Applying response surface methodology on the results of serial sequencing batch moving bed reactor

Mahdi Ghaderi¹ · Pariya Asadi² · Mahtab Kouhirostamkolaei²

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Abstract

This study introduces the new biological reactor that called serial sequencing batch moving bed reactor. In this research, this reactor was used for treatment of hospital wastewater. Furthermore, three independent variables (retention time, pollutant loading and media filling percentage) were investigated. For the first time, modeling of COD removal percentage (as the dependent variable) in hospital wastewater treatment was investigated by using of response surface methodology. According to the results, the COD removal efficiency increased from 58 to 91%, when pollutant loading decreased from 0.38 to 0.3 kgCOD/kgMLSS. Also, COD removal efficiency increased from 38 to 86% when retention time increased from 16.48 to 58.52 h. According to the results, the media filling percentage had the minimum effect on the COD removal efficiency, so that, COD removal efficiency increased from 63 to 78% with increasing in media filling percentage from 19.77 to 45%. The results revealed that the optimum condition to achieving the highest COD removal efficiency was at the retention time of 46.59 h, pollutant loading of 0.34 kgCOD/kgMLSS and media filling percentage of 42.24%. According to this research results, this reactor have high efficiency in hospital wastewater treatment.

Keywords Media filling percentage · Pollutant loading · Response surface methodology · Retention time · Serial sequencing batch moving bed reactor

1 Introduction

As the population growth, the widespread use of industry and medicine have led to a larger volume of sewage containing contaminants [1, 2]. The treatment of industrial wastewater were investigated in previous studies [3, 5, 10, 26, 29, 30, 45, 46, 58]. The pharmaceutical ingredients do not completely alter in the human body and it flows into the sewage system. These kind of contaminants remain unchanged during wastewater treatment operations. The stability of pharmaceutical ingredients in surface and underground water sources has given rise to numerous diseases. Medicines downgrade the quality of water and leave a toxic effect on microorganisms. Over the last two decades, studies have focused on this materials, its

effects and the removal of residual contaminants from the environment [55]. A hospital wastewater contains huge amounts of active pharmaceutical ingredients (APIs), discharge a substantial volume of medicines into urban sewage. Hospitals are the major consumers of antibiotics, which cause spread of antibiotic resistance [36].

Previously, physical, chemical and biological processes have been used for treatment of wastewaters. Numerous studies have been conducted on the hospital wastewater treatment [4, 11, 25, 27, 28, 35, 51, 52]. Using of nano materials and studying about nanofluids are new research interests in environmental engineering [37–44, 47–49]. Based on the results published by Hocquet et al., it was found that great quantities of antimicrobials discharged in wastewater have been stable [15]. Another research by

✉ Mahdi Ghaderi, m.ghadery.ace@gmail.com | ¹Mechanical Engineering Division, Torbat-e Jam High Educational Complex, Torbat-e Jam, Iran. ²Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran.

Han Tran et al. [14] showed the presence of 10 different antimicrobials in Singaporean wastewater samples. In a study by Walia et al. [56] the spread of β -lactamase spectrum (BL) and its resistance gene in hospital effluent and urban river was observed.

Considering the dangerous effects of hospital wastewater, various physical, chemical and biological solutions have so far been proposed and examined. Examples of physical methods studied for hospital sewage treatment are as membrane technology (Sancho et al. [50] and absorbance with active carbon [16]. It has been pointed out that these physical methods merely transfer contaminants from one environment to another without destroying contaminants. Examples of chemical methods used in hospital sewage treatment are fenton oxidation [60], Multi-Stage Ozone Injection [21], and ozonation/ H_2O_2 , UV photolysis/ H_2O_2 , photo-Fenton [7]. These ways are quite costly and are not ecofriendly due to involvement of harmful chemicals.

Examples of biological methods used in hospital wastewater treatment are fungal-reactors [22, 24], conventional activated sludge reactor [12], MBBR [19], MBR [57], and microalgae [23]. These methods are used largely in order to low costs. Due to low efficiency, however, they need to be strengthened through combination of biological and chemical methods. For example, it is possible to use the combination of photocatalyst TiO_2 , UV and H_2O_2 ; and sequencing batch reactor (SBR) [9]. The composition of Fenton-SBR [9] has been investigated for treatment of antibiotic-containing wastewater. Although this strategy is less expensive than the chemical method alone, it is environmentally harmful and more expensive than the biological method.

