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Research Paper

The Combining Constructed Wetland and Ultrafiltration to Increase Total Coliform Removal Efficiency of Wastewater

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Abstract The horizontal sub-surface flow constructed wetland (HSSF-CW) is a green and sustainable technology that imitates natural wetlands for wastewater treatment purposes, efficient in removing pollutants from various types of wastewaters. Hospitals in Palu, Indonesia, are facing problems due to the poor performance of existing WWTPs, especially in removing total coliform (TC) and total suspended solids (TSS). This issue needs attention because it can impact health and the environment. Efforts to use HSSF-CW for hospital wastewater treatment are expected to overcome these problems. The HSSF-CW usually produces an effluent low in organic matter and TSS but not for TC, so this system still needs to be combined with other systems. Combining HSSF-CW with ultrafiltration membranes (UF) is an exciting idea. The UF membranes with pores between 0.01 – 0.1 µm are expected can hold bacteria. This study aims to design the HSSF-CW and UF membrane combination system on a pilot-scale that considers aesthetic factors, then evaluates its performance using experimental methods. In this case, ware utilized ornamental water plants (Ludwigia adscendens, Echinodorus paniculatus, and Typha angustifolia) and gravel sand media measuring 5 – 8 mm. The results proved effective in removing TC and TSS parameters with 98.64% and 100% efficiency. Thus, the HSSF-CW and UF membrane combination system was suitable for hospital wastewater treatment in Palu, Indonesia.

Keywords: *Constructed Wetland, Hospıtal Wastewater, Total Colıform Removal, Ultrafiltratıon*

Introduction

Constructed wetland (CW) is a green and sustainable technology whose main components consist of media/substrate, water plants, microorganisms, and water that imitates natural wetlands for wastewater treatment purposes (Hammer, 1989). Several research results show that the performance of CW, especially the horizontal sub-surface flow constructed wetland (HSSF-CW), is quite efficient in removing pollutants from various types of wastewater, for example, Benassi & Coelho (2021) in municipal wastewater treatment; Jamwal et al., (2021) in septic tank effluent treatment; Maharjan, Amatya, & Toyama (2019) in domestic wastewater treatment; Witthayaphirom et al. (2020) in landfill leachate processing; Dires, Birhanu, & Ambelu (2019) in hospital wastewater treatment; Lancheros et al. (2019) in pharmaceutical wastewater treatment; Alemu, Mekonnen, & Leta (2018) in the treatment of leather tanning waste; Udom, Mbajiorgu, & Oboho (2018) in primary wastewater treatment of pigsty; Mbanefo Okoye et al. (2018) in the processing of abattoir waste; Lizama-Allende et al. (2018) in acid mine drainage; Zidan et al. (2015) in rural wastewater treatment.

The results of investigations from several hospitals in Palu, Indonesia, for the 2015 – 2019 period revealed that the hospital's wastewater treatment plant (WWTP) had low performance in the elimination of total coliform (TC) and total solid suspended (TSS). In this case, it can impact health and the environment if it does not get attention (Akhmad et al., 2020). The WWTP technology commonly used in hospitals is an aerobic-anaerobic biofilter system; its operation generally requires much artificial equipment, resources in the form of chemicals, and fuel oil energy sources through electricity or generators (Mangkoedihadjo and Samudro, 2010). In addition, the operational costs are high (Zulkifli, 2014).

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Efforts to use HSSF-CW technology for hospital wastewater treatment needs are expected can solve the problems faced by hospitals in Palu. Some of the advantages of the HSSF-CW system are simple construction, making it easy to manufacture; flexible in the selection of placement locations; flexibility in operating systems (e.g., gravity systems or using pumps); low cost, because if you use a gravity system, then the use of energy from outside is only sunlight; odor does not arise because the waste is not in contact with the outside air; reliable performance; not become a breeding ground for mosquitoes; and can be presented as a garden that has aesthetic value (Kadlec & Knight, 1996). In addition, Indonesia has a tropical climate where water plants are abundant and thrive throughout the year (Noor, 2007).

