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Experimental and empirical investigation of commercial and local biocarriers in moving bed bioreactor for treating low-strength domestic wastewater

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Abstract

The study aimed to optimise the operation conditions of the moving bed bioreactor (MBBR) for treating low-strength domestic wastewater using a commercial product, polyvinyl alcohol gel (PVA gel), and a local carrier, coir coconut fibre (CCF). A response surface design (RSD) was used to evaluate the interaction of two independent variables—biocarrier media ratio (%v/v) (10-30%) and hydraulic retention time (HRT) (60-300 min)—for the removal of chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP). The experiment was conducted in a lab-scale reactor capable of carrying 10 L of a wastewater sample, similar to a bubble column reactor. Further, analysis of variance demonstrated a high regression of determination and the significant effect of each variable. Based on the optimisation process using the RSD, the maximum COD removal efficiency was achieved at 300 min of HRT with 30% PVA gel (>70% removal efficiency) and 25% of CCF biocarriers (>50% removal efficiency). Moreover, the maximum removal efficiencies of TN (42-53%) and TP (38-42%) were found at a 30% media ratio with 300 min of HRT for both the biocarriers. Finally, mathematical correlations for both the biocarrier types were also determined for future estimation. These results and models are significant findings for the design criteria of the biofilm media applied in the MBBR or the activated sludge process for wastewater treatment.

Keywords: Biocarriers, Coir coconut fibre, Moving bed bioreactor, Polyvinyl alcohol gel, Response surface design

1. Introduction

Wastewater production has rapidly increased, particularly from anthropogenic activities due to the rising population, urbanisation expansion, and industry development. Hence, wastewater pollution has become an unavoidable concern for environmental and public health issues. Developing a cost-effective and efficient biological process for wastewater treatment is encouraged due to the presence of high amounts of organic matter and nutrients in wastewater effluent [1-3]. The moving bed reactor was introduced few decades ago and became popular in Europe [4]. Moreover, it has been widely applied for the treatment of industrial wastewater from the pulp and paper industry, cheese factory wastes, refinery, slaughterhouse, and newsprint mill among others, in addition to the treatment of municipal wastewater [5]. Therefore, a moving bed bioreactor (MBBR) has been developed with an additional small plastic media, while the mixed biomass attached moves freely in the reactor. A biofilm is developed on the carriers flowing in the reactor due to aeration. Various benefits can be observed in utilising such a reactor, including the non-cloggable biofilm without the requirement of backwashing, low head loss, high concentrations of active biomass over the surface of the biocarriers, and small footprint as it is a compact system [6-8]. Hence, bioreactors involving the biomass process play significant roles in detoxifying hazardous organic contaminants, i.e. volatile aromatic hydrocarbons, chlorinated solvents, and chlorinated aromatic [5].

The treatment performance of the MBBR is mainly dependent on factors such as the biofilm carrier type, shape, surface area, and the additional ratio [9]. Different biocarriers may have different shapes and surface areas, which results in different wastewater treatment efficiencies. Moreover, more carriers provide more sites for the microorganisms to attach or grow [1]. Shivakumaraswamy et al. (2013) [10] conducted the batch operation and operated on two reactors—one filled with a gravel bed and the other with areca husk. The experimental analysis indicated a significant amount of chemical oxygen demand (COD) removal (72-74%), biochemical oxygen demand (BOD) removal (92-94%), and NH_3-N removal (58-60%) within 4-16 h. The study found that the areca husk can be used as an alternative medium for domestic wastewater treatment. Moreover, Schmidt and Schaechter (2011) [11] reported that more than 90% of the biomass is likely to be trapped and cultivated in the media instead of being suspended in the liquid. Hence, different types of biofilm carrier and their ratio of MBBR have to be studied to define and optimise the wastewater treatment efficiency and amount of biofilm media ratio required to be added. Islam et al. (2017) [12] investigated wastewater treatment using coconut fibre for filtration. The experiments were performed under three different conditions, i.e. coconut fibre only, coconut fibre with sand, and coconut fibre with sand and stone chips, as filter media. The results indicated that the three mixing conditions provided better performance for removing nitrate, phosphate, COD, total coliform, and faecal coliform. Li and Visvanathan (2017) [13] used diluted domestic wastewater with COD at approximately 10 mg/L to feed the batch scale reactor. It was performed at various filling ratios of 2, 5, 10, 15, and 30% with 3 h of hydraulic retention time (HRT). The results indicated that in the batch testing, the 5% filling ratio had the highest oxygen uptake rate, and it can be chosen as a suitable filling ratio. Moreover, COD and ammonia removals of more than 50% and 96%, respectively, observed. According to Chu et al. (2010) [14], immobilisation of an inert polyurethane foam and biodegradable polymer polycaprolactone in reactors at ratios of 16.7% and 20% can remove the total organic carbon (TOC) and ammonia by 72-90% and 56-65%, respectively, under a 14-h HRT. Ni et al. (2018) [15] reported that using basalt fibres at a ratio of 30% at an HRT of 8 h could remove the COD and total nitrogen (TN) from the wastewater at removal rates of 90% and 82.7%, respectively. Furthermore, using the polyvinyl alcohol gel (PVA gel) as a biocarrier in the wastewater reactors with a 10% ratio might increase the treatment performance, with the COD and TN removal rates of 90.2% and 68.2%, respectively [16]. Dharmarathne and Kawamoto (2013) [17], in contrast, used the coconut fibre as the biocarrier and were only able to remove COD and TN of less than 50% with an HRT of several days. Wang et al. (2017) [18] designed an experimental system consisting of a PVA gel reactor, two active sludge reactors, a sedimentation tank, and an ultraviolet disinfection device. The initial COD of domestic sewage is 140-270 mg/L and a pH of 7.5-8.5. Its HRT ranged between 2 and 3 h, and 10% of PVA gel beads were utilised. The results indicated that the removal efficiency of the COD was 68-93%. The carrier selection in the MBBR for wastewater treatment is important within these different cases. It usually prefers the low cost, high effective surface area, good mechanical strength, and suitability for microbial aggregation [1]. Therefore, this study examined the optimisation and performed a comparison of a commercial product and local biocarrier for use in the MBBR for wastewater treatment.

