.00	25.00	5.77
FOG (mg.l^{-1})	0.07	0.01	0.06	0.01	0.05	0.01	0.04	0.01
TKN (mg.l^{-1})	0.02	0.00	0.03	0.01	0.03	0.01	0.03	0.01
TSS (mg.l^{-1})	5.10	0.12	4.75	0.13	4.50	0.08	4.35	0.06
TDS (mg.l^{-1})	166.00	3.65	147.50	5.51	135.00	2.58	132.00	5.16
EC (μS.cm^{-1})	281.50	11.82	247.00	2.58	233.00	3.83	227.50	7.19
Salinity (ppt)	44.50	2.08	36.00	1.83	52.50	1.29	31.00	1.83
Temperature (°C)	30.45	0.06	30.45	0.06	30.45	0.06	29.63	0.01

Table 5: The average concentrations of pollutants in the wastewater after passing through the aeration HSFCWs system.

HRT/effluent recirculation	1st (2 hr.)		2nd (4 hr.)		3rd (6 hr.)		4th (8 hr.)	
Parameters	Average	SD	Average	SD	Average	SD	Average	SD
pH	8.43	0.01	7.68	0.12	7.86	0.02	7.78	0.01
BOD (mg.l^{-1})	2.12	0.12	0.87	0.01	0.43	0.01	0.72	0.01
COD (mg.l^{-1})	50.00	4.08	18.75	2.50	5.25	0.96	2.50	0.58
FOG (mg.l^{-1})	0.03	0.01	0.01	0.00	0.01	0.00	0.02	0.01
TKN (mg.l^{-1})	0.03	0.01	0.02	0.00	0.02	0.01	0.02	0.01
TSS (mg.l^{-1})	5.20	0.14	4.83	0.10	4.43	0.10	4.08	0.10
TDS (mg.l^{-1})	225.50	10.25	186.00	9.93	347.50	9.00	252.00	7.30
EC (μS.cm^{-1})	367.00	11.83	346.50	3.42	306.00	4.32	237.00	2.58
Salinity (ppt)	63.50	3.87	42.50	3.11	61.75	1.71	43.25	2.22
Temperature (°C)	30.20	0.00	30.45	0.17	30.43	0.10	29.60	0.01

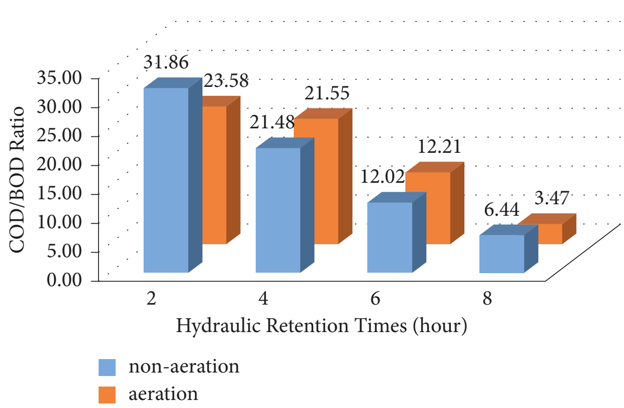

Figure 3: COD and BOD ratio of aeration and nonaeration HSFCWs systems.

parameters are usually BOD and COD; however, other pollutants such as TSS, total nitrogen, or ammonia nitrogen have also been used. Organic matter (BOD and COD), nitrogen compounds (total nitrogen, ammonia nitrogen, nitrate, and nitrite), phosphorus (total phosphorus and orthophosphate), coliform bacteria (*E. coli* and fecal coliforms), and heavy metals are pollutant indicators that can be used to evaluate CW performance. Physical properties (e.g., dissolved oxygen, electrical conductivity, pH, etc.) are also used to describe CW operating conditions [24].

The COD/BOD ratios were calculated from Tables 4 and 5. The results are shown in Figure 3. According to Davies [25], there is an empirical relationship between BOD, COD, and total organic carbon (TOC). The results of a COD test can also be used to estimate the BOD for a given sample. However, for each sample location in a wastewater treatment plant, a specific relationship must be established. That is, the relationship between BOD and COD from a particular sample location is unique to that location [26]. The COD test is useful for monitoring and process control once the correlation has been established.