Treatment efficiency prediction of the different reactors and the prediction of environmental phenomena have been studied in recent years. Response surface methodology is one of the most applied methods that can be used for prediction [6, 8, 18, 31–34, 53, 54].

With regard to the above facts, biological treatment of hospital wastewater has minimum cost and high efficiency and it is the best solution. Accordingly, this study proposed a new biological reactor that called SSBMBR for hospital sewage treatment. In addition, the retention time can be customized in the new proposed reactor. Microorganisms

in this new reactor has highly resistant to shock because of biofilm mechanism [26]. Also, in this research for the first time, several reactors were used in series to achieve the desired efficiency in a completely environmentally friendly procedure. In this study, the experimental results were analyzed statistically through ANOVA. Also, a mathematical model provided to predict efficiency using response surface methodology (RSM).

2 Materials and Methods

2.1 Wastewater

This study involved a real-life hospital wastewater with characteristics displayed in Table 1.

2.2 Structure of each reactor

The new proposed reactor consisted of seven reactors that connected to each other in serial mode. For each one of the seven reactors, the MBBR was used, those seven reactor were completely similar to each other. The total volume of each reactor was 5.7 L, while the height of each bioreactor was 70 cm. The reactors were made of Plexiglas so the contents were easily visible. The other specifications of each reactor have been given in Table 2.

One of the main components of each MBBR is the media used in it. For this purpose, Bee Cell 2000 media was used, which offers greater specific surface than other conventional media. The appearance of media and their characteristics can be seen in Fig. 1 and Table 3.

Another important component of the reactors was aeration, which supplied the oxygen needed for biologic

Table 1 Characteristics of the hospital wastewater

Parameter	Average (mg/L)
COD	663
TOC	180
NH_4-N	13
Total phosphorus	8.6

Table 2 Specifications of each bioreactor

Parameter	Level
Wall thickness (mm)	4
Inner diameter (cm)	10
Bioreactor height (cm)	70
Total volume of each pilot (L)	7/5

Fig. 1 Bee Cell 2000 (the used media)

Table 3 Characteristics of the media (Bee Cell 2000)

Parameter	Level
Composition of media	High density poly ethylene (HDPE)
Density (g/cm ³)	0.95
Specific surface (m ² /m ³)	650
Effective surface of one media (mm ² /piece)	857
Total surface of one media (mm ² /piece)	1800

reactions and mixing of media throughout the reactor. The aeration system included air pumps, hoses and aeration rocks. The commercial name of the pumps was Sonic 9908. Moreover, the outlet compressed air from the pumps was transferred through the hose to the aeration rocks placed at the bottom of the reactor. Additionally, the aeration took place at a rate of 33.3 L per minute per liter of liquid.

2.3 Biofilm formation on media

In moving-bed biofilm reactors, the main role in treatment were related to microorganisms attached to the media. At the first stage, microorganisms were prepared from the hospital treatment plant so these microorganisms were compatible with the wastewater. Then, the media were inserted into the reactor, letting the microorganisms grow and form biofilm on the media. So as to remove the microorganisms suspended in the treatment, the wastewater were slowly discharged from the lowest reactor outlet at

a slow rate. Subsequently, the reactors were filled and the main experiments were carried out.

2.4 Transfer of wastewater between reactors at each run

After biofilm formation on media, the reactors were connected to each other and the following steps were done at each alteration in the influent concentration (Fig. 2).

Step 1 At first, each reactor was filled (to useful volume) from influent wastewater. Following this, aeration took place until the retention time was completed. Then, the aerator was switched off for 30 min for separating media and sludge from wastewater. After that, the wastewater of Reactor 7 was discharged and sampled for testing. The wastewater of Reactor 6 was transferred to Reactor 7, and Reactor 5 was transferred to Reactor 6, and the wastewater of Reactor (n – 1) was transferred to Reactor (n). Once again, Reactor 1 was filled by wastewater with initial concentration.

Step 2 The previous step was repeated by aeration until the system reaches steady state. The efficiency of steady state for each initial concentration have been presented in this study.