The HSSF-CW system usually produces effluents low in organic matter and TSS but not for TC, so this system still needs to be combined with other systems, such as chlorine or ultra-violet disinfection (Headley et al., 2013). However, disinfection with chemicals such as chlorine can create other health and ecological problems due to trihalomethane formation (Toscano et al., 2013); also, UV disinfection is not always suitable for disinfection of effluent from HSSF-CW due to the development of a biofilm-like coating on the bulb. Can block UV rays (Richter & Weaver, 2003). Efforts to combine the HSSF-CW and ultrafiltration membrane (UF) for the needs of hospital wastewater treatment are an exciting idea. The working model of the membrane has a good concept because only compounds that have a diameter smaller than the pores can pass through the membrane filter (Nita & Septiana, 2012). UF membranes with pores between 0.01 – 0.1 μm can hold bacteria and soluble macromolecules such as proteins (Frenkel, 2015).

Therefore, this research aims to design a pilot-scale of the HSSF-CW and UF membrane combination system that considers aesthetic factors, then evaluates its performance in eliminating TC and TSS parameters by experimental methods. In this case, ware utilized ornamental water plants (Ludwigia adscendens, Echinodorus paniculatus, and Typha angustifolia) and gravel sand media measuring 5 – 8 mm.

Research Methods

Source of Hospital Wastewater

The source of hospital wastewater used for this experimental was taken from the WWTP inlet of a public hospital in Palu, which is a mixture of sewage from the domestic, clinic, and laboratory activities at the hospital; located at 0°53'57.38 latitude, 119°50'52.63 east longitude at an altitude of approximately 100 m above sea level.

Operational Arrangement

Several operational arrangements were made to realize an efficient HSSF-CW and UF membrane combination system, such as the use of fine sand-gravel media measuring 5 – 8 mm, taken from the Palu River. The use of small-sized versus large-sized granular media has been shown to increase the ratio of inactivation of fecal coliform and somatic coliphage (Ottová, Balcarová, & Vymazal, 1997; García, Vivar, Aromir, & Mujeriego, 2003). Likewise, Tanner, Sukias, Headley, Yates, & Stott (2012) observed better E. coli elimination in CW filled with fine sand than CW filled with coarser gravel. The water depth in the HSSF-CW cells is limited to 0.30 m. Moshiri (2020) recommends a water level of about 30 cm. Shallow cells are believed to have better waste aeration than deep cells. HSSF-CW analyzed in a study with 0.27 m water depth and 3.5 mm granular medium proved to be more effective than those designed with 0.50 m water depth and 10 mm medium size granular for the removal of TC, E. coli, and FE (Morató et al., 2014).

Vegetation Selection

For aesthetic considerations, water plant species are selected that have an aesthetic form, grow locally, grow fast, and have the potential to absorb pollutants. Therefore, Ludwigia adscendens, Echinodorus paniculatus, and Typha angustifolia were selected to represent low, medium, and tall ornamental water plants, respectively. L. adscendens grows wild in the Palu River. T. Angustifolia grows wild in the wetlands in the Palu area. Meanwhile, E. paniculatus is used as an ornamental pond plant.

The purification ability of the selected water plants has been reported in several references; for example, T. Angustifolia can absorb pharmaceutical waste containing ibuprofen through phytoextraction (Li et al., 2016). Also, T. Angustifolia was shown to have a positive effect on CW performance in the influent treatment of Lake Marriott in Egypt, which overall demonstrated high pollutant removal efficiency, BOD_5 removal of 83.3%; COD 95.8%; NH_3-N 99.9%; total nitrogen (TN) 94.7%; removal of total P (TP) 99.7%, Escherichia coli 100%; and total bacteria count of 92.3% (Gaballah et al., 2020).

The L. adscendens, which was applied to the restoration of pig manure in the subtropics, showed a perfect growth status and a net biomass growth rate of 539.8%, able to regulate the pH of wastewater, increase the potential for dissolved oxygen and oxidation-reduction, and reduce the value of electrical conductivity. The removal rates of NH_4^+–N, NO_3^-–N, NO_2^-–N, TN, TP, COD, dan Chl-a reached 98.67%, 64.83%, 26.35%, 79.30 %, 95.90%, 69.62%, and 92.23%, respectively (Xu et al., 2020).

References related to the ability of E. paniculatus were not found. However, there was Echinodorus palifolius from the same genus having the ability to absorb heavy metals (Hasbi et al., 2020).

Design of Experimental

The combining of HSSF-CW and UF membranes is expected to be mutually complementary. The HSSF-CW is placed for initial treatment (phase 1) to reduce large particles such as organic materials and suspended solids. Conversely, The UF membranes are placed for further treatment (phase 2) to hold the bacteria that escape in phase 1 without being burdened by organic materials and suspended solids. The construction arrangements of the combination system of HSSF-CW and UF membrane as presented in Figure 1.