One factor-at-a-time design is a classical experimental design, commonly used to optimise the wastewater treatment process. However, Karichappan et al. (2014) [19] and Bashir et al. (2015) [20] stated that this design of experiment (DOE) technique does not provide the cross effects between the investigated variables, requires more time and resources due to large experimental runs, and provides poor optimisation performance. Response surface design (RSD) is one of the statistical DOE methodologies that analyses the experimental data to define the effective behaviours of each independent variable with the response factor. The RSD can develop, improve, and predict process performance [21]. The RSD of the DOE technique was applied to optimise the reactor configuration and operation condition of the modified airlift reactor toward the mass transfer performance [22]. The investigated variables were considered a complex system to optimise; however, it was successfully optimised using the central composite design of the RSD. Trinh and Kang (2011) [23] also used the response surface method to optimise the combination of a coagulant dose and pH in terms of turbidity and dissolved organic carbon removal efficiency. The experimental results were found to be close to the predicted values of the models, which indicates that the statistical DOE approach can perform good predictions with fewer experiments.

Hence, this study aims to optimise the operation condition of the MBBR and conduct a comparative analysis between the commercial and local biofilm carriers using the RSD of the statistical DOE methodology for treating domestic wastewater. This study selected the PVA gel and coir coconut fibre (CCF) carriers as the commercial and local biofilm carriers, respectively. The optimum condition was defined by maximising the treatment efficiency of the COD, TN, and total phosphorus (TP) after varying the values of each independent variable, i.e. biocarrier media types (PVA gel and CCF), media ratio (%v/v) (10-30%), and HRT (60-300 min).

2. Materials and methods

2.1 Experimental set-up

A rectangular reactor constructed by an acrylic material with dimensions 0.3 m × 0.15 m × 0.5 m was used in this study as a lab-scale set-up for carrying 10 L of wastewater sample, as shown in Figure 1. Two long air stone diffusers connected with the air pump were installed at the bottom of the reactor, with plastic pipes connected to the air pump to provide an aeration capacity of 7 L/min. Within this capacity, the dissolved oxygen (DO) in the reactor could be maintained in the range of 5-6 mg/L, which is a sufficient level for aerobic respiration and nitrification activities [24, 25]. A sampling port was located at approximately 10 cm from the bottom for the water sample analysis. The experiments were conducted as a batch test to define the treatment performance. The wastewater sample collected from the domestic sewage and biofilm carriers was filled in the reactor before starting the experimental run. The wastewater samples and biocarriers are discussed in the following sections. The experiments were conducted based on the conditions designed by the RSD method, including types of biocarrier, biocarrier amount for the media ratio, and retention time.

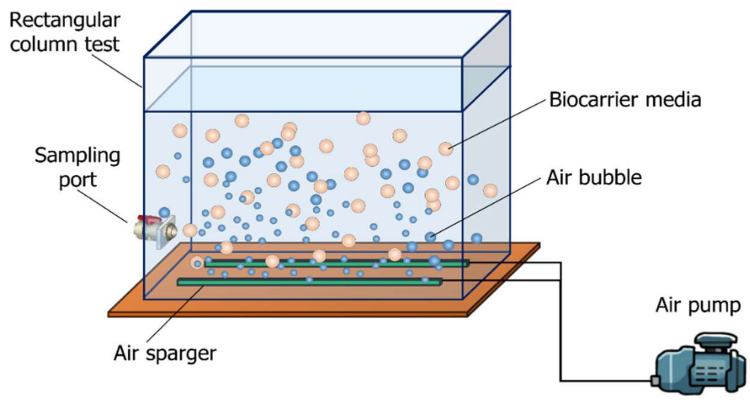

Figure 1 A drawing of the experimental set-up of the MBBR.