2.5 RSM and independent and dependent variables

In this study, a multivariable statistical analysis served to develop a new model and identify the optimal conditions

Fig. 2 Three-dimensional image of the reactor

for treatment of hospital wastewater in the SSBMBR. For that purpose, several tests were designed through RSM.

RSM is a mathematical method defining a relationship between several independent variables and a dependent variable. Previous studies have demonstrated that RSM is an acceptable method in comparison with other methods [17]. In this research, Design-Expert 7.0.0 was employed to design tests and analyze the results. The software suggested a total of 20 tests considering the details provided in Table 4. In this table, the columns display the independent variables and their units of measurement, while the subsequent columns list the values of variables in Levels 1 and – 1 separately. The last column displays the standard deviation in each variable. Values of three independent variables (retention time, pollutant loading and media filling percentage of each reactor) for each experiment are presented in Table 5.

2.6 Reactor control and periodic tests

The pH was measured on a periodic basis and kept steady at all stages within the range of 6.8–7.2. Moreover, the bioreactor temperature was within 21–25 °C.

2.7 Reference for tests

All tests were carried out based on instructions provided in Standard Methods for Examination of Water and Wastewater [13].

3 Results and discussion

In this study, analyzing of the experimental results was done by using of RSM. Furthermore, a mathematical model was used to predict efficiency through RSM. The interaction of independent variables on each other was the other result of model. The effective independent variables were retention time, pollutant loading and media filling percentage, whose effects of independent variables on COD removal efficiency were assessed. Table 6 provides the results of all experiments.

Table 5 RSM main experiment details

Run	Retention time (h)	Pollutant loading (kgCOD/kgMLSS)	Media filling (%)
1	25.00	0.25	0.30
2	37.50	0.30	70.23
3	50.00	0.25	0.30
4	25.00	0.35	0.60
5	16.48	0.30	0.45
6	37.50	0.30	0.45
7	50.00	0.35	0.30
8	58.52	0.30	0.45
9	37.50	0.30	0.45
10	50.00	0.35	0.60
11	25.00	0.35	0.30
12	37.50	0.30	19.77
13	37.50	0.30	0.45
14	37.50	0.30	0.45
15	37.50	0.30	0.45
16	50.00	0.25	0.60
17	37.50	0.38	0.45
18	25.00	0.25	0.60
19	37.50	0.22	0.45
20	37.50	0.30	0.45

3.1 Simultaneous effect of parameters

Simultaneous effect of every two parameters was investigated in this part. This section explores several 3D graphs, where in each graph; one variable is constant while the simultaneous relationship between the other two variables and COD removal efficiency is evaluated.

3.1.1 Simultaneous effect of retention time and pollutant loading

Figure 3 presents the simultaneous effect of retention time and pollutant loading on COD removal efficiency at 45% of media filling ratio. According to Fig. 3, the COD removal efficiency was 38% at a retention time of 16.48 h and pollutant loading of 0.3 kgCOD/kgMLSS. It was 58% at a retention time of 37.5 h and pollutant loading of 0.38 kgCOD/kgMLSS. It was 70% at a retention time of 37.5 h and pollutant loading of 0.3 kgCOD/kgMLSS. It

Table 4 Summary of model design based on independent variables

Factor	Name	Unit	Type	Low actual	High actual	Low coded	High coded	Mean	SD
A	Retention time	h	Numeric	25.00	50.00	– 1.000	1.000	37.500	10.329
B	Pollutant loading	kgCOD/kgMLSS	Numeric	0.25	0.35	– 1.000	1.000	0.300	0.041
C	Media filling percent	%	Numeric	30.00	60.00	– 1.000	1.000	45.000	12.395

Table 6 Results of all experiments

Run	Retention time (h)	Pollutant loading (kgCOD/kgMLSS)	Media filling (%)	Removal efficient (%)
1	25.00	0.25	0.30	60
2	37.50	0.30	70.23	78
3	50.00	0.25	0.30	92
4	25.00	0.35	0.60	41
5	16.48	0.30	0.45	38
6	37.50	0.30	0.45	70
7	50.00	0.35	0.30	74
8	58.52	0.30	0.45	86
9	37.50	0.30	0.45	70
10	50.00	0.35	0.60	79
11	25.00	0.35	0.30	32
12	37.50	0.30	19.77	63
13	37.50	0.30	0.45	70
14	37.50	0.30	0.45	70
15	37.50	0.30	0.45	70
16	50.00	0.25	0.60	95
17	37.50	0.38	0.45	58
18	25.00	0.25	0.60	73
19	37.50	0.22	0.45	91
20	37.50	0.30	0.45	70

was 86% at a retention time of 58.52 h and pollutant loading of 0.3 kgCOD/kgMLSS. Finally, the COD removal efficiency was 91% at a retention time of 37.5 h and pollutant loading of 0.22 kgCOD/kgMLSS. According to the results, increasing of retention time and decreasing of

pollutant loading caused to increasing of COD removal efficiency.

