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The Application of Moving Bed-Biofilm Sequencing Batch Reactor System in Decreasing Chemical Oxygen Demand (COD) Concentration on Palm Sugar Industry Wastewater

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Abstract: Palm sugar wastewater has a high concentration of COD (3270-3773 mg/L) which exceed the quality standard of Indonesia's Ministry of Environment and Forestry Law No. 5 of 2014. Moving-bed biofilm sequencing batch reactor is an attached growth system which able to tolerate high concentrations of organic matters in wastewater. This experiment was performed in a lab-scale reactor by varying detention time 12, 18 and 24 h. The ratio of BOD_5/COD before and after the treatment was increased from 0.46-0.69. It happens presumably due to the hydrolysis process which convert the complex organic compound to simple organic compound. During the experiment, the optimum dissolved oxygen was 2.41-2.62 mg/L. The results showed the COD removal efficiency at 12, 18 and 24 h detention time, respectively are 84-89, 86-91 and 88-92%. The decreasing of organic loading rate will result in increased removal efficiency of COD. Therefore, the optimum organic loading rate to reach COD removal efficiency above 88% is in the range of 3.27-4.27 kg COD/m^3 day. The highest removal efficiency reached was 92% in 24 h detention time with organic loading, dissolved oxygen and pH effluent, respectively at 3.27 kg COD/m^3 day, 2.51 mg/L and 8.6. This study, showed that MBSBR system has an acceptable performance to treat wastewater with a high load of organic carbon at a certain detention time.

Key words: Moving-bed biofilm sequencing batch reactor, attached growth, cod removal efficiency, detention time, palm sugar wastewater

INTRODUCTION

Sugar is one of the foodstuff which is being consumed daily by the people of Indonesia. It takes 235 tons of sugar to meet domestic sugar needs every month. The increasing demand for sugar, encourages the development of sugar home-based industry such as Arenga. Several litters of water are required during the production process for cleaning the equipment. Then, most of the water ends up being wastewater with a high concentration of Chemical Oxygen Demand (COD). As in Arenga, the COD concentration is ranging from 2000-4000 mg/L. In fact, based on the quality standard of Indonesia's Ministry of Environment and Forestry Law No. 5 of 2014, the concentration of COD in sugar industry wastewater with production capacity <2500 tons/day should not exceed 250 mg/L. Therefore, a wastewater treatment with a high COD removal efficiency for this sugar home-based industry is required.

The Moving Bed Biofilm Reactor (MBBR) system has a COD removal efficiency up to 99.4% but the system efficiency will reduce with the increasing of COD over 1000 mg/L (Zafarzadeh *et al*., 2010). While, the Sequencing Batch Reactor (SBR) system is capable to treat wastewater with a COD concentration up to 4000 mg/L but the COD removal efficiency varied only around 72% (Jena *et al*., 2016). By considering both the characteristic and quality standard of sugar wastewater, a system that can combine MBBR and SBR system is needed. That system is Moving-bed Biofilm Sequencing Batch Reactor (MBSBR). The MBSBR system is capable of treating wastewater with high organic loading and at the same time has a COD removal efficiency around 80-90% (Faridnasr *et al*., 2016). Based on their research, MBSBR can be used to treat sugar industry wastewater effectively. In the study, MBSBR was able to treat wastewater with COD removal efficiency up to 92.27% on the wastewater that contains 500-2500 mg/L COD (Faridnasr *et al*., 2016). Initially the variation of detention time used was 2-4 h, however, at the end of the research it was found that the optimum detention time will lie in the range of 4.5-7.5 h.

In general, the MBSBR processing system consists of 5 periods which is fill, react, settle, draw and idle. The COD removal efficiency reached 71% using the variation of 0 h fill, 12 h react, 1.5 h settle, 1 h draw and 9.5 h idle

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(Lim *et al*., 2012). The same COD removal efficiency reached by Jing *et al*. (2009) with a variation of 4 h fill, 16 h react, 1 h settle, 2 h draw and 1 h react. While by Faridnasr *et al*. (2016) study, the system consists of 4 period which is fill, react, settle and decant that each last for 30 min. One of the principles of MBSBR system is the aeration and non-aeration processes that take place sequentially. Faridnasr *et al*. (2016) experiments, the sequencing aeration and non-aeration processes take place during the fill and react periods. While in research conducted by Lim *et al*. (2013) the sequencing aeration and non-aeration took place in react period.