2.2 Biocarriers

The PVA gel, which is a biodegradable polymer, (see Figure 2) was used as a biocarrier for the immobilisation of microorganisms [26]. Each bead can hold up 1 billion microorganisms [27]. In this work, the PVA gel was provided by Kuraray Co., Ltd. It forms 4 mm spherical beads with a specific gravity of 1.025 ± 0.01, and it has a pore size of approximately 20 microns in diameter. The CCF (see Figure 2) is a natural fibre of coconut husk, and it is a thick and coarse but durable fibre [28]. It resists damage by saltwater and microbial degradation. In this work, the CCF was provided by a local supplier. CCF cubes of size 1 cm × 1 cm × 1 cm were selected for the batch experiment. Before use, the CCF was soaked with tap water to remove its colour and glue as it may affect the removal efficiency in the wastewater sample analysis.

The batch experiment involved filling the PVA gel and CCF in the ratio 10-30 (%v/v) by volume were carried out into 10 L of domestic wastewater contained in the MBBR, as shown in Figure 1. Therefore, the HRT of this test was selected as 60-300 min. The media ratio of the PVA gel and CCF was measured using a graduated cylinder. Aeration was provided by introducing oxygen into the reactor to maintain the mixing condition. The wastewater samples were kept analysed after collecting at 60 min, 180 min, and 300 min.

Figure 2 Biofilm carriers used in this study: PVA gel (A) and CCF (B).

2.3 Wastewater characteristics

The domestic wastewater used in this study was directly obtained from the Institute of Technology of Cambodia (ITC). It was transported from the effluent tank to the laboratory for conducting the experiment. The wastewater was analysed in terms of physical; chemical; and biological parameters, including pH, turbidity, DO, solids composition (i.e. total suspended solids (TSS), total dissolved solids (TDS), and total solid (TS)), BOD, COD, TN, and TP. The wastewater characteristics are listed in Table 1. The BOD/COD ratio for the domestic wastewater is approximately 0.5, which indicates that it can be treated through the biological process [29].

Table 1 Wastewater characteristics considered in this study.

Parameters	Unit	Value	Parameters	Unit	Value
pH	-	6.2-7.2	BOD	mg/L	17-48
DO	mg/L	1.8-2.1	COD	mg/L	33-93
TSS	mg/L	40-63	TN	mg/L	10.3-15.0
TDS	mg/L	223-462	TP	mg/L	1.5-3.2

2.4 Analytical methods

The water quality parameters were considered based on the Standard Methods. The COD value was measured by following the Standard Method 5220-COD/SM using a spectrophotometer (model UV-1800, Shimadzu). The BOD analysis followed the Standard Method 5210-BOD/SM. Finally, the TN and TP were determined following the Standard Methods 4500-TN/SM and 4500-TP/SM, respectively. The DO, pH, and turbidity concentrations were measured using a DO meter model Oxi3205, pH meter model OHAUS STARTER 2100, and turbidimeter model Hach 2100P, respectively. The solids compositions of TSS, TDS, and TS were also measured using a filtration apparatus.

2.5 Experimental design and statistical analysis

Optimisation of the response performance mainly depended on the operation conditions of the biocarriers. The biocarrier media types (PVA gel and CCF), media ratio (%v/v) (10-30%), and HRTs (60-300 min) were examined for the removal of the COD, TN, and TP. The RSD was used for the experimental design and data analysis using the computer software Minitab 17. Moreover, central composite design (CCD) of the RSD was utilised for modelling and analysing the responses for optimisation. The various operation variables (see Table 2) with factor levels considered in this study were media ratio (x) (10, 20, and 30% (v/v)) and HRT (y) (60, 180, and 300 min) with a total of 13 experimental runs. Analysis of variable (ANOVA) was employed to analyse and observe an optimum condition.

Table 2 Operation variables with factor levels for biocarrier optimisation.

Investigated factors	Unit	Factor levels		
		Low [−1]	Medium [0]	High [+1]
Media ratio (x)	[% v/v]	10	20	30
Hydraulic retention time (HRT) (y)	[min]	60	180	300

3. Results and discussion

3.1 Experimental and statistical analysis

The relationship between two significant independent variables, inclusive media ratio (x) and HRT (y), with three responses (see Table 3)—COD, TN, and TP—for treating the domestic wastewater in the MBBR was studied using the CCD of the RSD. ANOVA was conducted with 95% confidence level in the two-sided interval (α = 0.05). It covered the linear, square, and two-way interaction forms of the PVA gel and CCF biocarriers. The summary results of the models are presented in Table 4. The P-value is used to determine the statistical significance of the model. The P-value of the coded coefficient was identified that it is a significant effect, P-value less than 0.05, as suggested by Berthouex and Brown (1994) [30]. All the models are significant for COD, TN, and TP removal efficiencies.

Table 3 Experimental results of the removal efficiencies using different biocarriers.

