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Tempe Industrial Wastewater Treatment by using Combined Anaerobic Baffled Reactor and Biofilter Processes

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Abstract

Tempe industries have become one of key industries in many cities in Indonesia which increase concerns on wastewater treatment to meet environmental quality standards, as a consequence of its industrial activities. Tempe industrial wastewater contains high concentrations of organic contaminants thus requires to be treated prior to discharge to the environment. This research aims to assess the performance of innovative combined processes of anaerobic baffled reactor (ABR) and biofilter. This research was conducted using two laboratory-scale reactors with total effective volume of 80.99 L, consisting of four compartments of ABR and one compartment of biofilter. The performance was assessed based on the variation of wastewater influent concentrations (i.e., high strength of 20,000 mg COD L^{-1}, medium strength of 5,000-10,000 mg COD L^{-1} and low strength of 1,000-3,000 mg COD L^{-1}) and the process variation of combined ABR-biofilter (i.e., anaerobic-anaerobic process in reactor A and anaerobic-aerobic process in reactor B). The reactor was operated in a continuous system at the rate of 43.2 L day^{-1}. Diffuser was required in aerobic condition with oxygen transfer capacity of 4.5 L O_2 min^{-1}. Bioballs were used in the biofilter reactor as attached media for the microbial growth. Both reactors A and B were able to degrade organic substances with the highest removal percentage reached was 89.49% and 94.44% for COD, 95.25% and 97.56% for BOD_5, respectively. The results showed that the higher concentration of organic contaminants treated, the higher organic removal efficiency in ABR-biofilter processes will be obtained.

Keywords: aerobic biofilter, anaerobic baffled reactor, anaerobic biofilter, tempe wastewater

1. INTRODUCTION

Tempe industry is one example of growing industries in big and small cities in Indonesia. Some activities involved in tempe processing generate wastewater containing high concentrations of organic pollutants. As the consequences of these industrial activities, it is essential to improve wastewater treatment facility in order to meet environmental quality standards. The wastewater is generated from soybeans washing, equipments washing, cooking, and soaked soybeans solution. The amount of wastewater generated is approximately 15-20 L kg^{-1} of soybeans raw material [1]. The wastewater from soybean industry contains Biochemical Oxygen Demand (BOD) concentration of 5,000-10,000 mg L^{-1} and Chemical Oxygen Demand (COD) concentration of 7,000-12,000 mg L^{-1} [2].

Various attempts have been made to reduce the concentration of organic pollutants contained in tempe wastewater. The alternative treatments that can be done is by using Anaerobic Baffled Reactor (ABR). The anaerobic treatment has an efficiency of 50-70% with the condition of the effluent still contains high levels of organic pollutants and odors [2]. Therefore, it is essential to increase the removal efficiency by combining it with aerobic process.

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The combination of anaerobic and aerobic processes has a potential for obtaining high removal efficiency. Combination is done by combining Anaerobic Baffled Reactor (ABR) with Anaerobic/Aerobic biofilter (AF) for the treatment of tempe wastewater. This system also considers the amount of organic loading rate (OLR) of the wastewater. If the value of OLR is too small then the processing is not able to operate optimally. Therefore, it is necessary to study and analyse the effects of wastewater concentration variations in the application of ABR-AF combination. In addition, this study also determines the removal efficiency of using ABR-AF combination applied for the treatment of tempe wastewater by means of anaerobic-anaerobic and anaerobic-aerobic processes.

2. MATERIALS AND METHODS

2.1 Preliminary Research

The preliminary research was done to analyse characteristics of tempe wastewater derived from Kampung Tempe in Tenggilis sub-district area, Surabaya. The characteristics include the main parameters such as BOD_5, COD and Total Suspended Solid (TSS) as well as additional parameters such as ammonia, N, P, pH and alkalinity. The tempe wastewater used in this study was soybeans soaked wastewater and soybeans rinse wastewater as the diluent, i.e., to simulate the targeted wastewater concentration.

2.2 Reactor Design

This research was conducted using two laboratory-scale reactors with combination of ABR and AF in a single reactor. Reactors was made of glass material with dimensions of 89 cm × 26 cm × 37 cm. Media for microbial growth used in this reactor was bioball that made of PVC material. Two reactors were used, namely Reactor A with combination of anaerobic-anaerobic processes and Reactor B with combination of anaerobic-aerobic processes, both with the designated rate of 43.2 L day^{-1}. The design of reactor A and reactor B can be seen in Figure 1 and Figure 2.