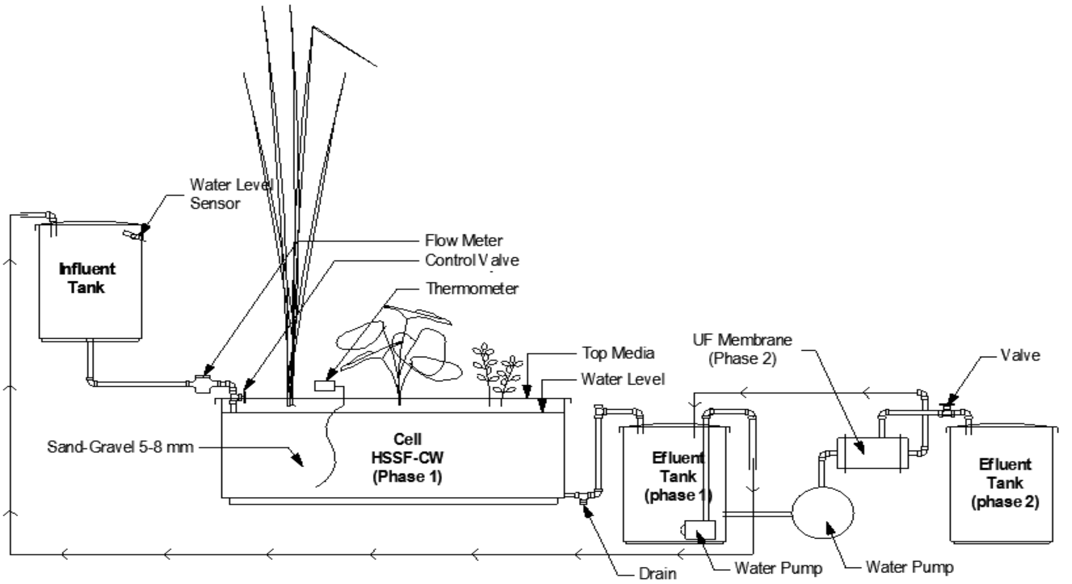

Figure 1. The Schematic of the HSSF-CW and UF Membrane Combination System on a Pilot Scale

The HSSF-CW cells are designed from fiberglass with long (L) 1.00 m, width (w) 0.45 m, and height (H) 0.35 m. The cell base slope (s) is set at 0.005. The depth of media is submerged (d) 0.30 m. The value of porosity (N) and hydraulic conductivity (KS) of fine gravel size 5-8 mm are 0.35 and 5000 m3/m2/hour, respectively (USEPA, 2000). The UF membrane utilized was a perforated fiber module (capillary) operated by cross-flow to prevent the cake layer from forming on the membrane surface. Effluent flowed past the UF membrane using a booster pump 1-3 bar. The HSSF-CW and UF membrane combination system is designed for the maximum loading rate (Q) 3,375 m3 / day obtained from Equation 1.

The surface area of the HSSF-CW (As) is determined based on the one-day HRT(T) to ease calculations. By Equation 2, the HSSF-CW area obtained is 32 m2, more expansive than the pilot cell area, only 0.45 m2. The effluent in phase 1 must be recirculated continuously at a constant hydraulic loading rate to achieve the 32 m2 equivalent. The 24-hour recirculation process is equivalent to one day's hydraulic retention time. This action taken is still following the principles of the HSSF-CW system, where the effluent continues to flow consistently.

$$Q = A_C . K_S . S \qquad (1)$$
$$A_S = \frac{Q \,.\, t}{d \,.\, n} \qquad (2)$$

Where, Q: Hydraulic Loading Rate (m^3/d); A_c: Cross-sectional Area CW (m^2); K_s: Hydraulic Conductivity (m3/m2/day), and; S: Cell Base slope; A_s: Surface Area CW (m^2); t: Hydraulic Retention Time (days); d: Submerged Media Depth (m), and; n: Media Porosity.

Experimental Operation

There are two of the HSSF-CW and UF membrane combination system on pilot-scale (CW1 and CW3). Both are a repetition, were planted with Typha angustifolia, Echinodorus paniculatus, and Ludwigia adscendens, respectively, by polyculture. Planting densities were seven clumps, two clumps, and 25 plant stems, respectively. CW2 without vegetation and membrane as a control. They all received the same wastewater load.