3.1.2 Simultaneous effect of retention time and media filling percentage

Figure 4 displays the simultaneous effect of retention time and media filling percentage on COD removal efficiency, where pollutant loading was assumed to be constant at 0.3 kgCOD/kgMLSS. The COD removal efficiency was obtained 38% at a retention time of 16.48 h and media filling percentage of 45%. Moreover, the COD removal efficiency was obtained 63% at a retention time of 37.5 h and media filling percentage of 19.77%. It was 70% at a retention time of 37.5 h and media filling percentage of 45%. It was 78% at a retention time of 37.5 h and media filling percentage of 70.23%. Finally, it was 86% at a retention time of 58.52 h and media filling percentage of 45%. Based on the results, retention time and media filling percentage had same effect on COD removal efficiency and increasing in this two parameters caused to increasing COD removal efficiency.

3.1.3 Simultaneous effect of pollutant loading and media filling percentage

Figure 5 shows the COD removal efficiency at a constant retention time of 37.5 h and simultaneous variations in pollutant loading and media filling percentage. The COD removal efficiency was obtained 58% at a pollutant loading of 0.38 kgCOD/kgMLSS and media filling percentage of 45%. Also, the removal efficiency was 63% at a pollutant loading of 0.3 kgCOD/kgMLSS and media filling

Fig. 3 Simultaneous effect of retention time and pollutant loading on COD removal efficiency (media filling percentage = 45.00%)

Fig. 4 Simultaneous effect of media filling percentage and retention time on COD removal efficiency (pollutant loading = 0.30 kgCOD/kgMLSS)

Fig. 5 Simultaneous effect of media filling percentage and pollutant loading on COD removal efficiency (retention time = 37.50 h)

percentage of 19.77%. The COD removal efficiency was 70% at a pollutant loading of 0.3 kgCOD/kgMLSS and media filling percentage of 45%. It was 78% at a pollutant loading of 0.3 kgCOD/kgMLSS and media filling percentage of 70.23%. Finally, it was 91% at a pollutant loading of 0.22 kgCOD/kgMLSS and media filling percentage of 45%. The results shows, this two parameters hasn't same effect on COD removal efficiency, so that, COD removal efficiency increased by increasing in retention time and decreasing in pollutant loading.

3.2 Individual effect of parameters

Individual effects of parameters were investigated in this part. This section contains several 1D graphs, where two variables are constant while the effect of variations in the third variable on the COD removal efficiency is evaluated.

Fig. 6 The effect of variations in retention time on COD removal efficiency (pollutant loading=0.30 kgCOD/kgMLSS, media filling percentage=45.00%)

3.2.1 Effect of retention time

In Fig. 6, the effect of variations in retention time on COD removal efficiency was presented at constant values for media filling percentage (45%) and pollutant loading (0.3 kgCOD/kgMLSS). The COD removal efficiency was obtained 38% at a retention time of 16.48 h, and 70% and 86% at retention times of 37.5 h and 58.52 h, respectively. According to the results, retention time has direct effect on the COD removal efficiency.

3.2.2 Effect of pollutant loading

Figure 7 displays COD removal efficiency under variations in pollutant loading and at a constant retention time (37.5 h) and media filling percentage (45%). Based on Fig. 7, the inverse effect of pollutant loading on COD removal efficiency can be concluded, so that the COD removal efficiency was 58% at a pollutant loading of 0.38 kgCOD/kgMLSS, 70% at a pollutant loading of 0.3 kgCOD/kgMLSS, and finally 91% at a pollutant loading of 0.22 kgCOD/kgMLSS.