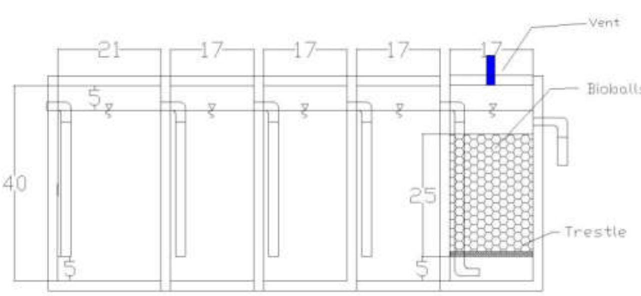

Figure 1. Reactor A with anaerobic-anaerobic processes

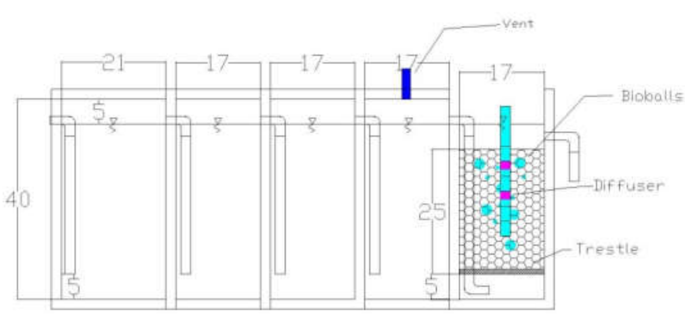

Figure 2. Reactor B with anaerobic-aerobic processes

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2.3 Seeding and Acclimatization Processes

Seeding and acclimatization processes were very essential during initial stages in order to ensure the sustainability of tempe industrial wastewater treatment process. Seeding process was aimed to increase the population of microorganisms growth by adding adequate amount of activated sludge into the reactor. The activated sludge was taken from the return activated sludge secondary clarifier unit in the sludge treatment plant.

During seeding process, substrate (i.e., sugar) was continuously added as a carbon source to support the growth of microorganisms [3]. The next process was acclimatization as microorganisms adaptation process with the wastewater condition as to growth in specific engineered conditions. The acclimatization process was reached when the stability of microorganisms efficiency in wastewater processing or decreasing of COD parameter has removal deviation of ≤ 5% from the previous measurement.

2.4 Measurement of Wastewater Concentration Variations

The study was conducted by flowing wastewater with various concentrations of organic substances. There were three concentration ranges of organic contaminants, i.e., high strength with ≥ 20,000 mg COD L^{-1}, medium strength with 10,000-5,000 mg COD L^{-1} and low strength with COD of 1,000-3,000 mg L^{-1} which refers to the concentration of existing wastewater treated. The experiment was started by flowing 100% of high strength wastewater with determining 5 routine analysis, namely COD, BOD_5, TSS, alkalinity and pH. Monitoring tests were carried out every 2 days. Sampling point was taken from the influent compartment, ABR compartment prior AF unit and the effluent compartment.

3. RESULTS AND DISCUSSION

3.1 Preliminary Characteristics Analysis of Industrial Waste Tempe

Tempe industrial wastewater used in this study was physically containing high turbidity and odor levels. The results of preliminary research can be seen in Table 1.

Table 1. Characteristics of Tempe Industrial Wastewater

Parameter	Unit	Soaked Wastewater	Rinse Wastewater
COD	mg COD L^{-1}	21,564	6,763
BOD_5	mg BOD_5 L^{-1}	12,100	1,101
NH_3-N	mg L^{-1}	2.08	1.50
pH	-	3.70	4.29
Alkalinity	mg L^{-1}	93	110
TSS	mg L^{-1}	1,190	450
N	mg L^{-1}	711.65	692.86
P	mg L^{-1}	94.31	76.45

3.2 Analysis of Hydraulic Loading Rate (HLR) Test

In HLR test, actual detention time can be determined when the concentration of fluorescent achieved its stability or reached steady state condition. This HLR test was performed using spectrophotometric method for determining the optimum wavelength and calibration of fluorescent solution. The test was conducted in each effluent point of reactors in every 15 minutes [4]. The sampling time started when the fluorescent was detected flowing out from the reactor at the first time. The rate that used in HLR test of each reactors was 43.2 L day^{-1}. The test results were used to compare the calculation of HLR detention time with the actual detention time which can be achieved by fluorescent in the effluent point of reactor. The concentration of fluorescent as a trace color which used was 30.69 mg L^{-1}. The calculation of detention time in the reactor A and B with HLR 0.474 m^3 m^{-2} day^{-1} were 44.15 hours. The results of HLR test for reactor A and B can be seen in Table 2.

