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Optimization of Fixed-Bed Sequencing Bio-Reactors Using Jute Fibre for Seafood Processing Wastewater Treatment

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Abstract: Seafood processing wastewater has high contents of nitrogen and ammonia which are the key nutrients for the occurrence of eutrophication. Therefore, the present study was performed to optimize the seafood processing wastewater treatment using activated sludge and jute fiber in the sequencing batch reactor (JF-SBR) compared to conventional SBR. The optimization was studied based on aeration rate and aeration time using response surface methodology. The results revealed that the JF-SBR has higher efficiency compared to the conventional SBR in the removal of BOD (66.86% vs. 53.52%), ammonia nitrogen (AN) (68.75% vs. 50.86%), COD (66.86% vs. 53.52%), TSS (95.65% vs. 78.26%), nitrite (100% vs. 50%), and nitrate (91.67% vs. 83.33%). The optimal removal of these parameters was recorded after 18.5 hrs with 44.14 L/min of aeration rate in both JF-SBR and SBR. These finding demonstrated that the JF-SBR is the viable option to treat seafood wastewater for safe disposal.

Keywords: Seafood processing wastewater, sequencing batch reactor, jute fibre, response surface methodology

1. Introduction

Seafood processing wastewater (SPW) has become among the source of pollutants which contribute to the occurrence of eutrophication in the natural water system, due to the high concentrations of biochemical oxygen demand (BOD) which might reach to 18,419 mg/L, with a suspended solids (SS) between 5,000 mg/L and 30,000 mg/L, nitrogen (29 to 35 mg/L) and chemical oxygen demand (COD) (496 to 140,000 mg/L) [1]-[3]. Sequencing batch reactor (SBR) is one of the techniques used for the wastewater treatment with high organic contents and is characterized by low or intermittent flow conditions as well as offering low cost and sustainable method compared to traditional wastewater treatment methods such as primary and secondary processes [4]. SBR has recorded high efficiency in the nitrogen and phosphorus removal from the piggery wastewater [5]. The efficiency is achieved due to the high microbial diversity in the sludge used in the SBR system [6]. However, the recent development has shown that the use of fiber biomass carrier for the sludge might contribute effectively in the wastewater treatment system. Hamidi et al. [7] stated that there are various types of fibers such as bio fringe acryl fiber, plastic fiber, polyester fiber, geotextiles, and fibrous packing that might be used as a carrier for the sludge biomass.

The use of jute fiber (JF) as adsorbent was used in textile wastewater treatment [8]. Jute fiber has complex matrix and interfaces bond which attributes to its potential transmission of load, high porosity and reduce the environmental disturbance. Ahmad et al. [9] revealed that the removal of COD from the combination of JF and activated sludge in treating the poultry slaughterhouse wastewater reached 92.59%. However, in order to increase the efficiency SBR with JF as a carrier in the treatment of wastewater with high organic content such as SPW, the treatment process should be optimized based on the factors affecting the removal process. Response surface methodology (RSM) design software is

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known as one of the best tools for studying the optimization of the model especially the polynomial model [10]. Moreover, the analysis obtained in central composite design (CCD) provide minimal number of experimental run for experiment where it provides accurate result compared to traditional optimization. The second-order quadratic model is used to represents the relationship between the independent factors used with selected parameters. Therefore, the present study was performed to optimize the SPW treatment using activated sludge and jute fiber in the sequencing batch reactor (JF-SBR) compared to conventional SBR. This study is an improvement of the previous study by using RSM as tools of optimization and jute fiber as main factor of removal in SBR. The optimization was studied based on aeration rate and aeration time using RSM to determine the best optimal condition for the SBR treating SPW.