Moving-bed biofilm sequencing batch reactor is an attached growth wastewater treatment system. Therefore, a medium as a place where the bacteria grow is needed. Nguyen and Nguyen (2013); Faridnasr research, Kaldness K1 is used as the media during the experiment. While the media which being used by Jing *et al*. (2009) are respectively, WD-F10-4 BioM a Poly Urethane (PU). Another consideration for MBSBR system is the ratio of the media to the working volume of the reactor itself. Research conducted by Jing *et al*. (2009) used a 30% ratio of media to the working volume. While by Faridnasr *et al*. (2016) experiments a 60% ratio of media to the working volume is used.

This study adopted the reactor size, media type and media ratios on the research that has been done by Faridnasr *et al*. (2016). The distinction of this research with previous research is the source of influent wastewater and the variance of detention time used. The influent wastewater is a real sugar industry wastewater from a home-based palm sugar industry as by Faridnasr *et al*. (2016) and Panrare *et al*. (2016) researched, they used an artificial sugar wastewater. The variation of detention time used is 12, 18, 24 h during the experiment. This research aims to reach a high COD removal efficiency which expected to produce an effluent wastewater with COD concentration below 250 mg/L based on the quality standard of Indonesia's Ministry of Environment and Forestry Law No. 5 of 2014.

MATERIALS AND METHODS

Wastewater characteristic : The characteristics of palm sugar wastewater used as an influent during the experiment can be seen in Table 1. It was the output wastewater of the production process in palm sugar home industry Arenga. It contains high concentrations of organic matters, therefore it has a high concentration of COD. The wastewater also has a high acidity with pH characteristic lies in the range 3.9-4.2. So, it is necessary to be adjusted the influent by adding NaOH until the pH reached 7.5. This is done because the bacteria in the biofilm are Aspidisca sp. and Cyanobacter which has a growth optimum pH between 7.5 and 8.5.

Table 1: Wastewater characteristics

Parameters	Units	Range concentration
BOD_5	mg/L	1504-1907
COD	mg/L	3144-3646
pH		3.9-4.2
DO	mg/L	2.12-2.63
Biodegradability (BOD_5/COD)		0.42-0.51

Lab-scale specification: This study is a lab-scale experiment with a quantitative approach. Moving-bed Biofilm Sequencing Batch Reactor (MBSBR) is a wastewater treatment system that combined an attached growth and suspended growth system (Lim *et al*., 2012; Roya *et al*., 2015; Truttim and Sohsalam, 2016). The reactor was made from a plexiglass with 25×25×50 cm width, length and height, providing total volume and working volume, respectively are 31 and 25 L.

Kaldness K1 made of HDPE with density of 0.7 g/cm^3 and porosity up to 68% filled the total working volume of 17 L. The reactor runs in a batch treatment system by utilizing the gravity system. An aquarium air pump Resun LP-60 with a capacity of 4200 L/h and 50 watts of power used during the sequencing aeration. The ratio of sequencing aeration was 3:1 with 1.5 h of aeration and 0.5 h non-aeration. A digital timer is used to operate the aeration pump automatically (Fig.1).

Lab-scale start-up: Activated sludge from WWTP Jababeka is flowed into the reactor at the seeding stage. It has a purpose to grow the biofilm on Kaldness K1. The MLVSS of activated sludge was set at 6500 mg/L to reach the recommendation of optimum MLVSS concentration in a lab-scale biological process. The batch flow system with a recirculation every 12 h takes place during this stage for a total of 11 days. This stage ends when the COD removal efficiency has reached steady state.

The end of the seeding stage becomes the beginning of acclimatization stage. Acclimatization is the stage which adjusts the microorganisms on biofilm with the palm sugar wastewater. At this stage, palm sugar wastewater will be put into the reactor in stages to prevent shock loading due to varied organic loading. The acclimatization process is divided into 5 stages that are divided based on differences in composition of volume influent. The combination composition used is a multiple of 20%. In the first stage, 20% of the activated sludge in