Table 2. The Results of HLR Test

Parameter	Reactor A	Reactor B
Q	43.2 L day^{-1}	43.2 L day^{-1}
HLR	0.474 m^3 m^{-2} day^{-1}	0.474 m^3 m^{-2} day^{-1}
Td calculation	44.15 hours	44.15 hours
Td actual	49 hours	49.75 hours
Td difference	4.85 hours	5.6 hours
% Td changes	10.99%	12.68%

In Table 2, it can be seen that detention time was increased in the reactor A by 10.99% and 12.68% in the reactor B. The increasing of actual detention time that occured in each reactor was caused by the unstable of fluorescent upflow rate due to the presence of dead space in the reactor. The values of dead space at ABR was less than 8% of hydraulic dead space on empty reactor without biomass, while the value of dead space in AF reached 50% -93% of the reactor volume [5]. The presence of dead space on the ABR and AF was also due to the fluctuating changes of the influent flow rate [6].

The decline of upflow rate in the ABR and AF affects the actual detention time of reactor. The smaller value of upflow rate, the longer detention time or HRT will be. The presence of bioballs as filter media in AF unit significantly affects the upflow rate, i.e., becomes smaller. Hydraulic efficiency affects the influent capacity which is mixed inside the reactor.

3.3 Analysis of Seeding and Acclimatization Process

The seeding process was done by filling the activated sludge in the reactor about 30% of the reactor volume in a batch condition. The actual volume of sludge used in each reactor was about 30.5 L for 5 compartments, thus 6.1 L each compartment. The seeding process was flowed by wastewater and sugar with concentration ratio of 50 : 50 (e.g., 5,000 mg COD L^{-1} wastewater : 5,000 mg COD L^{-1} sugar) for three days in a batch system. Therefore, the reactor was operated continuously for four days by the same wastewater. The seeding process was done after 7 days and with no sludge bulking was observed.

In the seeding process, initial measurement of mixed liquor suspended solid (MLSS) concentration was done for the activated sludge used in each reactor. MLSS value indicates the amount of solid mixture from sludge combination and wastewater influent in the reactor [7]. MLSS is the total amount of suspended solid in the form of organic material and minerals, including the microorganisms [8]. This indicates that the increasing of MLSS concentration as the increasing of microorganisms population in the reactor. The result of seeding process can be seen in Table 3.

Tabel 3. The Results of Seeding Process

Parameter	Reactor A	Reactor B
Initial MLSS	1,180 mg L^{-1}	1,373.33 mg L^{-1}
Final MLSS	3,920 mg L^{-1}	5,900 mg L^{-1}
Increasing of MLSS	2,740 mg L^{-1}	4,526.67 mg L^{-1}

Acclimatization process in this research was performed for 25 days by continuously flowing medium strength tempe wastewater with COD concentration of 10,000 mg COD L^{-1} until COD removal percentage reachs the steady state condition. The COD concentration was measured daily to determine the level of microorganisms

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adaptation in the wastewater treatment process, especially for organic pollutants. As can be seen in Figure 3, the COD removal percentage during the acclimatization process contained seemed to be stable after day 23.

