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Combined biological and chemical-physical processes for domestic wastewater treatment

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ABSTRACT

The present study aims to investigate the possibility of domestic wastewater treatment using biological system combined with chemical-physical processes, including Upflow Sludge Blanket Filtration (USBF) technology and PolyAluminium Chloride (PAC). Experimental results showed that the added PAC content played an essential role in improving the treatment efficiency and reached National Technical Regulation on domestic wastewater QCVN 14:2008/BTNMT (Column A) for BOD_5. With Jar-test results, the optimal pH of 7.0 and the PAC dosage of 170 mg/L were recorded with the highest removal efficiencies for suspended solids and organic matter. In the modified USBF bioreactor, the findings illustrated the pollutant removal efficiencies such as Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Suspended Solids (SS) were equal to 96.2 ± 1.4%, 85.8 ± 4.4% and 99.3 ± 2.1%, respectively. In the future, this USBF-based advanced technology has the potential to play a significant role in addressing water scarcity through wastewater reclamation and reuse.

Keywords*: bioreactor, domestic wastewater, USBF, chemical-physical process, PAC*

1. Introduction

Human activities have largely influenced global environmental issues. The problem of domestic wastewater treatment is being considered by many developed and developing

countries (Tchobanoglus et al., 2003; Tran et al., 2022). Therefore, it must be removed from wastewater to avoid pollution and eutrophication in aquatic systems (Nguyen et al., 2023; Oehmen et al., 2007;). Biological treatment processes are usually carried out for the removal of organic carbon and nutrient from wastewater. Upflow Sludge Blanket Filtration (USBF) bioreactor is a modification technology based on the conventional activated sludge process. The USBF process is a novel configuration that incorporates an anoxic zone, aerobic zone, and upflow sludge blanket filtration clarifier in one integrated bioreactor (Rajakumar et al., 2011; Wang et al., 2010). In general, the USBF process is similar to SBR (sequencing batch reactor) operations that have been used by many previous studies for pollutant removal purposes (Kargi et al., 2003; Noroozi et al., 2015; Obaja et al., 2005). For example, Fernández et al. (2001) have used the USBF process for treating domestic wastewater. This technology has the advantage of reducing effective pollution matters and excess sludge production. Mahvi et al. (2008) investigated the conventional USBF system in domestic wastewater treatment at different aeration times, and the maximum removal efficiency for BOD_5 was greater than 82%. In addition, PolyAluminium Chloride (PAC) was studied to improve coagulation efficiency as well as obtain treatment efficiency in the water (Delgado et al., 2003; Li et al., 2023; Pernitsky et al., 2006; Van Benschoten et al., 1990; Yan et al., 2008).

Based on that, this study deployed an aerobic reactor with PAC to remove pollutants such as SS, COD, and BOD_5. The main aim of this research is to assess the performance of the modified USBF (m-USBF) bioreactor. In order to improve the efficiency of the USBF system, the study was conducted in combination with adding a chemical-physical process to enhance the elimination of pollutants from domestic wastewater - a typical case at Le Meridien Saigon Hotel, Ho Chi Minh City. The study contributes to the field of wastewater treatment by introducing and evaluating the efficacy of a novel treatment approach, providing insights into optimal conditions, and emphasizing the potential for sustainable water management through wastewater reclamation and reuse. Furthermore, the findings suggest that the USBF-based advanced technology holds promise for addressing water scarcity through wastewater reclamation and reuse in the future.

2. Materials and methods

2.1. Wastewater characteristics

The wastewater treatment plant (WWTP) of Le Meridien Saigon Hotel (Ben Nghe ward, District 1, Ho Chi Minh City) is built in the basement B3 of the building. It has a designed capacity of 450m^3/day to handle the total wastewater volume generated by the hotel. The WWTP has a continuous operational capacity for 24 hours a day, 7 days a week. The wastewater treatment system consists of the tanks as: Wastewater → Oil separation tank → Equalization tank → Improved biological reactor (USBF) → Settling tank → Disinfection tank. In this study, to investigate initial wastewater characteristics, samples

were taken from the collection tank of Le Meridien Saigon Hotel. The characteristics of the domestic wastewater are given in Table 1.