Following are the operating procedures: filtering the gravel material to obtain a fine sand-gravel media of 5 - 8 mm size; Wash the media, then filling it in the HSSF-CW cells with a height of 0.35 m; installing the system components; testing to ensure all components are functioning correctly, this test still uses healthy water; planting of water plants in CW1 and CW3 with an acclimatization process for one month for the plant adaptation process, CW2 without vegetation as a control; started the experiment by draining water from the system and then replacing it with hospital wastewater.

Sampling and Analysis

Effluent sampling was carried out on each system three times on the 1, 2, and 3 days of hydraulic retention times. The effluent samples were taken and stored in 1000 ml plastic bottles for the TSS parameter test and 500 ml sterile glass bottles for the TC parameter test. The TSS and TC parameter tests were analyzed at the Laboratory of Analytical Chemistry – Environment and the Laboratory of Biology Education, PMIPA Tadulako University, Palu, Indonesia.

TSS parameter testing using the gravimetric method and The TC parameter testing uses the MPN (Most Probable Number) method, a statistical method based on probability theory.

Performance Evaluation of System

The performance evaluation of the HSSF-CW and UF membrane combination system was calculated by using Equation 3.

$$E = \frac{(C_{in} - C_{out})}{C_{in}} \, x \, 100\% \qquad (3)$$

E: Efficiency rate; C_{in}: Wastewater quality before treatment, and; C_{out}: Wastewater quality after treatment.

Results and Discussion

The TSS and TC Parameters Conditions

The quality of the TSS and TC parameters of hospital wastewater for this experiment is presented in Table 1. It appears that the TC is higher than the quality standard, >110,000 MPN/100 ml, the same as in the 2015-1019 period where the average TC is 45000 - 216000 MPN/100 ml (Table 2). The TC concentration of hospital wastewater is generally 104–107 MPN/100 ml (Carraro et al., 2016). The TSS condition was previously thought to be high but was lower than the quality standard, namely 12.40 mg/L, where The TSS parameter for hospital wastewater for the 2015-2019 period is in the range of 59 – 147 mg/L (Table 2).

Table 1. The TSS and TC Parameters Conditions of Hospital Wastewater

Parameters	Unit	Concentration*	Quality standards**
Total Suspended Solid (TSS)	mg/L	12,40	30
Total Coliform (TC)	MPN/100 ml	>110000	3.000

Source: *Laboratory test results, 2021; **Minister of Environment and Forestry Regulation No. 68 of 2016

Table 2. The TSS and TC Parameters Quality of Hospital Wastewater in Palu for the 2015-2019 Period

Parameters	Unit	Concentration Average					Quality standards
		2015	2016	2017	2018	2019	
TSS	mg/L	126	59	85	145	147	30
TC	MPN/100 ml	131000	140000	213000	45000	216000	3000

Source: (Akhmad et al., 2020).

Removal of Total Coliform

There was a decrease in TC during the experiment with increasing hydraulic retention time (Table 3). Generally, the HSSF-CW system has a better and more efficient reduction capacity due to a longer retention time (Wu et al., 2016). The reduction capacities of CW1 and CW3 (The HSSF-CW and UF membrane combination system) appear more efficient because they can reduce TC effluent to below the quality standard, an average of 1500 MPN/100 ml in retention time one day. The control could only reduce TC up to 46000 MPN/100 ml.

Table 3. Removal of Total Coliform

Treatment	Initial (MPN/100 ml)	TC of Effluent (MPN/100 ml) by Hydraulic Retention Time (days)					
		1		2		3	
CW2 (control)	>110000	46000		2800		2000	
CW1 phase 1	>110000	15000		2100		1500	
CW1 phase 2			2100		1500		900
CW3 phase 1	>110000	2800		700		400	
CW3 phase 2			900		400		<0,5
average	>110000	8900	1500	1400	950	950	450