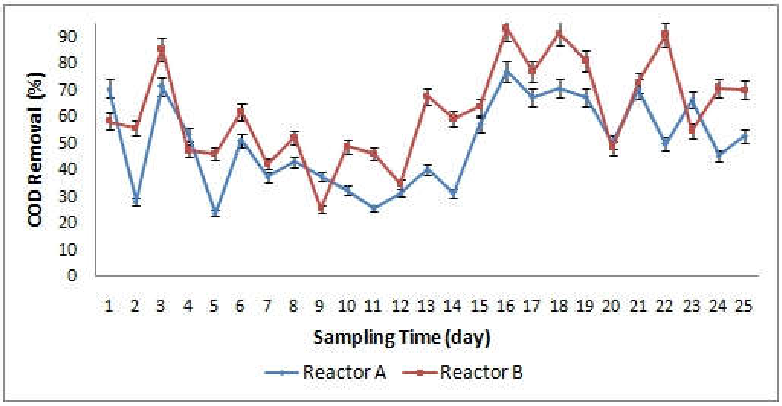

Figure 3. Removal Percentage of COD in Acclimatization Process

The highest percentage of COD removal in the acclimatization process was occured in the reactor with anaerobic-anaerobic process, i.e., 76.89% (Figure 3). In reactor B, COD removal by anaerobic-aerobic process was 93.18%. Reactor B has higher percentage of COD removal and thus is considered to be more capable in degrading organic pollutants compare to reactor A.

The actual detention time obtained from HLR test affects the contact time of tempe wastewater with the growing microorganisms in the reactor. Low detention time has a great value of upflow rate, thus decreased contact time between wastewater with microorganisms. This decreases mass transfer rate which results in the decreasing of reactor performance efficiency to degrade organic pollutants in wastewater [9].

The average COD removal percentage for acclimatization process in reactor A was 49.97% ± 16.65 and reactor B was 61.69% ± 18.13. Reactor A has smaller standard deviation from reactor B, thus it could be concluded that reactor A was more stable in removing COD during the acclimatization process. This is due to the higher hydraulic efficiency of reactor A with smaller difference of actual detention time than in the vase of reactor B. Hydraulic efficiency greatly affects the process of microorganisms adaptation to degrade tempe wastewater that flows into the reactor, thus affects overall the reactor performance in degrading COD.

3.4. Analysis of Concentration Variations Test

Analysis of concentration variation was conducted to evaluate the loading rate in which the biological processes of ABR-AF combination can be achieved. The experiment was started by evaluating the high strength wastewater, then subsequently evaluate the medium and low strength wastewater. This is done so that microorganisms can adapt to the wastewater treatment process with high concentration thus when it reachs steady state condition, the process become more stable and capable in treating wastewater with lower concentrations. Steady state condition indicates the current state of constant organic substances reduction on the specific organic and hydraulic load [10]. The steady state condition occurs when the degradation efficiency of organic substances is less than 5% for three consecutive days [11].

3.4.1 Analysis of COD and BOD_5

The decrease of COD and BOD_5 concentration determines the reactor efficiency to oxidize the organic matter contained in tempe wastewater during both anaerobic and

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aerobic processes. The overall COD removal efficiency for high strength, medium strength and low strength wastewater was in the range of 35.38%-89.49% in reactor A and 67.16% -94.44% in reactor B. The results of COD removal in each reactor for all wastewater concentration variations can be seen in Figure 4.

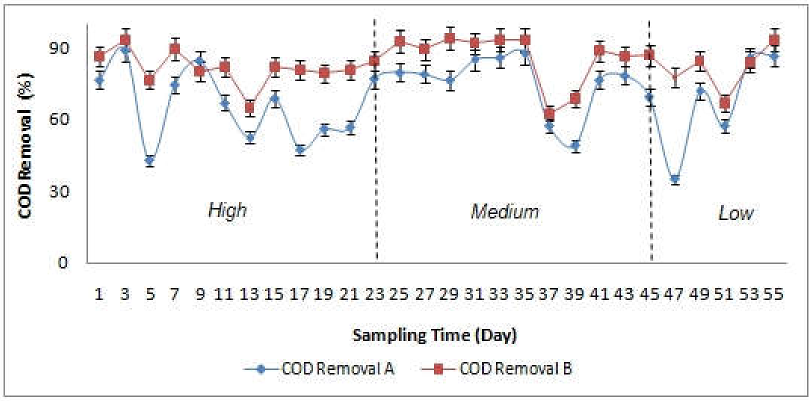

Figure 4. Removal Percentage of COD

In Figure 4, it can be seen that reactor B has more stable COD removal efficiency concentration than reactor A. The average COD removal percentage in the reactor A was 70.22% ± 15.28 and reactor B was 83.88% ± 9.07. The average COD concentration in ABR-AF effluents in high strength and medium strength wastewater concentrations were still relatively high, i.e., in the range of 1,179.14-6948.53 mg COD L^{-1}. On the other hand, in the low strength wastewater concentration, the concentration of COD effluent for reactor A and reactor B was 181.82 mg COD L^{-1} and 113.64 COD L^{-1}, respectively. These concentrations have met the regulated stream standards, i.e., 300 COD L^{-1} [12].