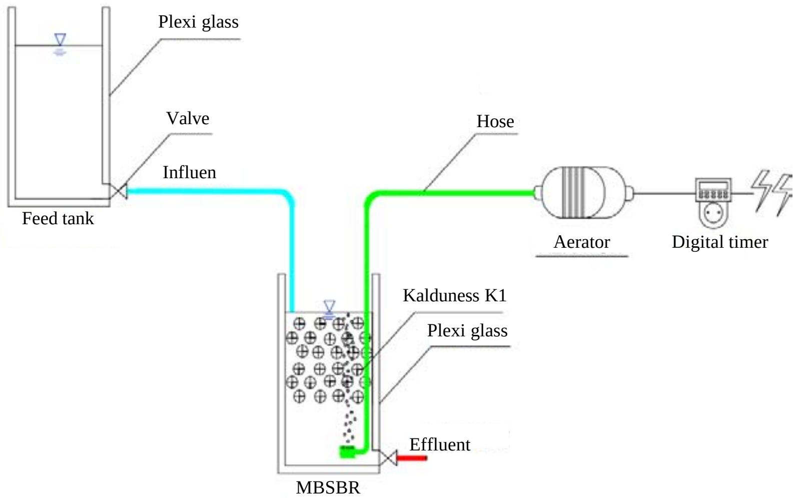

Fig. 1: Schematic of the MBSBR lab-scale experiment; specification; feed tank dimension = 250×25×50; MBSBR dimension = 250×25×50; media ratio = 60%; aeraror aquarium air pump with; Capacity of 70 LT/min

the reactor was replaced with the palm sugar wastewater. The process continues until 100% of the reactor was filled with palm sugar wastewater. This stage, lasted for 25 days until it aims the steady state of COD removal efficiency.

One cycle in acclimatization stage lasted for 12 h. As the lowest detention time, 12 h detention time has the largest value of organic loading. After one cycle is completed, the wastewater is then recirculated into the reactor. It aims to increase the hydraulic loading rate which can lead to the erosion of dead bacterial cells, so that it can regenerate the formation of biofilm layers (Aygun *et al*., 2008; Koh *et al*., 2016).

Chemical and analytical procedure: The sampling procedure is in accordance with SNI (Indonesian National Standard) number 6989.59: 2008 which explains the wastewater sampling method. The Chemical Oxygen Demand (COD) was measured using the close reflux titrimetric method (SNI 06-6989.2-2009). BOD_5 was measured using winkler with 5 days incubation time (SNI 6989.72.2009). The pH was measured using a digital pH meter based on SNI 06-6989.11-2004. Hach 51850-11 sension 6 portable dissolved oxygen meter was used to measure the concentration of dissolved oxygen.

RESULTS AND DISCUSSION

Feeding is a stage where all the influent consists of sugar wastewater. At this stage, the biofilm layer has formed and the microorganism's condition has reached its stationary phase. The stationary phase is the phase in which the removal efficiency has reached a steady state so that the total loading is possible. Three variations of detention time (12, 18 and 24 h) used during the feeding. In the process, the influent pH value was adjusted at 7.5. It aims to maximize the biological process. The period consists of fill, react, settle and draw which the sequencing aeration and non-aeration occur in react period. The ratio of sequencing aeration is 3.1, i.e., 1.5 h of aeration and 30 min non-aeration.

Three parameters which are COD, DO and pH was examined. Changes in Chemical Oxygen Demand (COD) concentration indicated the presence of bacterial activity in the decomposition of organic substances. The concentration of Dissolved Oxygen (DO) indicated the rate of oxygen consumed by the bacteria during the decomposition process. In biological treatment with aerobic system, the optimum concentration of dissolved is supposed to be <2 mg/L. Furthermore, the pH were monitored for compatibility with the optimum pH conditions of the bacteria (*Aspidisca* sp. and Cyanobacter).

Performance evalution: The concentration of COD influent on this stage was in the range 3270-3773 mg/L. The results of the COD removal efficiency at each detention time can be seen in the Fig. 2. The result showed that 12 h detention time had a minimum, average and maximum value of COD removal efficiency at 84.17%, 86.40 and 89.14%. Maximum COD removal efficiencies achieved when the concentration of COD influent was at 3270 mg/L resulting in an effluent concentration of 354 mg/L. While the minimum COD removal efficiency happened when the concentration of COD influent was 3773 mg/L followed by COD effluent at 577 mg/L.