Run	Operation condition		$R\%_{COD}$ [%]		$R\%_{TN}$ [%]		$R\%_{TP}$ [%]	
	x [%v/v]	y [min]	PVA	CCF	PVA	CCF	PVA	CCF
1	30	60	69.9	45.5	48.0	36.0	28.6	29.9
2	20	180	51.6	42.4	34.4	29.5	23.5	19.9
3	10	180	35.5	12.1	4.3	4.5	24.2	24.2
4	20	300	67.7	48.5	33.1	33.1	25.4	25.6
5	20	60	47.3	39.4	31.3	28.6	20.3	17.1
6	30	180	69.9	42.4	52.2	39.3	35.0	35.6
7	10	300	36.6	24.2	32.5	8.9	13.3	18.5
8	10	60	8.6	3.0	1.8	2.7	20.2	17.1
9-12	20	180	51.6	42.4	34.4	29.5	23.5	19.9
13	30	300	73.1	51.5	53.4	42.0	42.0	38.4

Table 4 Statistical analysis of the experimental results.

Model		F-Value		p-Value	
Type of biocarrier		PVA	CCF	PVA	CCF
COD	x	120.1	675	0	0
	y	18.3	889	0.004	0
	x^2	2.3	221	0.18	0
	y^2	0.01	7.77	0.92	0.03
	x^*y	6.3	23	0.04	0.002
TN	x	74.2	848	0	0
	y	8.2	12	0.02	0.01
	x^2	0.4	67	0.53	0
	y^2	0.3	0.3	0.86	0.6
	x^*y	5.8	0	0.05	1
TP	x	110.2	71.6	0	0
	y	5.6	13.4	0.05	0.01
	x^2	15.6	33.1	0.006	0.001
	y^2	4.6	0.8	0.07	0.4
	x^*y	27.5	2	0.001	0.2

3.1.1 Optimisation of MBBR with PVA gel

The CCD-RSD results shown in Figure 3 indicate that the main effects plot for COD, TN, and TP removal efficiency consisted of media ratio (%v/v) and HRT. The optimum condition was achieved at a media ratio of 30% among 10-30% and HRT 300 min among 60-300 min among all the responses. Under this condition, the highest COD, TN, and TP removal were 73.1%, 53.4%, and 42%, respectively. This indicates that a better COD, TN, and TP removal efficiency was obtained with the increasing media ratio and HRT value.

The finding is comparable to the results of a study by Wang et al. (2006) [31], which reports that DO should be retained up to 2 mg/L in the reactor for better COD and TN removal efficiency. Furthermore, this trend is also similar to the work of Nasr and Mikhaeil (2013) [32], which reports that decreased HRT reduces COD removal. Wang et al. (2005) [33] concluded that increasing the media ratio could increase the COD removal efficiency. Moreover, Almomani and Bohsale (2020) [34] reported that in stage 1 (anaerobic) of the experiment, removal of NH_4^+ remains unaffected by the increase or decrease of HRT. Zhang et al. (2013) [35] expressed that HRT has a considerable effect on biological nitrogen removal performance. In addition, the removal of TN is particularly dependent on the growth of bacteria and reproduction. Barwal and Chaudhary (2017) [36] reported that increasing the media ratio and reactor running time results in increased TP removal efficiency.

Additionally, Asadi et al. (2012) [37] explained that phosphorus could be removed during biological treatment in the form of polyphosphate through phosphorus-accumulating organisms, which are exposed to alternate anaerobic and aerobic conditions. Almomani and Bohsale (2020) [23] reported that HRT plays a significant role in increasing TP removal efficiency, that is, longer HRT results in increased TP removal. It can be concluded that a higher media ratio and HRT resulted in a better COD, TN, and TP removal performance of the PVA gel biocarrier.