2. Materials and Methods

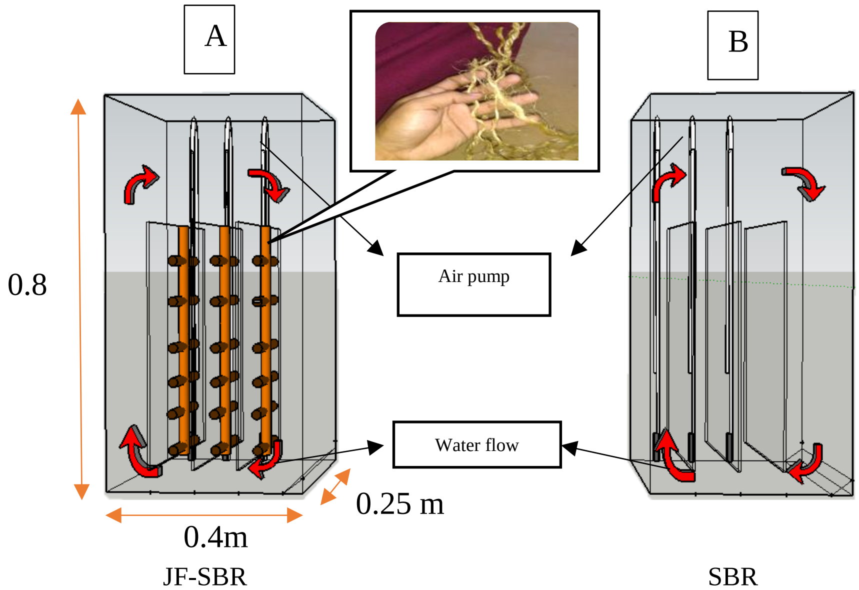
2.1 SPW and Activated Sludge Sampling

SPW samples were collected from a drainage of a seafood processing company located at Parit Samijan, Parit Raja, Batu Pahat, Johor (coordinate of 1.8449108,103.0684853) using grab sampling within 2 hours in the noon. The activated sludge was collected from a sewage treatment plant (STP) of Universiti Tun Hussein Onn Malaysia (UTHM) by using grab sampling for 30 minutes in the morning. The samples were kept and preserved according to the procedures described by APHA [11]. The characteristics of SPW including BOD, COD, TSS, nitrite, nitrate and ammoniacal nitrogen were determined according to APHA (2012) by using method 5210, method 5220, method 2540, method 4500-NO_3^-, method 4500-NO_2^- and method 4500-NH_3, respectively.

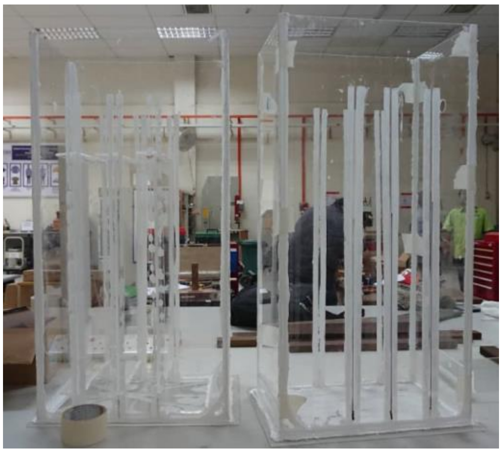
2.2 Experimental Set-up for SBR and JF-SBR

The SBR reactor was constructed by using clear acrylic perspex. The dimension of the reactor was 0.8 m height, length of 0.4 m and width of 0.25 m. This dimension is able to withstand 80-litre volume of wastewater in one time. The vertical length for the jute fiber was 0.5 m and for the horizontal length was 0.012 m. Transparent material is chosen to better observe the mixture of the activated sludge with seafood processing wastewater and settlement of the biomass after aeration. The volumetric capacity for both of the reactors is 0.08 m^3 which proves that maximum capability of the reactor can reach up to 80-liter of wastewater per day and the hydraulic retention time (HRT) is up to 0.024 hr. The schematic drawing is shown in Fig. 1.

Overview of the reactor operation is shown in Fig.1(a) and the designated reactor is shown in Fig.1(b). The JF was inserted in the JF-SBR reactor with the height of 665 mm and the activated sludge was filled in both reactors according to the volume specified from F/M ratio equation. The reactors were filled with 40 L of the SPW and the air pump was turned on for several hours as stated by RSM output for treatment purposes. After 3 hous of settlement and 1 hour idle, the treated SPW (500 mL) was collected for BOD, COD, TSS, AN, nitrite and nitrate analyses.