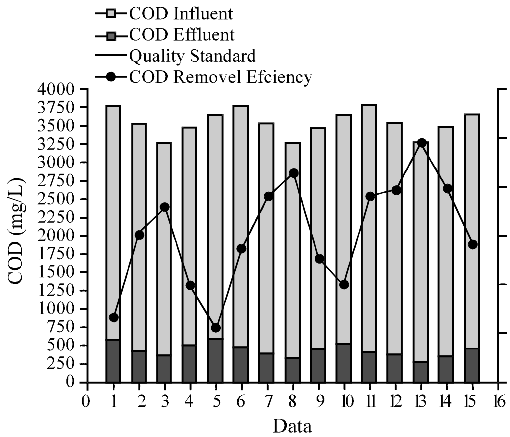

Fig. 2: Result of MBSBR performances

Table 2: Overview of labscale operation condition

HRT h/COD Concentration (mg/L) In	Ef	OLR (kg COD/ m^3 hari)	DO Concentration (mg/L)	pH In	Ef	COD Removal (%)
12						
3773	580	7.55	3.27	7.5	8.3	85
3530	421	7.06	2.62	7.5	8.4	88
3270	354	6.54	2.62	7.5	8.5	89
3480	489	6.96	5.76	7.5	8.4	86
3646	577	7.29	3.63	7.5	8.4	84
18						
3773	473	5.03	2.89	7.5	8.4	87
3530	368	4.71	2.47	7.5	8.4	90
3270	308	4.36	2.41	7.5	8.6	91
3480	450	4.64	2.53	7.5	8.5	87
3646	512	4.86	2.58	7.5	8.4	86
24						
3773	391	3.77	2.55	7.5	8.6	90
3530	358	3.53	2.43	7.5	8.6	90
3270	269	3.27	2.51	7.5	8.6	92
3480	350	3.48	2.04	7.5	8.6	90
3646	450	3.65	2.85	7.5	8.5	88

Furthermore, the 18 h detention time had a minimum, average and maximum value of COD removal efficiency, respectively, were 85.96, 88.12 and 90.57%. The maximum COD removal efficiency produced wastewater with COD effluent concentration of 308 mg/L. While the minimum efficiency produced wastewater with COD effluent concentration of 512 mg/L. Then, the 24 h detention time had a minimum, average and maximum value of 87.66, 89.77 and 91.78%. The COD concentrations at the minimum and maximum removal efficiency were respectively 269 and 450 mg/L. As can be seen in the Fig. 2, during the experiment, the highest COD removal efficiency was reached at the third day while the COD influent concentration was at its lowest point which is 3270 mg/L. It showed that the performance will increase simultaneously with a decrease in influent concentration Table 2.

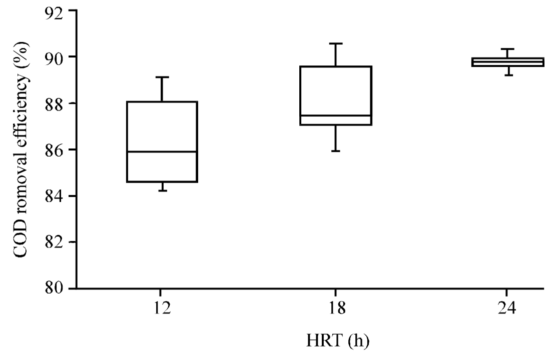

Fig. 3: Box plot of MBSBR performances

To review the performance at each detention time an independent-samples t-test was conducted to compare COD removal efficiency in 12 and 18, 12, 24 h and 18 and 24 h conditions. There was not a significant difference in the scores for 12 h detention time (M = 86.40, SD = 0.022) and 18 h detention time (M = 88.12, SD = 0.019) conditions; t (8) = -1.341, p = 0.217. There was also not a significant difference in the scores for 18 h detention time (M = 88.12, SD = 0.019) and 24 h detention time (M = 89.77, SD = 0.015) conditions; t (8) = -1.539, p = 0.162. However, there was a significant difference in the scores for 12 h detention time (M = 86.40, SD = 0.022) and 24 h detention time (M = 89.77, SD = 0.015) conditions; t (8) = 2.882, p = 0.020. These results suggested that detention time does not really have an effect on COD removal efficiency performance. However, it should be noted that COD removal efficiency on the longest detention time (24 h) appeared to be significantly different from the lowest detention time which was 12 h.