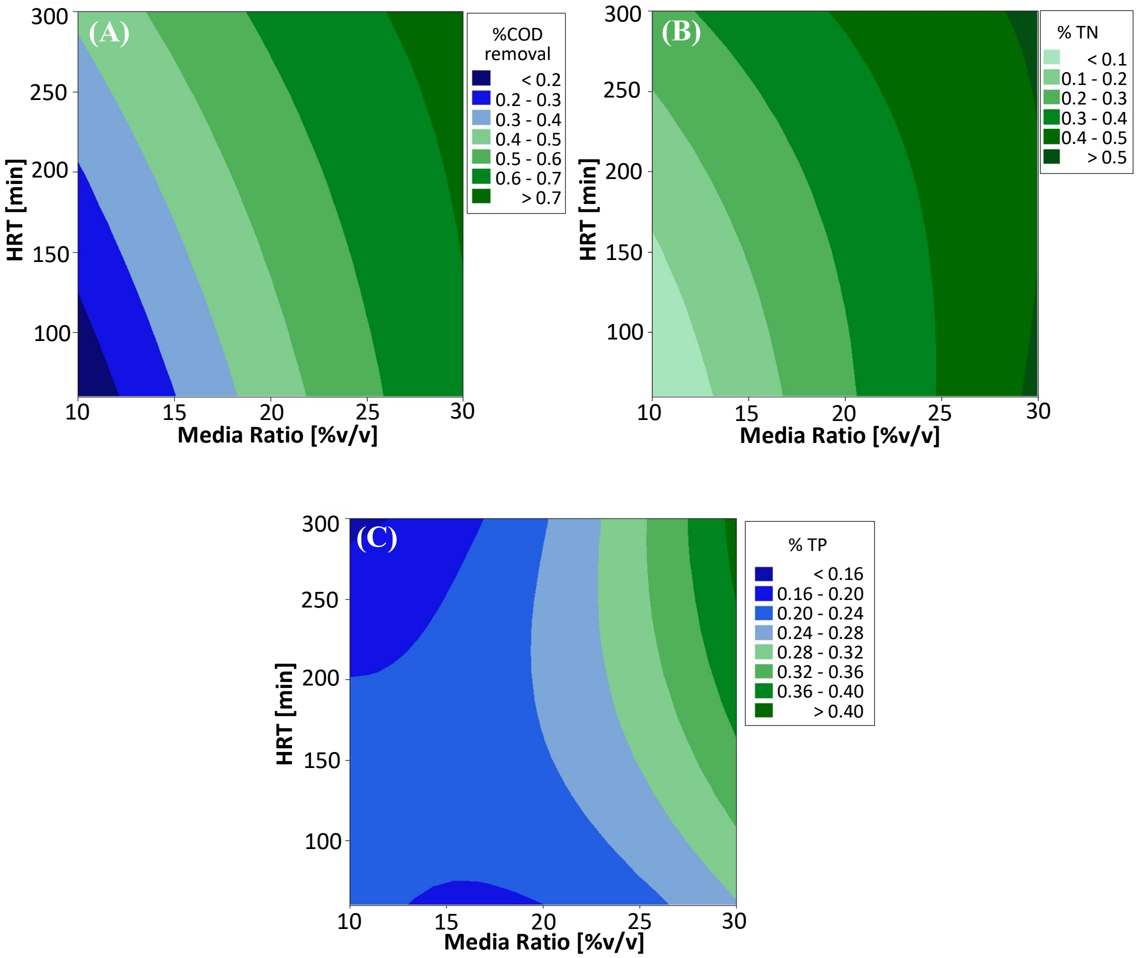

Figure 3 (A) COD, (B) TN, and (C) TP removal efficiencies of the PVA gel biocarrier.

3.1.2 Optimisation of MBBR with CCF

The COD, TN, and TP removal efficiencies of CCF were evaluated, and the results are presented in Figure 4. The results show similar trend to that of PVA gel, that is, increasing the media ratio and HRT resulted in better COD, TN, and TP removal efficiencies. However, at CCF media ratios above 25%, the COD removal efficiency decreased. It might be due to the clogging mechanism caused by significantly high amount of media, blocking its free movement into MBBR because a higher media ratio exhibited low movement than the lower ratio. However, a low filling ratio and HRT should be considered in moving bed bioreactor systems using CCF as biocarrier to treat domestic wastewater, particularly when COD removal is the performance indicator. Wang et al. (2005) [33] also studied PVA gel and reported that if the media ratio is increased up to 75%, the treatment performance in terms of COD removal decreases to 63%. Barwal and Chaudhary (2014) [8] reported that a decrease in suspended growth with increasing filling ratio linked to the suspended biomass can reduce MBBR treatment performance because this biomass has an important function in the hydrolysis of enzymes and bio-flocculation in the tanks. Their findings correspond well with the results of a previous study by Wang et al. (2005) [33], in which NH_4^+-N removal efficiency successively increased from 20% to 50%. Increasing media concentration could improve the nitrification process of biofilm in suspended carrier biofilm reactors. Moreover, Barwal and Chaudhary (2016) [38] demonstrated that the concentration of TKN did not extremely depend on the media ratio. However, the outcome of the study is more considerable with increasing aeration rate and HRT. In this study, the maximum TKN removal efficiency was 69% under the condition of a 40% filling ratio, 0.21 m^3/h aeration rate, and a 7-day retention time. Brown et al. (2011) [39] reported that HRT higher than 3 h is not recommended for stage 2 (anoxic) during the reduction of organic matter by phosphate accumulation organisms that guide to a reduction in source of energy for bacteria denitrification.