Source: Laboratory test, 2021

Vegetation factors more influenced the high TC reduction capacity in C1 and CW3. In the first one day retention time, there was a significant reduction TC from the initial condition >110000 down to an average of 8900 MPN/100 ml after passing through the cells HSSF-CW (Phase 1) was then refined to 1500 MPN/100 ml after to passing through the UF membrane (Phase 2). In this case, the use of UF membranes has increased the system's efficiency because it shorts the hydraulic retention time required to achieve TC quality according to quality standards. While on the control (HSSF-CW without vegetation) can only decrease to 46000 MPN/100 ml. The influence of vegetation on the TC removal may be as it has been reported that several fecal coliforms can be removed by adhering to plant root surfaces (Solano et al., 2004), or root exudates released by plant species containing bactericidal activity (Tuncsiper et al., 2012). The release of antimicrobial exudates may be toxic to pathogenic microorganisms and alter the physical and chemical environment of the rhizosphere and render it unsuitable for pathogen survival (Avelar et al., 2014).

The use of river sand-gravel media measuring 5 – 8 mm is also confirmed to influence the removal of TC through the filtering and sedimentation process, which can be shown from the presence of TC removal in control (HSSF-CW without vegetation). Because according to Karim et al., (2004), the screening mechanism plays an essential role in reducing pathogenic microorganisms, especially in HSSF-CW. The TC removal efficiency depends not on the type of filter used but on the smaller particle size (Redder et al., 2010).

With a TC load of >110000 MPN/100 ml, the optimum efficiency rate required to achieve TC quality according to quality standards is a minimum of 97.3%. In The combination system of HSSF-CW and UF membrane, the optimum efficiency rate can be achieved in a retention time of less than one day. While in the CW2 (control) was achieved with a retention time of 2 days (Table 4). Therefore, the performance of the HSSF-CW and UF membrane combination system has been shown to have a high reduction capacity and efficiency for TC removal.

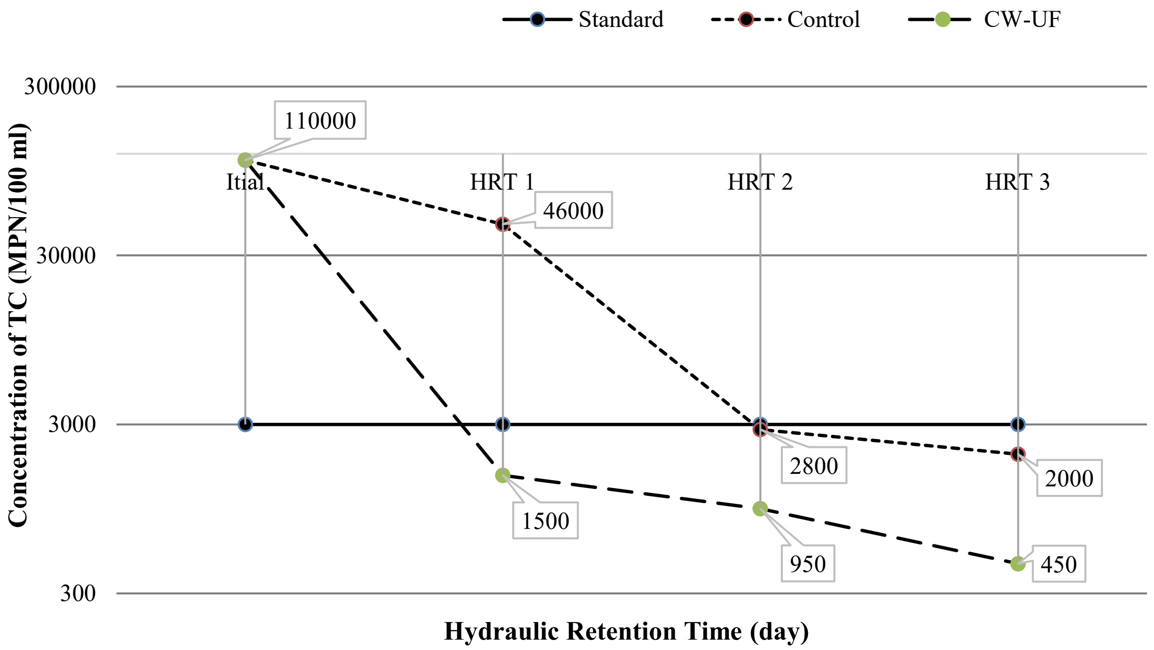

Figure 2. The Graph of Total Coliform Removal

Table 4. Performance of System in Total Coliform Removal

Treatment	Efficiency Rate (%) by Hydraulic Retention Time (days)					
	1		2		3	
CW2 (control)	58.18		97.45		98.18	
CW1 phase 1	86.36		98.09		98.64	
CW1 phase 2		98.09		98.64		99.18
CW3 phase 1	97.45		99.36		99.64	
CW3 phase 2		99.18		99.64		100.00
average	91.91	98.64	98.73	99.14	99.14	99.59