TABLE 1. Characteristics of the domestic wastewater

No.	Parameters	Unit	Mean	QCVN 14:2008/BTNMTT (A)
1	pH	-	7.3 ± 0.4	5-9
2	BOD_5	mg/L	176 ± 10.5	30
3	SS	mg/L	938 ± 23.7	-
4	Amoni ($N\text{-}NH_4^+$)	mg/L	31.9 ± 5.9	5
5	Nitrate ($N\text{-}NO_3^-$)	mg/L	0.17 ± 0.08	30
6	Phosphate ($P\text{-}PO_4^{3-}$)	mg/L	0.80 ± 0.12	6
7	Sulfur (H_2S)	mg/L	0.12 ± 0.04	1
8	Vegetable fats and oils	mg/L	3.12 ± 1.03	10
9	Surfactants	mg/L	0.43 ± 0.11	5
10	Total Coliforms	MPN/100mL	$2.4x10^5 \pm 1.2x10^2$	3000

Note: *QCVN 14:2008/BTNMT - National technical regulation on domestic wastewater.*

2.2. USBF bioreactor and Jar-test

USBF bioreactor of Le Meridien Saigon Hotel

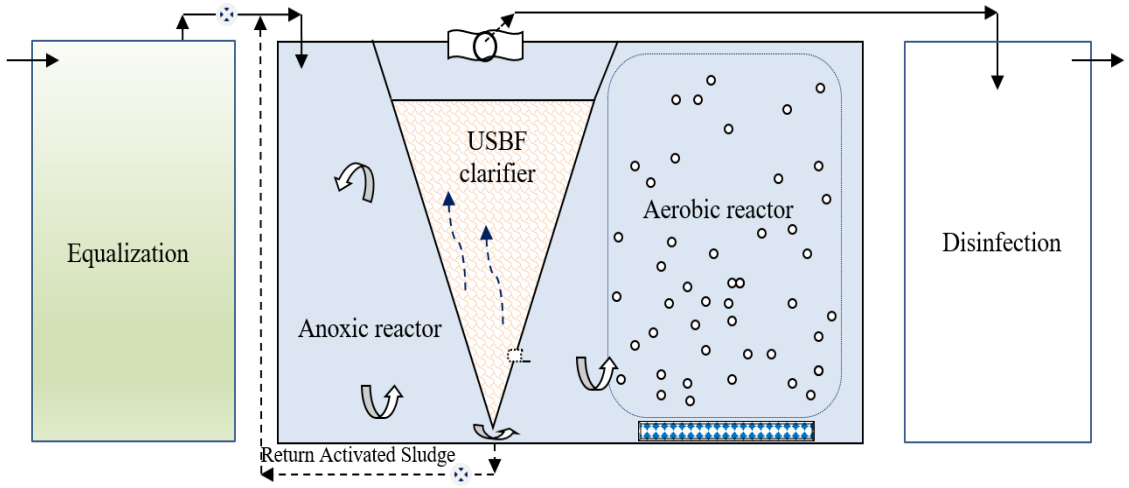

Figure 1. USBF bioreactor of Le Meridien Saigon Hotel.

In the USBF bioreactor, wastewater enters the anoxic tank and is then combined with activated sludge that has been recycled from the sludge clarifier (Fernández et al., 2001; Tran et al., 2022). The wastewater treatment plant of Le Meridien Saigon Hotel is conducted by using a USBF bioreactor that includes three units as an anoxic zone, an aeration unit, and upflow sludge blanket filtration clarifier (Figure 1). The total volume of the anoxic reactor is $76.9m^3$ and with a useful volume of $63.5m^3$; the aerobic reactor has a total volume of $285m^3$ and a useful volume of $235.1m^3$; and the total volume of the clarifier is equal to $63.6m^{3,}$ and it has a useful volume of $52.5m^3$. In this USBF plant, wastewater enters the anoxic zone, where it mixes with the recycled activated sludge (aerobic reactor) from the bottom of the clarifier.

Jar-test

Jar-test experiments (Jar-test six paddle stirrer, Japan, Figure 2) are conducted following order (i) Determining the reaction threshold of PAC; (ii) Fixing the reaction threshold and changing the pH to determine the optimal pH with values between 4.5 and 9.0; (iii) Fixing the optimal pH value and changing the PAC dosages to determine the optimal dosage in the ranges from 50 to 270 mg/L. A series of Jar-test experiments were run at 100 rpm for 1 minute, 30 rpm for 20 minutes, and 30 minutes for the settling process. The dosages of PAC from 50 mg/L to 270 mg/L were applied at pH ranging from 4.5 to 9.0 and at room temperature.