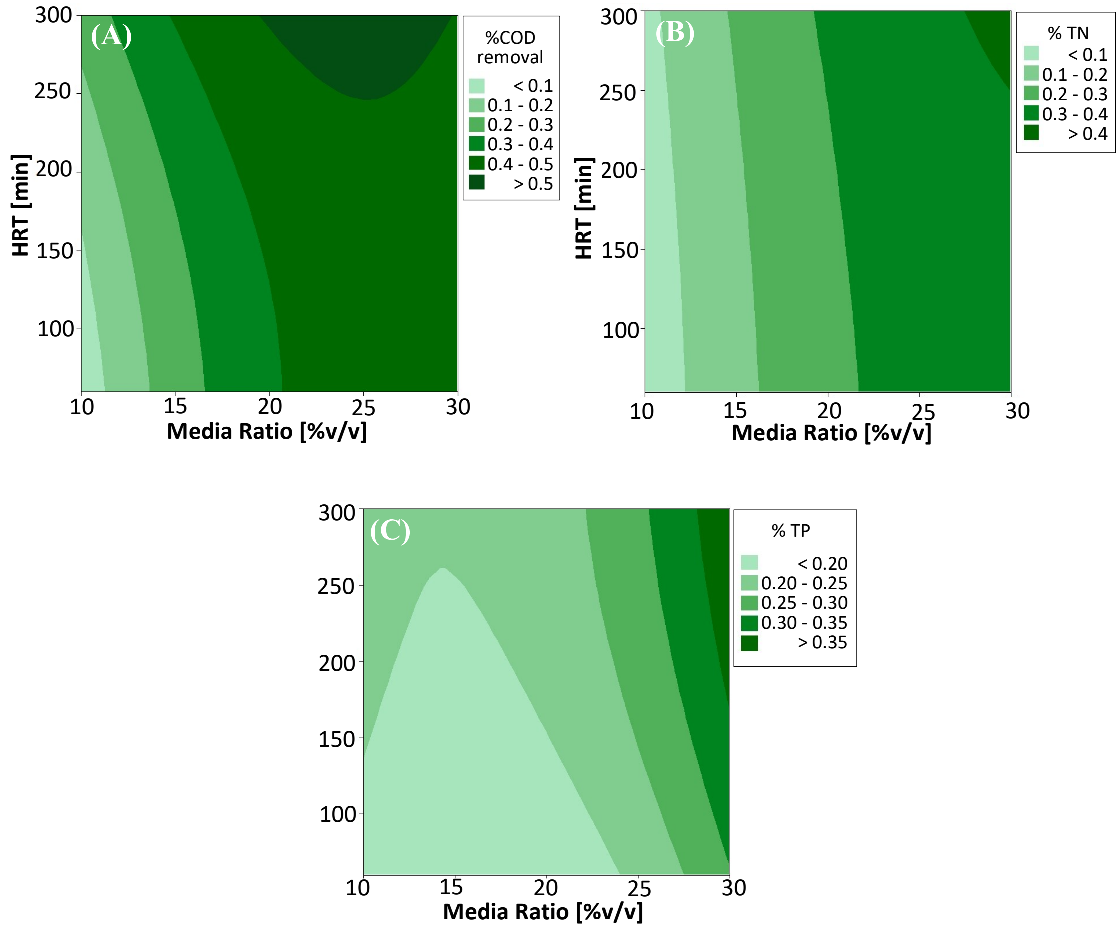

Figure 4 (A) COD, (B) TN, and (C) TP removal efficiencies of CCF.

3.1.3 Empirical correction prediction

Mathematical correlation between both independent variables and responses should be simulated and constructed for future estimation of the process performance. The experimental results of COD, TN, and TP removal with two biocarriers were utilised as input to identify optimum conditions and regression. Regression equations of media ratio and HRT of PVA gel and CCF in MBBR were constructed, where %R represents removal efficiency, x is the media ratio (%v/v), and y is the HRT (min). However, the correlation models can be derived through ANOVA of the values listed in Table 4. Based on P-value, the terms that have an insignificant effect on the response values (p-value > 0.05) will be removed. The derived correlations are expressed in Equation (1)-(6). In conclusion, all models have significant effects for both independent and response variables. The removal of these compounds increased as the media ratio and HRT increased. As shown in this study, COD removal could be improved from 3.0% to 73.1% under optimal conditions, while TN and TP removal could be increased from 2.7% to 53.4% and 17.1% to 42.0%, respectively. High HRT operation in the reactor could provide a sufficient period for microbial activities [40]. In addition, microbial activity inside the medium and absorption region may be associated with the considerable increase in this removal efficiency. When the media ratio in the aerobic reactors is increased, COD metabolism via aerobic respiration may occur in suspended sludge and the surface of the media. However, anaerobic respiration may play a substantial role inside the media. Similarly, the increased TN removal discussed in this study could be linked to simultaneous nitrification and denitrification reactions in the moving media. A combination of nitrifying activity, anoxic niches, and COD availability could lead to the growth of heterotrophic denitrification in the inner media layer [41, 42]. Since phosphorus is an essential nutrient for microbial growth, the increased sludge in suspension and attached media contributed to biological phosphorus removal in which phosphorus-accumulating organisms developed within anoxic/anaerobic zones of media [43]. Aside from degradation, TP removal efficiency variation may be related to the specific adsorption area and the saturation point of substrate adsorption of the media [44].

$$\%R_{COD}\ (\text{PVA gel}) = 0.0492x + 0.00167y - 0.00005xy - 0.395\ (R^2 \sim 0.84) \quad (1)$$

$$\%R_{COD}\ (\text{CCF}) = -0.00141x^2 + 0.000002y^2 + 0.079x + 0.00048y - 0.000032xy - 0.62\ (R^2 \sim 0.998) \quad (2)$$

$$\%R_{TN}\ (\text{PVA gel}) = -0.00021x^2 + 0.000001y^2 + 0.0373x + 0.0012y - 0.000054xy - 0.385\ (R^2 \sim 0.98) \quad (3)$$

$$\%R_{TN}\ (\text{CCF}) = -0.000702x^2 + 0.0449x + 0.000046y - 0.3479\ (R^2 \sim 0.97) \quad (4)$$

$$\%R_{TP}\ (\text{PVA gel}) = 0.00045x^2 - 0.000002y^2 - 0.018x - 0.000064y + 0.000042xy + 0.328\ (R^2 \sim 0.97) \quad (5)$$

$$\%R_{TP}\ (\text{CCF}) = 0.000734x^2 - 0.000001y^2 - 0.0243x + 0.000303y + 0.000012xy + 0.3262\ (R^2 \sim 0.95) \quad (6)$$