Source: Analysis results, 2021

Removal of Total Suspended Solids

Although the TSS parameter of hospital wastewater was low, the system's performance on TSS removal could still be observed. In Table 5, TSS removal of up to 0.12 mg/L in CW2 (control), even 100% in CW1 and CW3 (The HSSF-CW and UF membrane combination system). In this case, it cannot be separated from the influence of the media and plant roots on the HSSF-CW cells (phase 1). The role of the media focuses on aspects of the filtration and interception functions for larger particles and contaminants in the HSSF-CW system (Ji et al., 2021). Meanwhile, the role of plant roots is as a barrier to the flow rate to facilitate the process of solids sedimentation and assist the filtration process (Puspita et al., 2005).

Table 5. Removal of Total Suspended Solid

Treatment	Initial (mg/L)	TSS of Effluent (mg/L) by Hydraulic Retention Time (days)					
		1		2		3	
CW2 (control)	12,40	0,13		0,12		0,11	
CW1 phase 1	12,40	0,06		0,04		0,03	
CW1 phase 2			0,00		0,00		0,00
CW3 phase 1	12,40	0,04		0,04		0,02	
CW3 phase 2			0,00		0,00		0,00
Average	12,40	0,05	0,00	0,04	0,00	0,03	0,00

Source: Laboratory test, 2021

Condition of Other Parameters

Because vegetation and microorganisms in the HSSF-CW are biotic components, they are strongly influenced by environmental parameters such as temperature, pH, and dissolved oxygen (DO). In addition, it also depends on the availability of organic matter and nutrients.

The temperature was stable at 30.1ºC and pH at 7.8 during the experiment. Most bacterial growth reaches its optimum at a temperature of around 20 - 45 °C, and bacteria generally work optimally in the pH range of 6 - 8 (Prescott, 2008). Also, nutrients are easier to be absorbed by plant roots at a neutral pH range because, at that pH range, most of the nutrients are soluble in water. In this case, the existing temperature and pH conditions are not a barrier to the performance of the HSSF-CW combination system and UF membrane.

The DO conditions tended to increase almost the same for all treatments during the experiment (Table 6). Therefore, the increase in DO is not due to plant factors (release of oxygen on plant roots) but caused effluent recirculation factors. Wastewater recirculation allows extensive passive aeration resulting in diffusion of atmospheric oxygen (Cooper et al., 1996). The presence of DO in wastewater is essential because required as the final electron acceptor when aerobic bacteria oxidize organic matter (GARCÍA et al., 2010). Also, there is a relationship between increased DO and pathogen death in the aquatic environment (Fernández et al., 1992).

Table 6. Increasing of Dissolved Oxygen

Treatment	Initial (mg/L)	DO of Effluent (mg/L) by Hydraulic Retention Time (days)					
		1		2		3	
CW2 (kontrol)	7,2	7,1		7,8		8,7	
CW1 phase 1	7,2	7,7		8,1		8,5	
CW1 phase 2			7,9		8,5		8,4
CW3 phase 1	7,2	7,5		8,4		8,1	
CW3 phase 2			8,1		8,5		8,8
Average	7,2	7,6	8,0	8,3	8,5	8,3	8,6

Source: Laboratory test, 2021

The quality of BOD, COD, ammonia, and phosphate parameters of hospital wastewater for this experiment are presented in Table 7. It appears that the BOD and Ammonia are higher than the quality standard, which are 80.30 and 52.10 mg/L, respectively. The high ammonia content could be due to the influence of the high content of organic matter. The BOD parameter reflects the organic matter content of wastewater. Bacteria oxidize organic matter by utilizing DO as the final electron acceptor, releasing carbon dioxide, ammonia, and other stable chemical compounds (GARCÍA et al., 2010).

In The HSSF-CW, high organic matter can be removed through physical processes such as sedimentation, filtration, adsorption by the existing media. However, according to Tangahu & Warmadewanti (2001), this physical process can only reduce the concentration of COD and BOD solid and TSS, while dissolved COD and BOD are removed through a degradation process by the activity of microorganisms and plants. The process of reducing high organic matter is a nutrient for plants and will also contribute significantly to the supply of C, N, and energy for microbial life (Handayanto, E. dan Hairiah, 2007).