Figure 3 showed the performance of COD removal efficiency at 12, 18 and 24 h in a box plot form. The box plot of 12 h and 18 h detention time was comparatively tall. It suggested performance at 12 and 18 h hold quite varied of COD removal efficiency. However, the 24 h box plot was comparatively short so it was suggested that performance at this detention time had a similar value of COD removal efficiency. Further more, based on the Fig. 3, the 24 h detention time had a higher average COD removal efficiency trend. The mean value of COD removal efficiency at 24 h detention had a tendency to approach its maximum value compared to other detention time. It might occur because the longer the detention time, the greater probability of the bacteria in the biofilm to complete the degradation process.

In addition to the detention time, several other variables affect the COD removal efficiency. The variables were DO concentration, pH value and organic loading rate. A Pearson correlation statistical test used to figure out the correlation between COD removal efficiency and each variable. In this study, the DO concentration and COD removal efficiency had a strong negative correlation with Pearson value -0.46. Negative correlation is the correlation between two or more variables that run contradictory or in an opposite direction (Riadi, 2016). In this case, the negative correlation occurred because the COD removal efficiency was increasing while the DO decreased. As can be seen in Fig. 3 when the DO concentration reached its maximum point of 2.8 mg/L, the COD removal efficiency was at its minimum point of 88%. The decreasing of bacterial activity due to external factors such as reduced nutrient intake will result in an incomplete nitrification and denitrification process (Aygun *et al*., 2008). This condition allowed the occurrence of phenomena in which heterotrophic bacteria would eat autotrophic and other heterotrophic bacteria. In the end, DO concentration would increase because there was no decomposition activity which resulted in the decreasing of COD removal efficiency In this study, the optimum DO range achieved to obtain optimum efficiency was 2.41-2.62 mg/L.

Characteristics of pH value and COD removal efficiency had a positive and a very strong correlation with pearson value +0.80. The positive correlation is the correlation between two or more variables that run in the same direction or corresponding (Riadi, 2016). It indicated that an increase in pH value would result in increased efficiency of COD removal and vice versa. In Fig. 3, it can be seen that the effluent pH value at each detention time on the third day were at its maximum value of 8.5, 8.6 and 8.6 for HRT 12 , 18 and 24 h. This corresponded to the COD removal efficiency at each detention time that also increased on the third day is 89, 91 and 92% for HRT 12, 18 and 24 h. In wastewater treatment, pH functioned in degrading heavy metals and other toxic metals. Increasing the pH value will increase the number of chains between negative hydroxide ions and positive metal ions (Meenakshipriya *et al*., 2008). This chain would form solid metal particles that did not dissolve in water which then end up as a sludge. Conversely, under acidic pH conditions, excess hydrogen ions will destroy bacterial cells, slow their growth or kill them directly (Mohammed, 2015). So, at a low pH condition, decomposition activity of organic material would decrease which resulted in a decreasing COD removal efficiency.

In this study, Fig. 4 organic loading rate and COD removal efficiency had a very strong negative correlation with pearson value -0.85. In this case, a negative correlation occurred because the COD removal efficiency