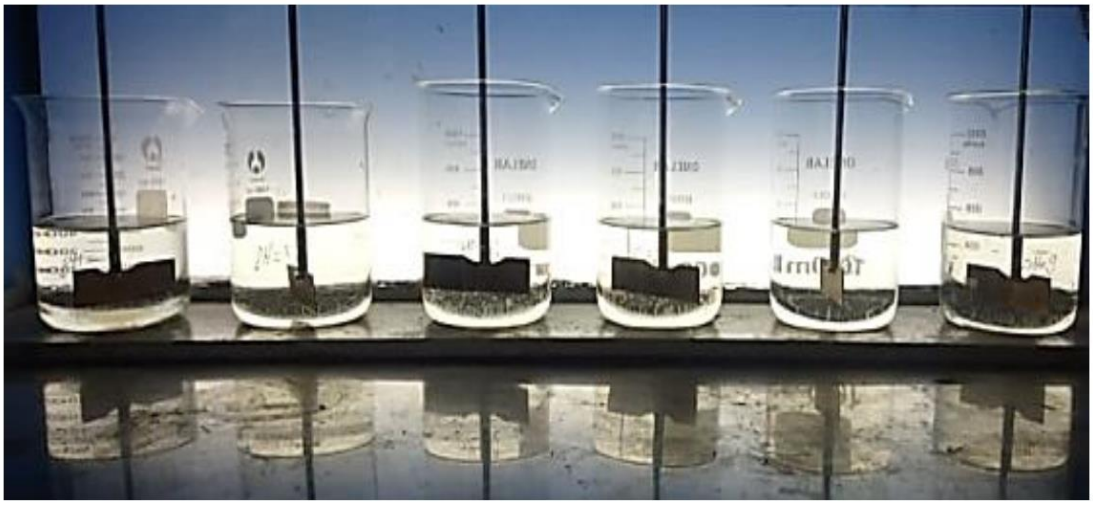

Figure 2. Jar-test procedure.

2.3. Wastewater sampling and analysis

Wastewater sampling is conducted by TCVN 6663-1:2011 (ISO 5567-1:2006) - Water quality - Sampling - Part 1: Guidance on the design of sampling programs and sampling techniques. Parameters such as COD, SS, N-NH_4^+, N-NO_3^-, and P-PO_4^{3-} were analyzed according to Standard Methods for the Examination of Water and Wastewater (APHA, 2012; Ky et al., 2022). BOD_5 was measured by an improved Winkler at 20°C in 5 days. Other parameters such as DO, Temp, and pH were measured online with an AquaCombo HM3070 (Singapore). Wastewater analysis including pH, DO, Temp, BOD_5, COD, and SS were measured on samples every day.

The Sludge Volume Index (SVI, mL/g) for the sludge blanket of the clarifier was determined according to Equation (1) (Tchobanoglus et al., 2003; My et al., 2017):

$$SVI = \frac{\mathrm{V}\times 1000}{\mathrm{MLSS}} \quad \text{(Eq. 1)}$$

Where, V is the volume per mL of settled sludge from 1-liter sludge of blanket filter of the clarifier after 30 minutes, and MLSS (mg/L) is the mixed liquid suspended solid content of the sludge.

2.4. Statistical analysis

The mean and standard deviation values of the influent and effluent samples are examined. Independent-sample t-test analysis was applied to find significant statistical differences between experiments at $p < 0.05$. The statistical analyses were performed using SPSS 13.0 for Windows.