The COD/BOD ratio should remain constant and can be used to estimate the site's performance and removal efficiency [11]. In this study, the COD/BOD ratio decreases as the HTRs increase. This is due to the fact that the HRT per effluent recirculation was set to only 2 hr. When an ultra-short time is set, the result is a high COD level. The authors believe that increasing the HRT will lower the COD/BOD ratio. Davies proposed a COD/BOD ratio of 2.1 as an appropriate value [25]. These ratios, however, are only a guide and may differ significantly from what is actually occurring at an individual wastewater treatment plant. The BOD and COD are insignificant for resolving the medical rubber glove wastewater problem. As shown in Tables 3 and 4, the COD/BOD ratio shown in Figure 3 is acceptable, and 2 hr. per effluent recirculation is useful for treating large amounts of wastewater.

3.2. Removal Efficiencies of Organics and Inorganics. Figure 4 shows, as a function of HRTs, the removal efficiency of BOD and COD in aeration and nonaeration HSFCWs with emergent plant systems. The medical rubber glove

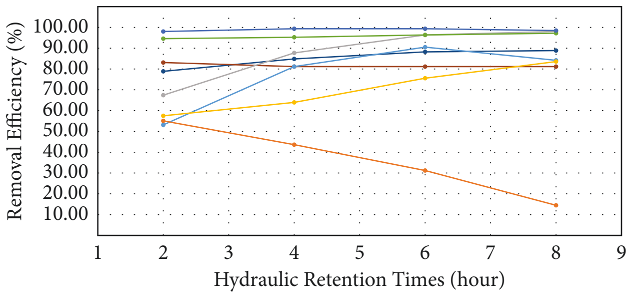

Figure 4: The removal efficiencies of BOD, COD, TKN, and FOG in aeration and nonaeration HSFCWs systems.

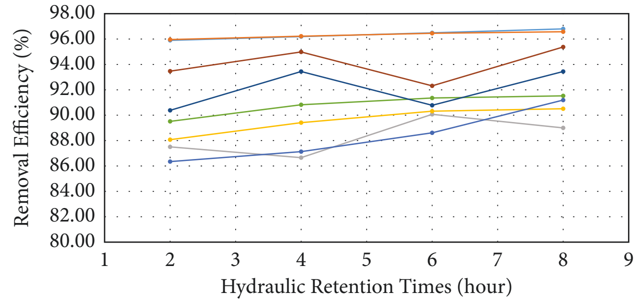

Figure 5: Removal efficiencies of TSS, TDS, EC, and salinity in aeration and nonaeration HSFCWs systems.

wastewater was fed into the nonaeration HSFCWs system, with an initial BOD average of $4.55 \pm 0.18\,mg.l^{-1}$, and the first effluent recirculation was observed. With a removal efficiency of 55.12%, it was reduced to $2.04 \pm 0.02\,mg.l^{-1}$, while the HSFCWs aeration system produced an average BOD of $2.12 \pm 0.12\,mg.l^{-1}$ with a removal efficiency of 53.25%. Furthermore, the initial COD average of $152.75 \pm 3.30\,mg.l^{-1}$ was reduced to $65.00 \pm 5.77\,mg.l^{-1}$ in a nonaeration HSFCWs system, whereas the HSFCWs aeration system presented an average COD of $50.00 \pm 4.08\,mg.l^{-1}$.

The removal efficiencies of COD for nonaeration and aeration HSFCWs systems were 57.38% and 67.28%, respectively. During the first 6 hr. of operation of the aeration HSFCWs system, the BOD removal efficiency was found to be increased. Figure 4 compares the variation of BOD concentration in aeration and nonaeration HSFCWs at different HRTs. Interestingly, in terms of BOD parameters, aerated systems outperformed nonaerated systems. Aerobic microbial degradation and subsequent processes in the substrates are thought to be responsible for BOD removal in emergent wetlands. Microbial growth on media surfaces removes soluble organic compounds, which are then attached to plant roots and rhizomes [27]. The most common microorganisms found in HSFCWs were chloroflexi, proteobacteria, acidobacteria, bacteroidetes, firmicutes, cytophagaceae, pseudomonadaceae, and anaerolineaceae. These microorganisms play an important role in the removal of organic compounds in rhizosphere sediments [28]. Organic matter in wastewater contains nearly 45–50% carbon (C), which is consumed as a source of energy by a diverse range of microorganisms since microorganisms consume less oxygen while decomposing organic matter [29]. Moreover, the aeration system′s organic matter content is reduced. However, the aeration system initially increased but began decreasing around the 8 hr. due to the higher amount of organic matter in the water. As a result, microorganisms require more oxygen to decompose organic matter. Aerated systems are more effective than nonaerated systems at removing COD. The oxidized organic matter in the water compared to carbon dioxide is greater in the aerated system due to the high oxygen content, and the organic matter is reduced more rapidly than in a nonaerated system [23].