3.2 Comparative analysis of the biocarriers

3.2.1 Removal efficiency

Based on experimental designs and results, the effects of removal efficiency on water quality parameters, such as COD, TN, and TP, were evaluated. To understand the removal efficiency well, two main important factors, such as media ratio (%v/v) and HRT (min), were compared. The first condition, that is, the holding value of 30% of media ratio and variation of HRT, was investigated. The second condition includes variation of media ratio (10-30%) and the holding value of 300 min for HRT. Figure 5 shows COD removal efficiency for both PVA gel and CCF media. It can be seen that increasing the media ratio and HRT resulted in a higher COD removal efficiency for both media. In terms of COD removal, PVA gel exhibited enhanced performance (~73% on an average) compared to CCF. The TN removal efficiencies of both media were analysed and compared, as shown in Figure 6. Similar to the COD removal case, herein higher media ratio and HRT resulted in a better removal efficiency; however, TN removal was obtained at a 20% media ratio. Overall, PVA gel still provided a higher percentage of TN removal (~53% on an average) than CCF.

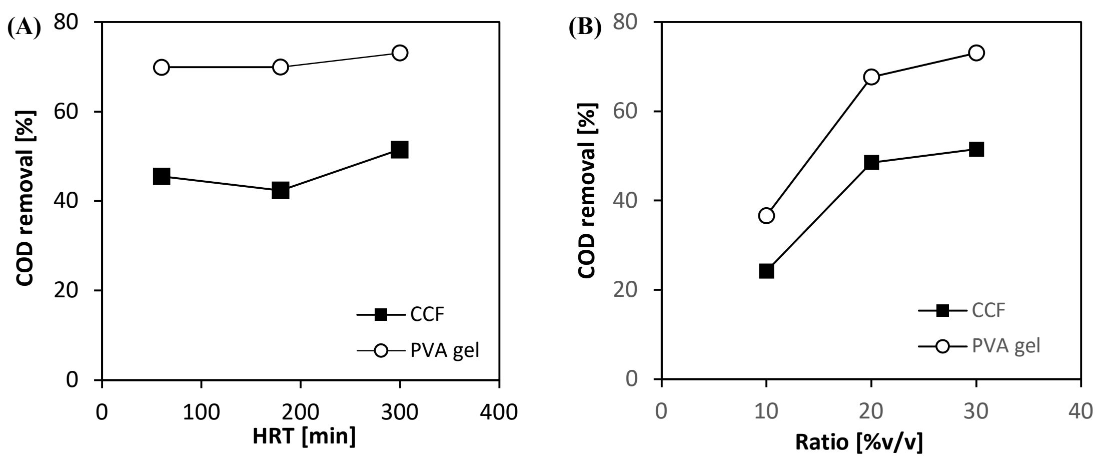

Figure 5 Comparison of the COD removal efficiencies of CCF and PVA gel: (A) different HRT at 30% media ratio, and (B) different media ratios at 300 min of HRT.

Besides COD and TN removal, TP removal performances of the PVA gel and CCF biocarriers were also analysed at different media ratios and HRT, and the results are presented in Figure 7. The removal efficiency of 13-42% was achieved using PVA gel, while 17-38% was obtained using CCF in MBBR. Both biocarriers exhibited comparable treatment performances.

The analyses suggest that adding biocarriers in MBBR could enhance wastewater treatment from several perspectives. Higher content of biocarriers (10-30%) and longer retention time (60-300 min) resulted in higher removal efficiencies of both the biocarriers towards water quality parameters such as COD, TN, and TP. The PVA gel biocarrier exhibited significantly improved water treatment performance in terms of COD and TN removal compared to natural CCF. However, the overall performances of both the biocarriers were comparable.