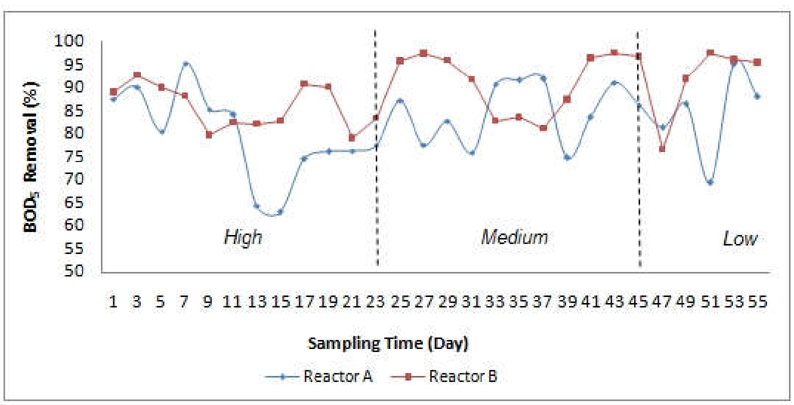

Figure 5. Removal Percentage of BOD_5

Reactor performance was also evaluated by means of BOD removal efficiency. The overall BOD_5 removal efficiency for all concentrations (i.e., high strength, medium strength and low strength) was in the range of 62.95%-95.25% in reactor A and 76.64%-97.56% in reactor B (Figure 5). The average BOD_5 removal percentage for high strength concentration in reactor A and reactor B was 79.61% and 85.85%, respectively. The average effluent concentration achieved in reactor A and reactor B was approximately 1,705.03 BOD_5 mg L^{-1} and 1,172.45 BOD_5 mg L^{-1}, respectively. The combination of

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ABR-AF for both reactors showed the highest efficiency in reducing BOD_5 concentration at the medium strength wastewater load. Both reactors were capable of degrading BOD_5 concentration with the highest removal percentage of 91.97% for reactor A and of 97.56% for reactor B.

Reactor A and reactor B tend to decrease BOD_5 concentration in the low strength concentration variation. The BOD_5 removal percentage obtained in reactor A and reactor B was 84.06% and 91.50%, respectively. This was due to the low concentration of organic substances utilized by microorganisms with approximately 540.66 mg BOD_5 L^{-1} in reactor A and 573.80 mg BOD_5 L^{-1} in reactor B. The less organic substances used by microorganisms, the smaller BOD_5 removal percentage can be obtained in the tempe wastewater.

Similar to COD concentration, the average concentration of BOD_5 in ABR-AF effluents were still relatively high for high strength and medium strength concentrations, i.e., 167.61 and 3,279.11 mg BOD_5 L^{-1}, respectively. The BOD_5 concentration of the effluent in the case of low strength concentration wastewater was 25.94 mg BOD_5 L^{-1} in reactor A and 12.13 mg BOD_5 L^{-1} in reactor B. Likewise, the BOD_5 concentration of ABR-AF effluents in the reactor A and B have met the regulated quality standards, i.e., 150 mg BOD_5 L^{-1} [12].

3.4.2 Analysis of BOD_5/COD

The ratio of BOD_5/COD indicates the value of wastewater biodegradability that processed in the reactor. There were decreasing of *BOD_5/COD* in the concentration variations of medium strength, high strength and low strength in each reactor. The value of BOD_5/COD were in the range of 0.17 to 0.42. This indicates that the process occurred were on biodegradable zone. Biodegradable zone is the amount of organic substances that can be degraded by microorganisms in natural conditions and the processing conditions which have been determined [13]. The relationship between the ratio of BOD_5/COD in each reactor contained in Figure 6.