Figure 4 shows the TKN's removal efficiencies at 2 to 8 hr. of flow in aeration (the blue line) and nonaeration (the brown line) HSFCW systems. The TKN removal efficiencies in aerated and nonaerated HSFCW systems were determined by the previous TKN value and reached a high constant level during the first effluent recirculation. The highest removal percentage of TKN for aerated and nonaerated HSFCW systems was 88.93 and 83.10%, respectively. The removal rates in both TKN systems were close to each other. In terms of removal, the aerated system was found to be more effective than the nonaerated system. Depending on the form of nitrogen available in the soil, plant species differ in their preferred forms of nitrogen absorption [30]. The movement of nitrogen through emergent plants improves processes other than those in the soil, water column, and associated biofilms [31]. The nitrogen-absorbing plant *T. angustifolia* L. was used in this study and proved to be suitable for total nitrogen removal. Emergent plants, for example, *T. angustifolia* L., are suitable for the TKN treatment process. As a result, plants can use nitrogen for their growth, resulting in fewer TKNs. Figure 4 also shows the FOG removal efficiencies at different HRTs of the HSFCW systems. The highest removal percentage of FOG was 99.24% and 97.11%. Lipid degradation in aerated systems is superior to that in nonaerated systems due to the high number of microorganisms [29, 30].

Figure 5 depicts the removal efficiencies of aerated and nonaerated HSFCW systems for TSS, TDS, EC, and salinity parameters. Because oxygen caused small solids to remain suspended in water, the removal efficiency of aerated and nonaerated HSFCW systems was different, but not significant, in terms of TSS removal; small solids bind together, causing the molecular weight of a large amount of water to rapidly decrease. Because the wastewater inside the pond is stagnant, the small suspension settles slowly. TDS removal efficiency is higher in nonaerated systems than in aerated systems. Furthermore, because the aeration system contains oxygen, the water conditions are constantly changing, causing the suspensions to move. As a result, the activated carbon absorbs more slowly than the nonaerated system with immobile water conditions. It only takes a few minutes to absorb absorbent charcoal. Because lighter organic matter settles on roots via rhizofilteration and physicochemical absorption and heavier suspended particles accumulate at the bottom and undergo anaerobic decomposition, TSS and TDS removal were improved [32]. The roots act as a living substrate for microorganisms to attach, providing a significant degree of treatment. The major mechanisms involved in *T. angustifolia* L. are the growth of both aerobic and anaerobic microorganisms around the roots, which leads to improved wastewater biodegradation [33].

According to Table 5, salinity in the aerated HSFCWs system was significantly reduced from 651.00 to 44.50 ppt, with salinity removal efficiency reduced by more than 90% during the first effluent recirculation of treatment. Nonaerated HSFCWs are slightly more valuable than aerated HSFCWs. Previous research has found that high salinity levels have an impact on the performance of CWs and microbial fuel cells (MFCs). Liu et al. tested the MFC with NaCl concentrations ranging from 200 to 400 mM, and the electric power generation increased with each increase [34]. They calculated that the maximum NaCl concentration at which microbial growth inhibition would occur is around 3%. Regarding CWs, some studies have found that salinity inhibits microbial processes within wetlands [35, 36]. Regarding the potential negative impact of high salinity on plants, only a clear deterioration during the last period, that is, under 43.25 ppt of salt, was observed in the current study. Previous research has tested various macrophyte plants in constructed wetlands treating high salinity wastewater. Gao et al. studied 12 different plants and discovered that high salinity inhibited growth while also reducing nutrient uptake capacity and aeration potential in the root zone [35]. The most resistant species, however, was *Phragmites australis*, which functioned normally up to a salt concentration of 20 $g.l^{-1}$. In contrast, *T. angustifolia* L. showed a significant level of removal efficiency of salinity in the HSFCWs system. This is due to the fact that in terms of nitrogen retention, *P. australis* and *T. angustifolia* L. are very similar.