(a)



(b)

Fig. 1 - Sequancing batch reactors: (a) Schematic drawing of sequancing batch reactors; (b) SBR reactors set up in the laboratory

2.3 Optimization of SBR and JF-SBR

Two independent variables included aeration rate and aeration time was used to optimaze the treatment process of SPW based on the response surface methodology (RSM). The total numbers of the experiments (13 runs) and the paramters for each expeiment are illustrated in Table 1 as designed by Design Expert software version 10. The independent factors investigated included aeration time (X_1) and rate (X_2) with the dependent factors such as COD (Y_1), Nitrate (Y_2), Nitrite (Y_3), BOD (Y_4), AN (Y_5) and TSS (Y_6). The response Y is the function of the levels of independent variables as given in (1):

$$Y = f(x_1, x_2, x_3, \dots, \dots, x_n) + \varepsilon \quad (1)$$

where Y is the response yield, f is the response functions, ε is the experimental error and $(x_1, x_2, x_3 \dots \dots x_n)$ are independent variables. The expected response is:

$$E(y) = f(x_1, x_2, x_3, x_4, x_5, x_6) = \eta \quad (2)$$

and the surface area is represented by:

$$\eta = f(x_1, x_2, x_3, x_4, x_5, x_6) \quad (3)$$

The second-order polynomial model for the reduction of COD, PO_4, and Na is explained according to (4):

$$Y = \beta 0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{i<j}^{n} \beta_{ij} x_i x_j \quad (4)$$

where: Y is the predicted response for the reduction percentage, β_0, β_i, β_{ii}, β_{ij} represents the regression coefficients, x_i represents the coded variables, and x_j represents independent variables in coded form, while k is the number of independent variables. The relationship between the natural variable ε_i and coded variables x_i is:

$$x_i = \frac{\varepsilon_I - [HL + LL/2]}{[HL - LL/2]} \quad (5)$$

where: x_i is the coded variable, ε_i is the natural variable, HL is the maximum value of the independent variable, and LL is the minimum value of the independent variable. The minimum, intermediate, and maximum values of each variable were labelled as +1, 0, and -1, respectively in (Table 2).

Table 1 - Experimental design of aeration rate and time for 13 experiments

Run	Aeration rate (L/min)	Aeration time (hr)
1.	44.14	18.50
2.	30.00	18.50
3.	30.00	18.50
4.	15.86	18.50
5.	30.00	18.50
6.	40.00	20.00
7.	30.00	18.50
8.	30.00	20.62
9.	40.00	17.00
10.	20.00	20.00
11.	30.00	18.50
12.	30.00	16.38
13.	20.00	17.00

Table 2 - The coded and un-coded levels of the independent variables

Factor	Symbol	Level	
		Low (-1)	High (+1)
Aeration time (hour)	X_1	17	20
Aeration rate (L/min)	X_2	20	40

The calculation of the removal efficiency was conducted according to Eq. (6)

$$\text{Removal efficiency}, X = \frac{A - B}{A} \times 100\% \tag{6}$$

where: X = Analyzed parameter, A = Raw sample, B = JF-SBR / SBR sample.

2.4 Scanning Electron Microscope (SEM)

The surface morphology of the JF was analyzed using SEM. The SEM images were observed after the JF is taken out from the reactor, being cut with the approximate dimension of 1.25 x 1.25 cm and dried before being analyzed by EVO LS 10 VPSEM serial no 30-27. SEM is used to observed the attachment of the bacteria in the JF by using the condition of JF surface and the clogged of pores. It is believed that the observation can prove the capability of the JF in wastewater treatment.

3. Results and Discussions

3.1 SPW Characteristics

The characteristics of the SPW in comparison with previous studies are illustrated in Table 3. The concentration of BOD (58.58 mg/L) slightly exceeds the EQA (2009) Standard B. The high amount of BOD is associated with low dissolved oxygen (DO) which may affect the biodiversity ecosystem. COD concentration is 146.44 ± 39.96 mg/L which is lower than the EQA (2009), 200 mg/L for standard B and other studies. As for TSS, the concentration obtained of 27.33 ± 25.22, is lower than the EQA (2009), standard B but higher than the study of Kiattisak et al. [12] by 2.9 folds. Nevertheless, data shows that the TSS amount is within the range of the literature review which is in the range of 9.37 mg/L to 2000 mg/L. According to the EQA (2009), the value of nitrate should be less than 10 mg/L. In this study, the nitrate concentrations are 5.44 ± 2.70 mg/L lower than the EQA (2009) permissible standard. AN concentration was 2.83 ± 0.46 mg/L which is within the acceptable discharge for AN (less than 5 mg/L).