3. Results and discussions

3.1. Jar-test results and operational conditions

TABLE 2. Jar-test results

	Jar-test experiments											
pH	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0		
H_{COD}, %	35.4	45.9	46.3	56.8	59.3	62.2	58.6	53.1	50.2	47.5		
H_{SS}, %	85.4	89.1	88.2	94.7	95.0	99.4	92.5	90.8	87.6	85.5		
PAC, mg/L	50	70	90	110	130	150	170	190	210	230	250	270
H_{COD}, %	37.5	40.0	40.7	42.5	44.8	45.0	47.5	35.0	25.0	10.0	25.5	10.0
H_{SS}, %	90.4	90.2	90.5	93.4	94.1	97.7	100.0	96.8	95.5	90.5	90.0	85.2

The Jar-test experiments provided evidence that the coagulation process could provide sufficient COD and SS removal efficiencies. The high SS removal (SS > 90%) was obtained at the pH range of 6.0–8.0 values. The Jar-test result shows that the PAC reaction threshold is 50 mg/L, and the optimal pH in the experiment was recorded at 7.0, resulting in the highest COD and SS removal (equal to 62.2 and 99.4%, respectively). Similarly, the optimal PAC dosage of 170 mg/L was recorded with the highest treatment efficiency of 100.0 and 47.5% for SS and COD, respectively (Table 2). Thus, the study used the optimal PAC dosage of 170 mg/L to improve pollutant removal efficiencies in the m-USBF bioreactor. PAC coagulant used in combination was found to be more effective in reducing COD, BOD_5, and SS.

TABLE 3. Operational conditions of USBF bioreactor

Parameters	Unit	USBF bioreactor		
		Min	Max	Mean
F/M	day^{-1}	0.043	0.145	0.092 ± 0.044
SVI	mL/g	102.6	118.3	109.7 ± 5.2
MLSS	mL	3467	5700	4950 ± 805
pH	-	6.5	8.1	7.3 ± 0.3
DO_{anoxic}	mg/L	0.7	0.9	0.8 ± 0.1
$DO_{aerobic}$	mg/L	3.2	5.9	4.5 ± 1.0
$DO_{clarifier}$	mg/L	1.5	4.2	2.6 ± 1.1
Temp	^0C	36.0	39.9	38.1 ± 2.5

The operational conditions evaluated in the present study included the F/M, SVI, MLSS, pH, DO, and Temp of the USBF bioreactor (Table 3). The experiments were performed

at a pH between 6.5 and 8.1. The airflow rate was regulated to supply the DO concentration of 0.8 ± 0.1 mg/L (anoxic zone), 4.5 ± 1.0 mg/L (aerobic zone), and 2.6 ± 1.1 mg/L (clarifier zone), respectively. During the experiment process, an initial feed at a total hydraulic retention time (HRT) of 19.4 hours and a sludge retention time (SRT) of 25 days were maintained. The biomass concentration in the anoxic and aerobic zones was in the range of 3467–5700 mL/g. SVI in a system that remained stable within the range of 102.6 to 118.3 mg/L. The SVI results show that activated sludge works well and is easily settled. Furthermore, the sludge volume index SVI ranges from 50-150 mL/g indicating good biological activity (Tchobanoglus et al., 2003; Tran et al., 2022).

3.2. Suspended solids (SS) removal

The efficiency of the system in suspended solids (SS) removal was good after adding PAC to the USBF bioreactor. Figure 3 shows the fluctuation of content and the ability to remove SS during the experiment.

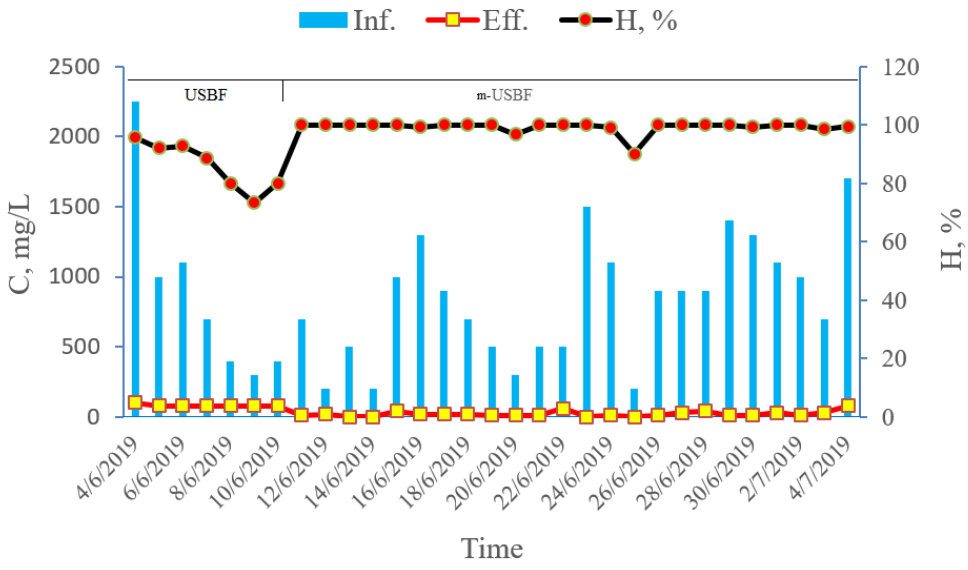

Figure 3. Suspended solids (SS) removal.