Ammonia is an inorganic compound containing nitrogen (N), where plants and microorganisms need the element N as a source of nutrients. In wastewater, high ammonia levels are highly toxic to fish species (El-Bourawi & Khayet, 2007).

Table 7. The Quality of BOD, COD, Ammonia, and Phosphate Parameters of hospital wastewater

Parameter	Unit	Concentration*	Quality Standards**
BOD	mg/L	80,30	30
COD	mg/L	84,00	100
Ammonia	mg/L	52,10	10
Phosphate	mg/L	9,20	-

Source: *Laboratory test, 2021; **Minister of Environment and Forestry Regulation No. 68 of 2016

The HSSF-CW and UF membrane combination system appears to have a good and efficient reduction capacity for organic matter removal (BOD) because, in the first one-day retention time, the quality of BOD can be produced on average 5.48 mg/L, far below quality standards. At the same time, only achieved 17.96 mg/L at the control (Table 8). The high reduction capacity of the HSSF-CW and UF membrane combination system is clearly due to the degradation process by microorganisms and plant activity supported by normal environmental parameters, DO availability, and biodegradable characteristics of organic matter. The BOD/COD ratio is 0.96, indicating that the organic matter content of the wastewater is quick to degrade

Tabel 8. Removal of BOD

Treatment	Initial (mg/L)	BOD of Effluent (mg/L) by Hydraulic Retention Time (days)					
		1		2		3	
CW2 (kontrol)	80.30	17.96		3.66		1.00	
CW1 phase 1	80.30	6.30		3.06		0.10	
CW1 phase 2			5.63		0.40		0.10
CW3 phase 1	80.30	6.80		3.00		0.10	
CW3 phase 2			5.33		0.40		0.10
Average	80.30	6.55	5.48	3.03	0.40	0.10	0.10

Source: Laboratory test, 2021

Ammonia and phosphate in HSSF-CW are sourced from the decomposition of organic matter. Ammonia easily dissolves in water and forms ammonium cations (NH_4^+). Ammonia removal can be done through the nitrification process, where ammonium (NH_4^+) is converted to nitrite (NO_2^-) by Nitrosococcus and Nitrosomonas bacteria, then to nitrate (NO_3^-) by Nitrobacter bacteria. Plants absorb this nitrate. Plant nitrogen absorption ranges from 10 to 16% of nitrogen compounds dissolved in water (Sun et al., 2005). Ammonia can also be removed by denitrification. In the anaerobic zone, there is a denitrification process where nitrate is converted into N_2 gas with the help of Pseudomonas and Micrococcus bacteria. The removal of phosphate can be done through plant absorption. Plants absorb phosphorus in the form of orthophosphate ions ($H_2PO_4^-$) and secondary orthophosphate ions ($HPO_4^{=}$).

Table 9. Removal of Ammonia

Treatment	Initial (mg/L)	Ammonia of Effluent (mg/L) by Hydraulic Retention Time (days)					
		1		2		3	
CW2 (control)	52.10	10.50		5.20		0.11	
CW1 phase 1	52.10	3.60		1.60		0.08	
CW1 phase 2			0.30		0.11		0.08
CW3 phase 1	52.10	2.50		1.90		0.15	
CW3 phase 2			0.10		0.13		0.06
Average	52.10	3.05	0.20	1.75	0.12	0.12	0.07

Source: Laboratory test, 2021

During the acclimatization to post-experimental period, Ludwigia adscendens, Echinodorus paniculatus, and Typha angustifolia planted polycultured on HSSF-CW cells showed a perfect growth status.

Conclusion

The HSSF-CW and UF membrane combination system on pilot-scale that was designed by utilizing ornamental water plants (Ludwigia adscendens, Echinodorus paniculatus, and Typha angustifolia) and gravel sand media measuring 5 – 8 mm, proved effective in removing TC and TSS parameters with an efficiency of 98.64% and 100%, respectively, within a retention time of 1 day. This case was supported by stable temperature and pH, high organic matter content and biodegradable, high DO by effluent recirculation factor, and the water depth of 0.30 m. Thus, the HSSF-CW and UF membrane combination system was suitable for hospital wastewater treatment in Palu, Indonesia.

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