3.2 Optimization of SPW treatment process by SBR and JF-SBR

The JF-SBR removed 66.86% of BOD, 66.86% of COD, 95.65% of TSS, 68.75% of AN, 91.67% of nitrate, and 100% of nitrite (Table 4). In comparison, the conventional SBR removed 53.52% of BOD, 53.52% of COD, 78.26% of TSS, 50.86% of AN, 83.33% of nitrate and 50% of nitrite. Wang et al. [17] stated that jute fiber has a high potential to adsorb the chemicals substances on their cellulose surface. Ghosh et al. [18] emphasized that the yarns made of jute fiber has high potential in treating SPW with high mechanical strength, loading tensile and durability.

Table 3 - Characteristics of seafood processing wastewater compared with previous studies

Parameters	Unit	Lawrence et al. [13]	Boopathy et al. [14]	Kiattisak et al. [12]	Kiattisak et al. [15]	Sherly et al. [16]	This study	EQA, 2009 (Standard B)
BOD	mg/L	250–2000	NR	100–3000	NR	NR	58.58 ± 15.99	50
COD	mg/L	500–3000	1593 ± 36	1000–18000	10400	1500–3666	146.44 ± 39.96	200
TSS	mg/L	200–2000	33.1 ± 3.9	NR	9.37	125.6–680.6	27.33 ± 25.22	100
Nitrite	mg/L	NR	250 ± 22.7	NR	NR	NR	0.01 ± 0.01	NR
Nitrate	mg/L	NR	31.3 ± 1.4	NR	NR	NR	5.44 ± 2.70	10
AN	mg/L	NR	NR	80-1000	870	NR	2.83 ± 0.46	5

NR: Not reported

Table 4 - The efficiency of SBR and JF-SBR treatment for seafood processing wastewater

No	Parameter of Testing	SBR	JF-SBR
		Removal Efficiency (%)	Removal Efficiency (%)
1.	BOD	53.52	66.86
2.	COD	53.52	66.86
3.	TSS	78.26	95.65
4.	AN	50.86	68.75
5.	Nitrate	83.33	91.67
6.	Nitrite	50.00	100

The relationship between the independent variables including aeration rate (x_1) and aeration time (x_2) with the dependent parameters tested BOD (Y_1), COD (Y_2), TSS (Y_3), AN (Y_4), nitrate (Y_5), and nitrite (Y_6), are shown in Eq. (7) to Eq. (12) and Fig. 3.

$$Y_{1\ JF-SBR} = 197.47 - 10.51x_2 + 1.40x_1 + 0.34(x_2^2)^2 + 0.08x_1^2 - 0.35x_1x_2 \quad (7)$$

$$Y_{2\ JF-SBR} = 197.47 - 10.51x_2 + 1.40x_1 + 0.34x_2^2 + 0.08x_1^2 - 0.34x_1x_2 \quad (8)$$

$$Y_{3\ JF-SBR} = 1499.91 - 137.61x_2 - 12.50x_1 + 3.63x_2^2 + 0.24x_1^2 - 0.05x_1x_1 \quad (9)$$

$$Y_{4\ JF-SBR} =- 4.58 + 34.33x_2 - 16.46x_1 - 2.05x_2^2 - 0.14x_1^2 + 1.32x_1x_2 \quad (10)$$

$$Y_{5\ JF-SBR} =- 1877.88 + 206.96x_2 + 4.80x_1 - 5.61x_2^2 - 0.02x_1^2 - 0.14x_1x_2 \quad (11)$$

$$Y_{6\ JF-SBR} =- 257.43 + 63.26x_2 - 14.83x_1 - 2.40x_2^2 + 0.76x_1x_1 \quad (12)$$