3.2.3 Effect of media filling percentage

Figure 8 presents the values of COD removal efficiency under variations in media filling percentage and at a constant retention time (37.5 h) and pollutant loading (0.3 kgCOD/kgMLSS). The COD removal efficiency was 63% at

Fig. 7 Effect of Variations in Pollutant loading on COD Removal Efficiency (Retention Time=37.50 h, Media Filling Percentage=45.00%)

a media filling percentage of 19.77%, and 78% at a media filling percentage of 70.23%.

Similar studies on the effect of different COD loadings on biological phosphorus removal demonstrated that removal efficiency decreases by increasing in loadings [59].

Fig. 8 Effect of variations in media filling percentage on COD removal efficiency (retention time=37.50 h, pollutant loading=0.30 kgCOD/kgMLSS)

Fig. 9 Simultaneous effect of three variables on COD removal efficiency

In previous studies, a polyurethane sponge was employed as a biofilm carrier in a MBBR for domestic synthetic wastewater treatment. The results suggested, filling percentage had a simultaneous positive effect on the removal of total nitrogen (TN) as well as on nitrification and denitrification [61].

3.3 Effects of all parameters

Figure 9 illustrates the simultaneous effect of retention time, pollutant loading and media filling percentage on COD removal efficiency. The lowest COD removal efficiency was 32% at a retention time of 25 h, pollutant loading of 0.35 kgCOD/kgMLSS, and media filling percentage of 30%. Moreover, the highest COD removal efficiency was 95% at a retention time of 50 h, pollutant loading of 0.25 kgCOD/kgMLSS and media filling percentage of 60%.

3.4 Interaction effects

Interaction effects of parameters were investigated in this part. Every graph present the interactive pair-wise effect of variables. Effects of variations in these variables are either synergistic or inverse.

3.4.1 Interaction between retention time and media filling percentage

Figure 10, displays the interactive effect of retention time and media filling percentage on COD removal efficiency (at a constant pollutant loading of 0.3 kgCOD/kgMLSS). In the shortest retention time (25 h), when media filling percentage increased from 30 to 60%, COD removal efficiency increased from about 45 to 55%. At

Fig. 10 Interactive effect of media filling percentage and retention time on COD removal efficiency (pollutant loading=0.30 kgCOD/kgMLSS)

the maximum retention time of 50 h, when media filling percent increased from 30 to 60, COD removal efficiency increased from about 80 to 85%. Therefore, there was an evident synergistic effect between retention time and media filling percentage. Since the increase in COD removal efficiency at the minimum retention time (25 h) had a similar trend to that at the maximum retention time (50 h) when increasing media filling percentage from 30 to 60%, it can be argued that two independent variables, retention time and media filling percentage, had significantly positive effects on each other.

3.4.2 Interaction between retention time and pollutant loading

Figure 11 shows the interactive effect of retention time and pollutant loading on COD removal efficiency at a constant media filling percentage of 45%. At the maximum pollutant loading of 0.35 kgCOD/kgMLSS, the COD removal efficiency increased from about 35 to 75% within a retention time range of 25–50 h. This indicated a synergistic trend. As shown in the figure, the increase in COD removal efficiency at the maximum pollutant loading is greater than that at the minimum value of this variable. Therefore, it can be argued that there was a significant relationship between retention time and pollutant loading.

3.4.3 Interaction between media filling percentage and pollutant loading

Figure 12 shows the interactive effect of media filling percentage and pollutant loading on COD removal

Fig. 11 Interactive effect of pollutant loading and retention time on COD removal efficiency (media filling percent = 45.00%)

efficiency at a constant retention time of 37.5 h. At the minimum media filling percentage of 30%, pollutant loading increased from about 0.25 kgCOD/kgMLSS to 0.35 kgCOD/kgMLSS, where the COD removal efficiency dropped from about 78% to 60%. At the maximum media filling percentage of 60%, the COD removal efficiency decreased from about 87% to 67% with the same variation in pollutant loading. Therefore, the reduction of COD removal efficiency due to increased pollutant loading was identical at different media filling percentages. Therefore, it can be argued that there was no significant relationship between the two independent variables (media filling percentage and pollutant loading).

Fig. 12 Interactive effect of media filling percentage and pollutant loading on COD removal efficiency (retention time = 37.50 h.)