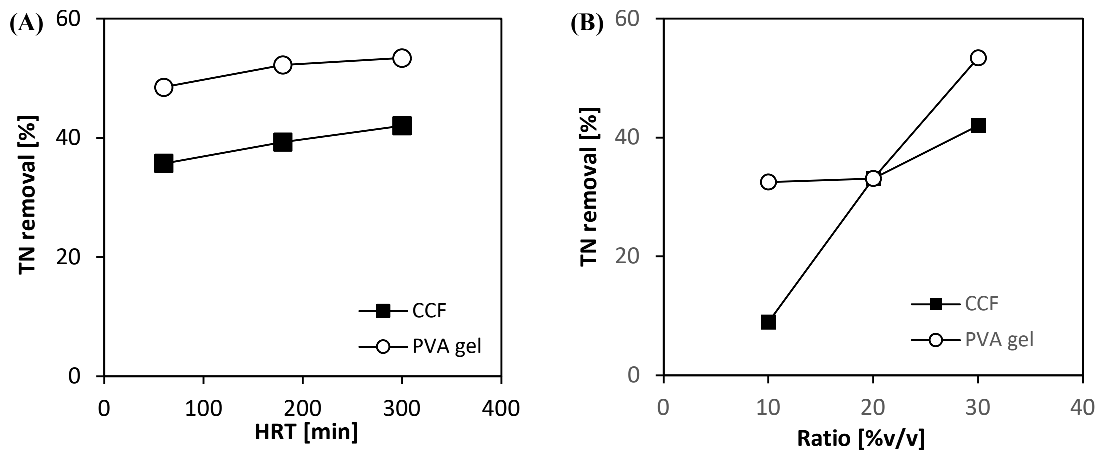

Figure 6 Comparison of the TN removal efficiencies of CCF and PVA gel: (A) different HRT at 30% media ratio, and (B) different media ratio at 300 min of HRT.

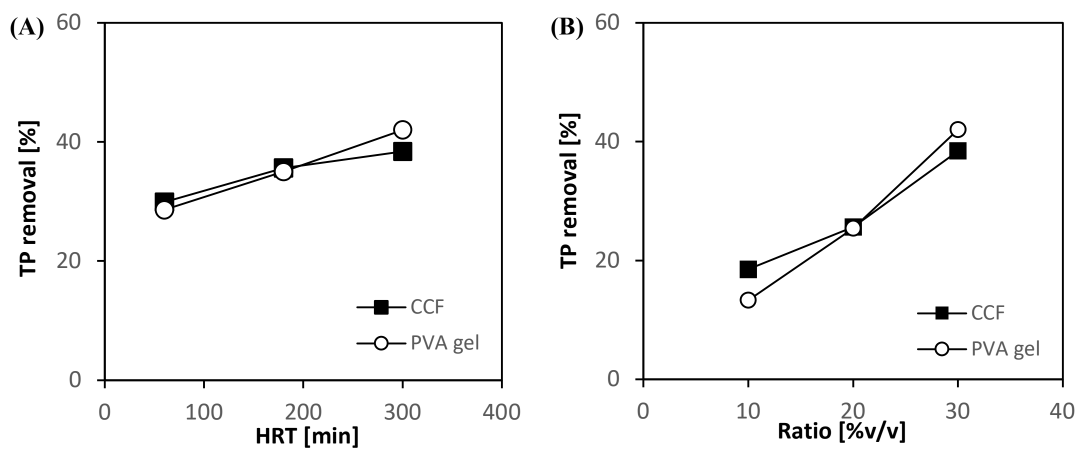

Figure 7 Comparison of the TP removal efficiencies of CCF and PVA gel: (A) different HRT at 30% media ratio, and (B) different media ratio at 300 min of HRT.

3.2.2 Cost of biocarriers addition

CCF is widely used in lab-scale, pilot scale, or industrial wastewater treatment. CCF is a local product, and it costs approximately USD 5.00 per kilogram. Since the volume ratio used in this study is a bulk volume, the bulk density of CCF is approximately 50 g/L. Therefore, 30% of media (i.e. 300 L/m^3) is equivalent to 15 kg of CCF, which would cost approximately USD 75.00 per 1 m^3 of wastewater. Considering the cost of adding biocarriers in MBBR, PVA gel is 20 times more expensive compared to the local product, CCF. PVA gel is considered a polymetric gel with a porous microstructure suited for bacteria retention and has a specific gravity demonstrated effectiveness in wastewater. The company has established PVA gel beads as an effective biological wastewater treatment technology after over a decade of research and development. The optimum condition of PVA gel addition in MBBR is 30% by volume; therefore, 1 m^3 of wastewater volume requires 300 L of PVA gel. This would cost significantly more than USD 75.00 in the PVA gel market Cambodia. Hence, wastewater treatment design and the operation can evaluate their performance and estimate the cost for the system.

4. Conclusion

This work aimed at optimising the operation condition of MBBR using a commercial product, polyvinyl alcohol gel (PVA gel), and a local carrier—CCF—to treat low-strength domestic wastewater using the RSM-DOE methodology. Moreover, a comparative analysis was conducted between the investigated biocarriers in terms of COD, TN, and TP removal efficiency. The experimental results and mathematical-statistical analyses revealed that all investigated independent variables significantly affected COD, TN, and TP removal ($P\text{-value} < 0.05$). The results of this study can be summarised that higher media ratio and HRT resulted in a better treatment performance of PVA gel toward COD removal, except the CCF ratio. The maximum removal efficiency was determined at 300 min of HRT with a 30% and 25% media ratio of PVA gel and CCF, respectively. Using both biocarriers, TN and TP exhibited the maximum performance at a 30% media ratio with 300 min of HRT. Mathematical models were also constructed for future estimation ($R^2 = 0.84$-0.998). Optimisation using CCD-RSD potentially removed COD, TN, and TP requiring less time and low energy usage, thereby providing economic and environmental sustainability. These results and models provide significant design criteria for biofilm media applied in MBBR or even in the activated sludge process for wastewater treatment. For the future work, a study on operation in continuous mode to ensure steady-state operation and investigation of the biocarriers lifetime to propose the system condition should be conducted.

5. Acknowledgements

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