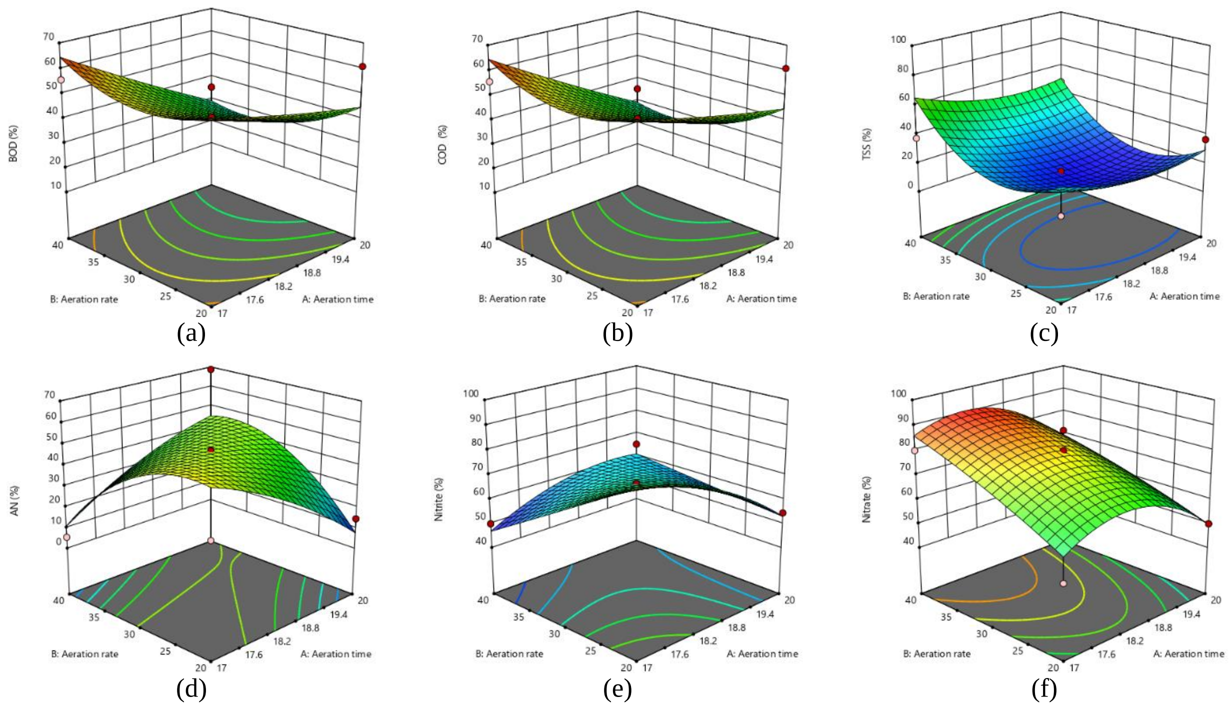


Fig. 3 - 3-D surface plot of JF-SBR for independent factors: (a) BOD; (b) COD; (c) TSS; (d) AN; (e) nitrate and (f) nitrite

RSM has shown the significance between the factors and the parameters tested (Table 5a, b, c). The significance was determined by evaluating at P-value which was 0.07 for COD and BOD, 0.23 for AN, 0.07 for TSS, 0.12 for nitrite and 0.00 for the nitrate. Therefore, independent factors had higher significance for nitrate. Despite that, BOD, COD, AN, TSS and nitrite was found to have less significance to the factors tested. The significance of the model and regression coefficient for the removal of nitrate from PSW is shown in Table 4c. The interactions between these factors is determined by using the least square method and the 95% confidence level of P-value is used to indicate the significance between both of the factors used. The results obtained shows that x_1 and x_2 have significant effect onto the removal efficiency of pollution parameters from SPW especially in nitrate removal where the p<0.05. The main reason of the high nitrate removal is that the denitrification process is occurred by using the large range of microorganisms in SBR and JF is used to increase the denitrification thorough the reactor.

Table 5a - ANOVA of quadratic model in JF-SBR, Y_1 = BOD; Y_2 =COD

Source	Degree of Freedom	Sum of Squares		Mean Square		F – value		P – value	
		Y_1*	Y_2 **	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Model	5	1825.19	1825.19	365.03	365.04	3.39	3.39	0.07	0.07
Residual error	7	753.07	753.07	107.58	107.58			non-significant	
Lack – of – fit	3	753.07	753.07	251.02	251.02			P > 0.05	
Pure error	4	0.00	0.00	0.00	0.00				
Total	12	2578.26	2578.26						