The EC parameter was used to compare the removal efficiency of aeration and nonaeration HSFCW systems. The wastewater fed into the systems had an initial EC of 2,691.25 $\mu S.cm^{-1}$. It was reduced to 281.50 $\mu S.cm^{-1}$ during the first effluent recirculation of the aerated HSFCWs system. The aeration system was found to be more effective at reducing EC than the nonaeration system. This is due to the fact that the dissociation of charge in an aerated system is less than that of a nonaerated system, and it was discovered that the aerated system is more effective in removing salinity than the aerated system due to the dissociation of charge in the aerated system. According to these findings, the authors believe that high salinity in industrial effluents could have a positive impact on the development of HSFCWs with emergent plants because this system decreased salinity and electrical conductivity. The challenge would be to adapt halo-tolerant microorganisms and plants to these conditions, which could be the focus of future research.

3.3. Correlations of the Analyzed Pollutants. The Pearson correlation coefficients for the eight pollutants from the nonaeration and aeration HSFCWs system are shown in Tables 6 and 7, respectively. The pH in the nonaeration system is strongly correlated with the COD, FOG, TSS, TDS, and EC (Table 6). It is reasonable to assume that TSS, TDS, and EC were all directly proportional to the pH since these variables are determined by the presence of an electric charge. BOD, on the other hand, is inversely correlated—at a two-tailed 0.01 significance level—with TSS, TDS, EC, and pH.

Table 7 shows the Pearson correlation coefficients from the aeration HSFCWs system. The pH in the aeration system is strongly correlated with BOD, COD, FOG, TSS, TDS, and salinity. These findings imply that increasing the oxygen supply can improve BOD levels. Similarly, at a 0.01 significance level (two-tailed), BOD and COD are correlated with FOG, TSS, TDS, and EC. Except for pH, there was no correlation between salinity and the other pollutants. The strong correlation between BOD and COD suggests the same behavior of the two pollutants. An inverse but nonsignificant correlation between FOG and EC was found.

3.4. Aeration versus Nonaeration HSFCWs Analysis by the ANOVA. The ANOVA technique—a type of independent samples t-test that can be applied to any number of groups or treatments—was used to investigate how various types and combinations of factors affect the mean of a variable. Statistical tests were performed on the BOD, COD, FOG, TKN, TSS, TDS, salinity, and EC data groups. At the $p < 0.05$ significance level, one-way ANOVA was used. There were no significant differences in TSS between the aeration and nonaeration HSFCW systems, indicating that the system had no influence on TSS pollutants. When a range is determined to be nonsignificant, no further subsets of the TSS group are tested. When a significant effect is found using analysis of variance, Duncan's multiple range test was used to analyze the significant variables, which were BOD, COD, FOG, TKN, TDS, salinity, and EC. Duncan's statistics table (not shown) revealed that the aeration system performed statistically better at treating BOD, COD, and FOG than the nonaerated HSFCWs system. Meanwhile, at a significance level of 0.001, the nonaerated system was more effective than the aeration HSFCWs system in treating pH, TDS, EC, and salinity. The aeration HSFCWs system was more effective than the nonaerated system in treating TKN at a significance level of 0.05; however, the nonaerated system was better at treating TDS than the aerated system at a significance level of 0.01.

3.5. Cost Analysis versus Sustainable Solution for the Industrial Sector. The total cost of the aeration HSFCWs with emergent plants includes significant capital costs along with minor operational and maintenance costs. The total cost of the process is estimated between USD 100 and 200 per HSFCWs system, which covers the cost of ten cement pipe chimneys, baskets, and a solar cell. The land cost is not included in the budget because it was installed at the existing

Table 6: Correlation coefficients of various pollutants from nonaeration HSFCWs.

Parameters	pH	BOD	COD	FOG	TKN	TSS	TDS	EC	Salinity	Temp
pH	1									
BOD	−0.939**	1								
COD	0.942**	−0.878**	1							
FOG	0.739**	−0.741**	0.677**	1						
TKN	−0.141	0.195	−0.033	0.075	1					
TSS	0.918**	−0.902**	0.891**	0.601*	−0.236	1				
TDS	0.836**	−0.788**	0.852**	0.601*	−0.336	0.896**	1			
EC	0.876**	−0.831**	0.812**	0.669**	−0.139	0.926**	0.855**	1		
Salinity	0.437	−0.464	0.323	0.227	−0.053	0.390	0.277	0.321	1	
Temp	0.500**	−0.399	0.467	0.723**	0.070	0.224	0.274	0.237	0.302	1

*Correlation is significant at the 0.05 level (two-tailed) and **correlation is significant at the 0.01 level (two-tailed).