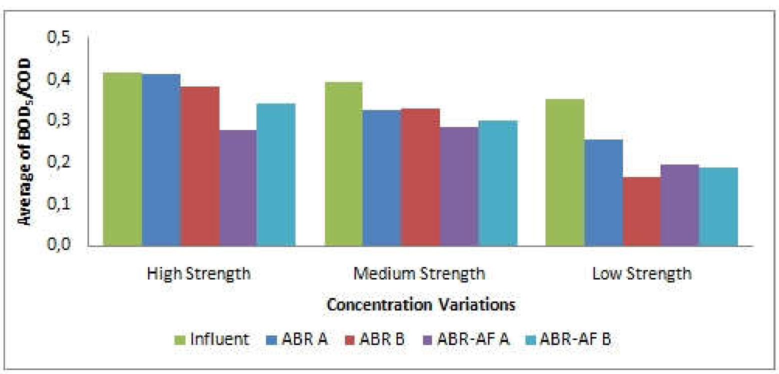

Figure 6. The ratio of BOD_5/COD

The low ratio of BOD_5/COD indicates the preference of organic substances degraded in wastewater was more biodegradable, so that showing higher capability in reducing BOD_5 than COD concentration. The ratio of BOD/COD for biological processes in the range of biodegradable, i.e 0.2-0.5 [13]. The ratio of BOD/COD between 0.2 and 0.5 can be processed with a biological process, but the process of decomposition is slower because microorganisms required acclimatization with the wastewater [14].

3.4.3 Analysis of Total Suspended Solid

TSS analysis aims to determine the level of suspended solid in the wastewater represented by three predetermined sampling points in each reactor. The analysis of TSS concentration also served to determine the stability of active sludge in the reactor [4]. The TSS concentration in the wastewater influent for each reactor was ranged from 205-1,660 mg L^{-1}. The amount of TSS concentration directly proportional to the concentration of tempe wastewater. The removal efficiency of TSS concentration at each concentration variations was presented in Figure 7.

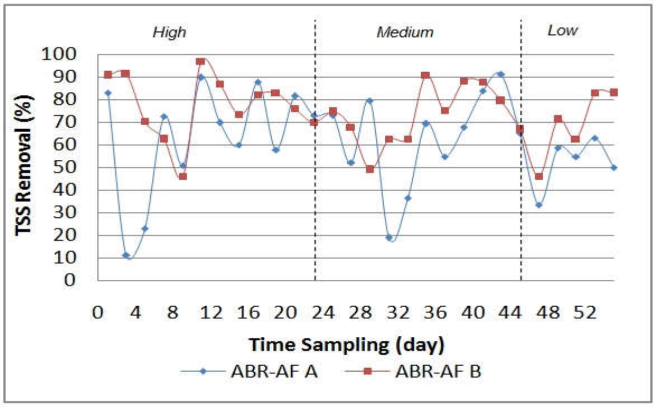

Figure 7. Removal Percentage of TSS

In Figure 7, it can be seen that reactor B tends to be more stable in reducing the TSS concentration compared to reactor A. This was influenced by the actual detention time of reactor B which was longer than reactor A. It was due to the settling time suspended solid wastes needed more time than the reactor A. The smaller retention time in the biofilter reactor, the smaller removal efficiency of reactor achieved [8]. The highest percentage of TSS concentration in each reactor was 91.18% in reactor A and 96.87% in reactor B.

The average of TSS concentration in the ABR-AF effluent for high strength and medium strength concentration variations were still relatively high, which were in the range of 339,17 and 149,09 mg L^{-1}, respectively. In the concentration variation of low strength, the effluent of ABR-AF could reach up to 120 mg L^{-1} in reactor A and 50 mg L^{-1} in reactor B. The effluent of ABR-AF in the reactor B for low strength variation has met the standard, i.e., 100 mg L^{-1} of TSS [12].

3.4.4 Analysis of pH and Alkalinity

Anaerobic wastewater treatment process requires specific environmental condition to operate the reactor. Several things must be considered in the design of anaerobic treatment for reaching the equilibrium of microorganisms activity in the processing phase of organic matter. It is important because its performance sensitivity to the fluctuations of quantity and quality wastewater influent [7]. One of important factor in the anaerobic treatment was the pH of wastewater. The pH of influent in each reactor at each various concentrations was ranged from 4.81 to 6.96. There was increasing of pH in each of processing both for reactor A and B.