*R ^{2}=0.7079, ** R ^{2} =0.7079

Table 5b - ANOVA of quadratic model in JF-SBR, Y_3 = TSS; Y_4 = AN

Source	Degree of Freedom	Sum of Squares		Mean Square		F – value		P – value	
		Y_3	Y_4	Y_3	Y_4	Y_3	Y_4	Y_3	Y_4
Model	5	5614.949	2985.34	1122.99	597.07	3.39	1.83	0.07	0.23
Residual error	7	2316.954	2287.16	330.99	326.74			non-significant	
Lack – of – fit	3	2316.95	2287.16	772.32	762.39			P > 0.05	
Pure error	4	0.00	0.00	0.00	0.00				
Total	12	7931.903	5272.50						

*R ^{2}=0.7079, ** R ^{2} =0.5662

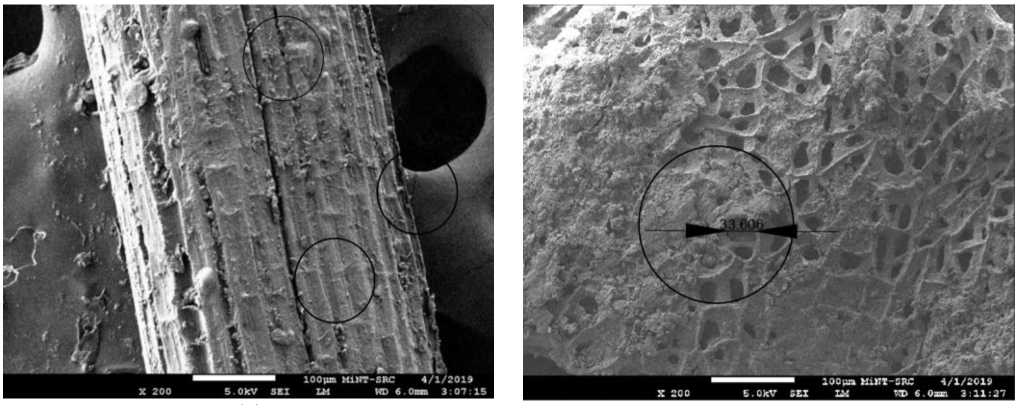
Table 5c - ANOVA of quadratic model in JF-SBR, Y_5 = Nitrate; Y_6 = Nitrite

Source	Degree of Freedom	Sum of Squares		Mean Square		F – value		P – value	
		Y_5	Y_6	Y_5	Y_6	Y_5	Y_6	Y_5	Y_6
Model	5	2489.20	1337.37	497.84	267.47	11.55	2.59	0.00	0.12
Residual error	7	301.64	723.27	43.09	103.32			significant	non-significant
Lack – of – fit	3	301.64	723.27	100.55	241.09			P < 0.05	P > 0.05
Pure error	4	0.00	0.00	0.00	0.00				
Total	12	2790.83	2060.63						

*R^2=0.7079, ** R^2=0.6490

3.3 Surface Morphology of Jute Fiber

Jute fiber surface morphology was determined before and after treatment by using scanning electronic microscope (SEM) as shown in Fig. 4(a) and (b). The results revealed a change in the properties of jute fiber from smooth surface with less void into rough surface and more voids up to 33.61 μm as observed by the SEM analyses. Zhong et al. [19] emphasized that the rough surface of jute fiber provided more sensitivity towards the attachment of bacteria. Wang et al. [18] claimed that the change of jute fiber properties can be affected by the interaction of the bacteria. Hence, it shown that the used of JF is capable to improve the condition of wastewater in terms of BOD, COD, TSS, AN, nitrate and nitrite.



(a) (b)

Fig. 4 - (a) Surface morphology of jute fiber before the treatment; (b) Surface morphology of jute fiber after the treatment

4. Conclusion

Jute fiber added in the sequencing batch reactor has increased the removal efficiency of SBR by 66.86 for BOD, 66.68% for COD, 95.65% for TSS, 68.75% for AN (68.75%), 91.67% for nitrate and 100% from SPW. Based on ANOVA, aeration time and aeration rate contributed higher significance in removing nitrate by 100% with P<0.05 compared to others parameter. Therefore, JF-SBR shows that the used of jute fiber is recommended to treat the seafood processing wastewater.

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