Several studies showed that USBF bioreactors could effectively treat domestic wastewater (Mesdaghinia et al., 2010; Noroozi et al., 2015). In this USBF system, the average influent and effluent SS contents were 878.6 ± 679.4 and 82.9 ± 7.6 mg/L, respectively. The average treatment efficiency was 86.0 ± 8.3%. The study has combined with the chemical-physical process by adding PAC into the settling tank, and the SS removal efficiency is improved. The suspended particles are not easily sedimented. Therefore, the addition of coagulants combines these particles to enhance the settling capability (Irfan et al., 2017). When the coagulants as PAC are added to water, the process of the rapid Al^{3+} hydrolysis reactions forms other dissolved and Al-hydroxide precipitates (Van Benschoten et al., 1990). Results showed the initial and effluent SS contents were 833.3 ± 424.9 and 20.0 ± 19.6 mg/L in turn. The SS treatment efficiency increased and

reached 99.3 ± 2.1%. Thus, the improved treatment efficiency is due to the amount of PAC, which supports the process of creating the flocs and settling better to remove suspended solids from domestic wastewater. Based on concentration reductions, high SS removal efficiencies were achieved for the m-USBF bioreactor (>90%).

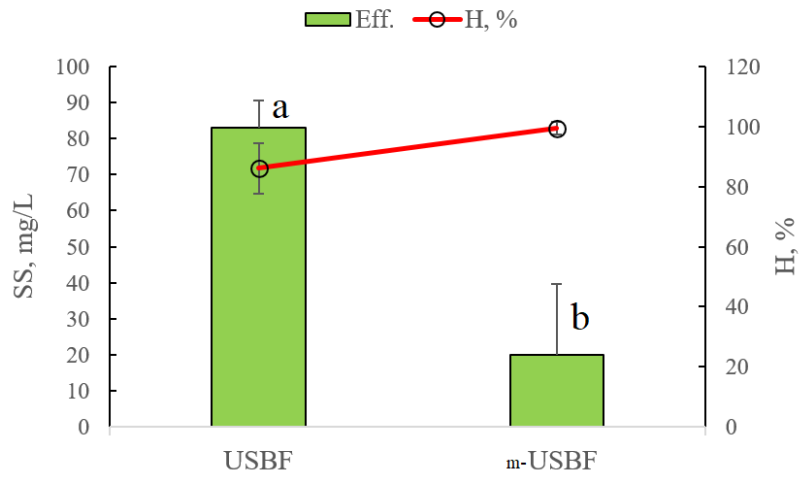

Figure 4. Comparing SS removal efficiencies.

Moreover, the statistical analyses show the high SS treatment efficiency after this study improved the USBF system by enhancing the chemical-physical process (Figure 4). The results of the Independent-samples t-test showed a statistically significant difference ($t = 8.135$, $p < 0.001$). It means the high performance of SS removal through improvement by the m-USBF bioreactor.

3.3. Organic matter removal

The performance of the USBF process for the different wastewaters is shown in previous studies (Arthur et al., 2022; Mahvi et al., 2008; Noroozi et al., 2015). Mesdaghinia et al. (2010) evaluated the system's performance in terms of organic matter (i.e., COD) removal with synthetic wastewater of about 86%. In this study, the concentration of influent COD was 305.5 ± 148.2 mg/L, and after the treatment process by USBF bioreactor was equal to 67.3 ± 15.4 mg/L with the average removal efficiency of 71.9 ± 18.1%. Similarly, the average BOD_5 concentration was 117.4 ± 40.6 mg/L, and after the USBF treatment process was 32.0 ± 8.6 mg/L (reached removal efficiency of 71.2 ± 9.0% and satisfied QCVN 14:2008/BTNMT - Column B). This level of effluent BOD_5 exceeded the Vietnamese standards for domestic wastewater Column A (<30 mg/L), but it satisfied Column B (<50 mg/L). In general, to meet the high standards for domestic wastewater (e.g., Column A), these systems may need to be further improved, such as by the addition of preliminary treatment and/or advanced tertiary treatment, etc. In this study, we improved by using PAC in the system for removing pollutants. Differences in the mean effluent wastewater parameters of the system are presented in Table 4. The more excellent organic matter removal by the m-USBF bioreactor indicates that the system includes COD and BOD_5.