Table 7: Correlation coefficients of various pollutants from aeration HSFCWs.

Parameters	pH	BOD	COD	FOG	TKN	TSS	TDS	EC	Salinity	Temp
pH	1									
BOD	0.878**	1								
COD	0.851**	0.958**	1							
FOG	0.730**	0.724**	0.588*	1						
TKN	0.594*	0.680**	0.768**	0.453	1					
TSS	0.649**	0.804**	0.894**	0.294	0.654**	1				
TDS	0.698**	0.906**	0.916**	0.573*	0.784**	0.880**	1			
EC	0.474	0.432	0.637**	−0.046	0.475	0.786**	0.475	1		
Salinity	0.748**	0.398	0.403	0.353	0.270	0.302	0.197	0.447	1	
Temp	0.065	0.055	0.174	−0.233	0.029	0.366	0.172	0.517*	0.090	1

*Correlation is significant at the 0.05 level (two-tailed) and **correlation is significant at the 0.01 level (two-tailed).

university campus treatment plant. The substrates layer and *T. angustifolia* L. were excluded in the cost analysis because they were collected on-site. The effectiveness of aeration HSFCWs with emergent plants has been demonstrated. The wastewater can be remediated at a rate of 254.8 l per hour or 6,115.2 l per day by using this system. If the medical rubber glove factory produces 3,000 m^3 per day, pilot-scale aeration HSFCWs should be modified. In particular, the cement pipe chimney should be replaced with a $2 \times 4 \times 4$ m^3 cement well. A wastewater volume of 32 m^3 can pass through every 2 hr. or 384 m^3 per day. The oxygen supply system could be attached to the side of the well and powered by solar cells. The substate layers and emergent plants can be collected from the surrounding area.

The economic viability, technical feasibility, environmental protection contribution, and social acceptance of the aeration HSFCWs system demonstrate the system's sustainability [37]. Furthermore, this system completes the wastewater flow cycle, allowing the safe reuse of treated effluents. Furthermore, the sustainable sanitation approach incorporates public health and hygiene, environmental and natural resource protection, technological and operational parameters, financial parameters, and sociocultural aspects [37, 38]. The concept of constructed wetlands was defined in the field of sustainability. Although the term "sustainability" is commonly used currently—although its meaning is often misunderstood—it is used here to refer to the incorporation of environmental aspects into the treatment process. Claims regarding the sustainability of wetland systems, particularly for industry, relate to the benefits of promoting both economic growth and the protection of ecosystems and public health, which are the real advantages of wetland technology to the industry. Lastly, low energy consumption and the use of natural materials (gravel, soil, sand, and plants) are two critical factors for the system's sustainability.

4. Conclusions

We successfully report the characteristics of aeration and nonaeration HSFCW systems with emergent plants for remediating large amounts of primary-treated wastewater from the rubber glove industry. The results showed that increasing the hydraulic retention time increases removal efficiencies. At a hydraulic retention time of 2–4 hr., aerated HSFCWs had higher BOD removal efficiencies than the nonaerated HSFCWs system. Other pollutants were removed more effectively at a hydraulic retention time of 2–4 hr. The roots of *T. angustifolia* L. serve as a living substrate for attached microorganisms, including aerobic and anaerobic microorganisms. An aeration supply, in addition to substrate layer sequences, stimulated the reaction and reported improved organic and inorganic pollutant removal efficiencies. Statistical results confirmed that the aeration system performed statistically better at treating BOD, COD, and FOG than the nonaerated HSFCWs system.

These findings concluded that the hydraulic retention times of 2–4 hours are satisfied for the large volume of primary-treated wastewater from a medical rubber glove factory.

The total cost of aeration HSFCWs with emergent plants includes both capital costs and minor operational and maintenance costs. These designed HSFCW systems are economically and environmentally diverse, which increase aesthetic value by creating a natural and sustainable pollutant removal mechanism. This approach will significantly contribute to the regulation of water bodies and the resolution of the water scarcity crisis, establishing the way for sustainable development.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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