The range of pH in the ABR-AF effluent in each reactors have met the environmental quality standard of pH parameter, i.e., in the range of 6-9 [12]. The pH in the ABR-AF effluent for reactor A and B has the smallest value of 7.2 and the highest value of 9.04. The value of pH were in the neutral range to support the environmental condition of reactors to do optimum treatment in anaerobic or aerobic condition. Another additional parameter which played important role in anaerobic or aerobic condition was alkalinity. Alkalinity is the ability to neutralize the acid without decreasing the value of pH solution. The results of alkalinity and pH in all concentration variations can be seen in Figure 8.

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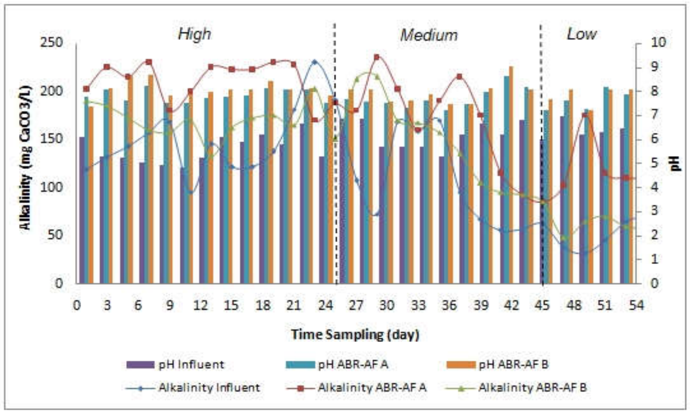

Figure 8. The Relations of alkalinity concentration and pH

In Figure 8, it can be seen that the concentration variations of high, medium and low strength increased alkalinity concentration followed by the increasing of pH in the effluent of reactor A and B. The alkalinity is useful for maintaining the pH of tempe wastewater treated. The alkalinity concentration in the ABR-AF effuent for each concentration variations was in the range of 85-235 mg $CaCO_3$ L^{-1} in reactor A and 47.5-215 mg $CaCO_3$ L^{-1} in reactor B. The water quality standard for natural alkalinity concentration never exceeded 500 mg $CaCO_3$ L^{-1} [16]. It can be concluded that based on the results of alkalinity analysis, the alkalinity concentration in the ABR-AF effluent for all concentration variations have met the environmental quality standards of alkalinity parameter [16].

3.5. Reactor Performance Efficiency

The performance of ABR-AF combination with the process of anaerobic-anaerobic and anaerobic-aerobic conditions for the treatment of tempe industrial wastewater was capable of achieving high removal efficiency of organic pollutants. The average performance of reactor A and B with combination of ABR and AF in each concentration variations was presented in Table 4.

Table 4. Performance of ABR-AF Combination

Parameter	Unit	*High strength*		*Medium strength*		*Low strength*	
		A	B	A	B	A	B
COD	%	66.49	82.17	75.42	86.70	67.70	81.76
BOD_5	%	79.61	85.85	84.88	91.50	84.06	91.50
TSS	%	63.32	77.41	62.89	73.08	51.93	69.02

Reactor A with combination of anaerobic-anaerobic processes has high percentage removal of organic matter. However, reactor A was not able to further process ammonia-nitrogen contained in the wastewater, instead increase the concentration of ammonia-nitrogen because the nitrification process did not occur. The advantage of reactor A was capable of decreasing the nitrates concentration contained in wastewater by combination of anaerobic processes in the AF unit. Reactor B has high percentage removal in overall parameters except the nitrate-nitrogen parameters for high, medium and low strength concentration variations. Another disadvantage of reactor B was adequate energy

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requirement to operate AF unit in aerobic process and the necessity of advanced post-treatment to further conversion of nitrates.

4. CONCLUSIONS

Anaerobic-anaerobic reactor (A) and anaerobic-aerobic reactor (B) were able to degrade organic substances with the highest removal efficiency reached 89.49% and 94.44% for COD, 95.25% and 97.56% for BOD_5 and 91.18% and 96.87% for TSS parameter, respectively. Reactor B was more effective than reactor A with the measured concentration of effluent reached 113.82 mg COD L^{-1} and 12.13 mg BOD_5 L^{-1} for the low strength influent.

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