TABLE 4. Comparison of organic matter removal

Day	Parameters						Remark
	COD, mg/L			BOD_5, mg/L			
	Inf.	Eff.	H, %	Inf.	Eff.	H, %	
04/6/2019	480	73.9	84.6	160.5	35.0	78.2	USBF bioreactor
05/6/2019	480	73.9	84.6	156.0	38.0	75.6	
06/6/2019	228	54.4	76.1	151.5	44.0	71.0	
07/6/2019	240	54.4	77.3	76.8	23.0	70.0	
08/6/2019	246	64.0	74.0	76.8	19.2	75.0	
09/6/2019	80	54.4	32.0	72.8	35	51.9	
10/6/2019	384	96.0	75.0	127.2	30.0	76.4	
11/6/2019	208	57.6	84.6	124.8	3.6	97.1	m-USBF bioreactor
12/6/2019	475	32.0	91.9	220.8	11.9	94.6	
13/6/2019	405	56.3	87.8	131.2	5.2	96.0	
14/6/2019	160	54.4	84.0	88.0	3.9	95.6	
15/6/2019	672	35.2	96.7	124.0	5.2	95.9	
16/6/2019	317	41.6	85.6	176.8	5.2	97.1	
17/6/2019	325	54.4	90.2	161.6	5.0	96.9	
18/6/2019	329	56.3	90.3	168.0	5.2	96.9	
19/6/2019	317	77.4	84.4	103.2	6.9	93.3	
20/6/2019	240	77.4	90.7	88.0	4.8	94.6	
21/6/2019	192	54.4	81.7	148.8	6.8	95.4	
22/6/2019	256	35.2	86.3	163.2	7.8	95.2	
23/6/2019	224	48.0	84.3	158.4	8.8	94.4	
24/6/2019	224	38.4	78.6	116.0	2.2	98.1	
25/6/2019	112	38.4	82.9	76.8	2.7	96.5	
26/6/2019	240	38.4	80.0	160.0	6.0	96.3	
27/6/2019	192	44.8	88.3	174.4	5.2	97.0	
28/6/2019	416	48.0	89.2	217.6	2.6	98.8	
29/6/2019	240	51.2	82.7	152.0	8.8	94.2	
30/6/2019	229	51.2	83.2	192.0	9.6	95.0	
01/7/2019	224	28.2	88.6	167.2	4.2	97.5	
02/7/2019	224	57.6	78.6	137.6	4.2	97.0	
03/7/2019	272	51.2	82.4	162.4	5.0	96.9	
04/7/2019	192	57.6	86.7	165.6	4.4	97.3	

The USBF bioreactors are a novel technology, and after improvement by PAC, the organic matter removal (e.g., BOD_5) was in the range of 93.3 to 98.8%, whereas with data on COD removal ranged from 78.6 to 91.9%. The post-treatment efficiency was improved by PAC with average COD and BOD_5 parameters of 85.8 ± 4.4 and 96.2 ± 1.4%, respectively. Especially, BOD_5 parameter achieving QCVN 14:2008/BTNMT - National technical regulation on domestic wastewater - Column A. The coagulants form hydroxides when dissolved in water, and these hydroxides will adsorb into the organic anionic particle surface and become insoluble (Licsko, 1997). Contents of effluent COD and BOD_5 decrease due to added PAC into settling tanks, flocculation process occurs, which reduces the number of suspended solids and sharply changes the concentration of pollutants (i.e., COD and BOD_5). The investigations show that the PAC is the most effective agent for

contaminant removal because of its high stability and positive electric charge (Duan and Gregory, 2003; Van Benschoten et al., 1990). The results in Table 4 show that the average effluent COD and BOD_5 levels were respectively 49.4 ± 12.4 and 5.6 ± 2.4 mg/L (BOD_5 < 30 mg/L, satisfied QCVN 14:2008/BTNMT - Column A). Treatment efficiency of COD and BOD_5 owing to combined between USBF bioreactor and chemical-physical process were 13.9 and 25.0%, respectively. The concentration of organic matter values is reduced with PAC support, which causes the accumulation of suspended organic substances to be removed faster and more through biological treatment (Yan et al. 2008).