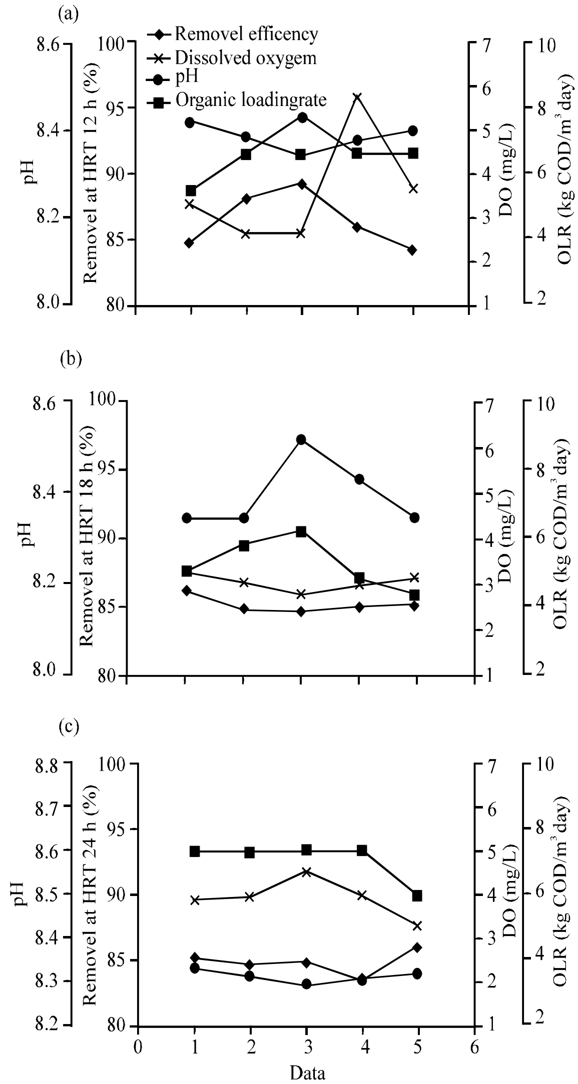

Fig. 4: Correlation between COD removal rfficiency, pH, DO and OLR at: a) 12 h detention time; b) 18 detention time and c) 24 h detention time

had increased under low organic loading rate conditions. The very strong correlation between these two variables was indicating that the organic loading rate had a major effect on the decomposition process that occurs during the feeding stage. Increasing the OLR will result in decreased COD removal efficiency since high OLR would inhibit the process of nitrification and denitrification. In a study conducted by Aygun and Berktay, the COD removal efficiency decreased from 95.1-45.2% due to an increase in OLR from 6-96 g COD/m^3. In this study, to obtain a COD removal efficiency above 88%, the value of influent OLR should be adjusted in the range 3.27-4.69 kg COD/m^3 day.

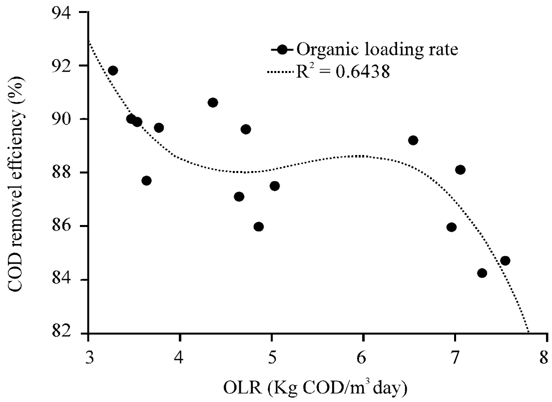

Fig. 5: Effect of organic loading rate on COD removal efficiency

Palm sugar industrial wastewater has a biodegrad ability ratio (BOD_5/COD) of 0.46. After treatment process using the MBSBR system, the BOD_5/COD ratio increased to 0.69. It presumably occurred because the organic matters in wastewater contained more complex organic material than the simple one. Therefore, the biological treatment process at each detention time was still in the early stages of the hydrolysis process where the breakdown of complex organic material into simple organic compound occurred. It was then denote by reduced COD concentration and increased biodegradability ratio.

The MBSBR system expected to be capable of producing industrial wastewater in accordance with the existing quality standards during the experiment. The quality standard of effluent used as a reference is the Indonesia's Ministry of Environment and Forestry Law No. 5 of 2014 for the type of sugar industry with production capacity >2500 tons/day. Based on the quality standard, the concentration of COD for industrial wastewater to be discharged into surface water should not exceed 250 mg/L. To consider 3540 mg/L as the average COD influent concentration, the system must have a COD removal efficiency up to 93%. The efficiency value was not achieved during the experiment with the variability of detention time used. However, based on experimental results, it can be forecasted that the MBSBR system can achieve COD removal efficiency up to 93% if the influent OLR is >3.25 kg.COD/m^3 day. Hence, it's recommended to utilize a pre-treatment in advance of the biological treatment using MBSBR system Fig. 5.

CONCLUSION

MBSBR is an attached growth wastewater treatment system that combines SBR and MBBR systems. This system is capable to treat wastewater that contains a high organic loading rate with a high COD removal efficiency. Therefore, the system is suitable for treating sugar industrial wastewater which has a concentration of COD more than 3000 mg/L while the quality standard is strictly at 250 mg/L. The experimental results show that the MBSBR system is able to achieve COD removal efficiency more than 92% which influenced several factors such as pH value and influent organic load. To obtain a COD removal efficiency above 88% it's recommended to adjust the pH value and organic loading rate of the influent to be around 7.5-8.5 and 3.27-4.69 kg COD/m^3 day.

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