3.5 Mathematical model

The mathematical model was presented based on the response surface methodology. The removal efficiency was changed by 1.5, −745.8, and +0.7 units for a unit increase in retention time, pollutant load, and media filling percentage, respectively. It was changed by +5.2 units for a unit increase in the retention time and pollutant load, by −0.00933 units for a unit increase in the retention time and media filling percentage, by −0.33 units for a unit increase in the pollutant loading and media filling percentage, by −0.019 and 578.2 units for a unit increase in the retention time squared and the pollutant load squared, respectively, and by 1.39×10^{-4} units for a unit increase in the media filling percentage squared.

$$\begin{aligned}
 \text{Removal Efficiency Percent} = & +140.20822 + 1.54531 * \text{Retention Time} - 745.86197 \\
 & * \text{Pollutant loading} + 0.70707 * \text{Media Filling Percent} + 5.20000 * \text{Retention Time} \\
 & * \text{Pollutant loading} - 0.00933333 * \text{Retention Time} * \text{Media Filling Percent} - 0.333333 \\
 & * \text{Pollutant loading} * \text{Media Filling Percent} - 0.019033 * \text{Retention Time}^2 \\
 & + 578.20919 * \text{Pollutant loading}^2 + 0.000139153 * \text{Media Filling Percent}^2
 \end{aligned}$$

Table 7 The results of ANOVA based on RSM

Source	Sum of squares	df	Means squares	F value	P value prob. > F
Model	5517.48	9	613.05	151.31	<0.0001
A-retention time	3376.13	1	3376.13	833.25	<0.0001
B-pollutant loading	1636.54	1	1636.54	403.91	<0.0001
C-media filling	223.33	1	223.33	55.12	<0.0001
AB	84.50	1	84.50	20.86	0.0010
AC	24.50	1	24.50	6.05	0.0337
BC	0.7327	0.12	0.50	1	0.50
A ²	0.0002	31.46	127.45	1	127.45
B ²	30.11	1	30.11	7.43	0.0213
C ²	0.014	1	0.014	3.487E-003	0.9541
Residual	40.52	10	4.05		
Lack of fit	40.52	5	8.10		
Pure error	0.000	5	0.000		
Core total	5558.80	19			

Regarding the above relationship and based on the direct first-order effect of factors, it can be argued that the effect of variations in pollutant load on variations in removal efficiency was greater than that of the other two factors. In general, the effects of three variables can be described as follows:

Pollutant loading > Retention Time > Media Filling Percentage

3.6 Analysis of Variance

Analysis of variance (ANOVA) is a method by which, variations or dispersions in a dataset are divided into different components [20] and show the significance of parameters. Table 7, displays the results of ANOVA. An important column in the table displays *P* value. When *P*-value is lower than 0.025, i.e. the effect of parameter is significant at a 95% significance.

3.7 Optimal conditions

According to the results obtained by RSM, the optimum conditions to achieve the maximum COD removal efficiency were at 46.59 h of retention time, 0.34 kgCOD/kgMLSS of pollutant loading, and 42.24% of media filling percentage. In the optimum conditions, mathematical model presented COD removal efficiency of 73.47%. Experiments in the laboratory showed an efficiency of 76.47% in mentioned conditions.

4 Conclusion

Given the significant existence of pollutants in hospital wastewater, a variety of techniques have been adopted to remove pollutants. This study examined the biological removal of such hazardous pollutants in a SSBMBR. The capability of SSBMBR in treatment of hospital wastewater was confirmed in this research. Also, in this research, the removal efficiency is predicted by a mathematical model based on RSM, where the interactive effect of independent variables on each other as well as on the dependent variable is verified. Retention time, pollutant loading and media filling percentage were effective independent variables on COD removal efficiency. According to the results, pollutant loading variation have the greatest effect on removal efficiency and the COD removal efficiency increased from 58% to 91% by increasing pollutant loading from 0.22 kgCOD/kgMLSS to 0.38 kgCOD/kgMLSS, at constant values of retention time (37.5 h) and media filling percentage (45%). Furthermore, the removal efficiency increased from 38% to 86% with an increase in retention time from 16.48 to 58.52 h and at constant values of 0.3 kgCOD/kgMLSS and 45% for pollutant loading and media filling percentage, respectively. According to the results, this reactor can prove to be a good alternative to the conventional bio-reactors in hospital wastewater treatment.

Compliance with ethical standards

Conflict of interest The authors declare that the authors do not have conflict of interest.

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