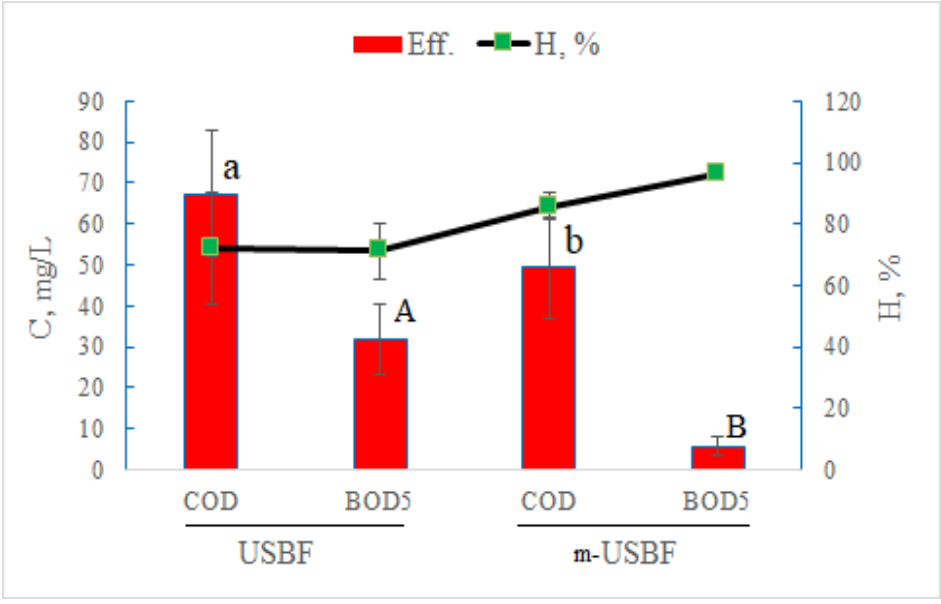

Figure 5. Comparing COD and BOD_5 removal efficiencies.

Thus, the coagulation process proves a high removal efficiency of pollutant parameters, mainly such as COD and BOD_5. As shown in Figure 5 and Table 4, the mean effluent organic matter levels in the m-USBF system were 85.8 ± 4.4% (COD) and 96.2 ± 1.4% (BOD_5), respectively. Furthermore, the concentration of BOD_5 met the Vietnamese standard QCVN 14:2008/BTNMT – Column A for domestic wastewater. It shows that for PAC, the presence of organic matter would increase the velocity of floc formation. The removal mechanism of contaminants by PAC follows as the complexation mechanism includes neutralization and adsorption, respectively (Wu et al., 2023; Yan et al., 2008). This study found that the COD concentration in the m-USBF bioreactor (49.4 ± 12.4 mg/L) had statistically significantly lower than USBF (67.3 ± 15.4 mg/L), which compared to after added PAC content ($t = 3.067$, $p < 0.01$). Similarly, BOD_5 content was significantly different before and after being supplemented with PAC ($t = 7.974$, $p < 0.001$). The experiments showed that this system efficiently removed COD and BOD_5 in greater than 85% of the cases after 25 days. Results illustrated the improved performance of the m-USBF bioreactor for pollutant removal from domestic wastewater.

4. Conclusion

The results revealed that the modified wastewater treatment plant had a good capacity for pollutant removal. The present study showed the removal efficiencies for SS, COD, BOD_5 from domestic wastewater. The effluent pollutant concentration such as BOD_5 met Vietnamese standards for domestic wastewater (QCVN 14:2008/BTNMT). Results indicate that the m-USBF bioreactor obtains a suitable approach to removing organic matter and suspended solids. The combined bioreactor performed the COD and BOD_5 removal efficiencies of 85.8 ± 4.4 and 96.2 ± 1.4%, respectively. Regarding suspended solids, treatment efficiency reached 99.3 ± 2.1%. This study contributes to perfecting the process of treating domestic wastewater, saving water resources, and solving the environmental pollution caused by domestic sewage.

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