J. T. K. L.
JURNAL TEKNIK KIMIA DAN LINGKUNGAN

J. Tek. Kim. Ling. **2024, 8 (1), 14-24**
p-ISSN : 2579-8537, e-ISSN : 2579-9746
http://jurnal.polinema.ac.id/index.php/jtkl
DOI: http://dx.doi.org/10.33795/jtkl.v8i1.3340

Palm Oil Mill Effluent Treatment Technology using Sequencing Batch Reactor (SBR) with Oxidation Reduction Potential (ORP) Monitoring

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ABSTRACT

Palm oil industries have products like Crude Palm Oil (CPO), and 70% of others contain waste. One of the wastes is the liquid waste known as Palm Oil Mill Effluent (POME). The potential of POME to be reprocessed into clean water will be profitable. One of POME's reprocessing methods is the Sequencing Batch Reactor with Aerobic Granulated Sludge (SBR-AGS), which has five main phases: filling, idling, aeration, settling, and discharge, with a cycle time of 360 minutes. The first step in using this reactor is the start-up process, a granule-forming process from some sludge that has already acclimatized. In one complete cycle, the Oxidation-Reduction Potential (ORP) parameter is used to observe the electron transfer process that shows the oxygen supply into the reactor, which enables the condition of each phase in the process to be analyzed. The trend of ORP value is constantly changing in every phase. For the idling phase, the ORP tends to decrease in a value of (-300)-(-400) mV, and for the aeration phase, it will increase in a value of (-100)-100 mV.

***Keywords*:** Aerobic Granular Sludge, Oxidation-Reduction Potential, POME, Sequencing Batch Reactor.

1. INTRODUCTION

In the last ten years, the growth of palm oil mills in Indonesia has increased rapidly. United States Department of Agriculture (USDA) data shows that Indonesia and Malaysia account for 85% of world palm oil production [1,2]. The most extensive distribution of palm oil mills in Indonesia is on the island of Sumatra, with a production contribution of 52.9% of Indonesia's total production [3]. As the number of palm oil mills increases, Indonesia gains a significant advantage because it adds to its foreign exchange by exporting crude palm oil (CPO). However, the waste generated and the need for processed water are problems that are difficult to overcome.

According to the results of a survey on the oil palm industry, it was obtained that the average water requirement for oil palm plantations was 0.73-12.90 m^3 H_2O/ton fresh fruit bunches (FFB). Meanwhile, water needs to produce CPO ranging from 3.44-58.30 m^3 H_2O/ton CPO [4]. Based on data from the Directorate General of Plantations 2019, crude palm oil production volume is estimated to reach 42.8 million tons in 2022 [3]. If the assumption is taken that the water requirement per tonne of CPO is 3.5 m^3, it can be estimated that the need for CPO production will be substantial, namely around 147 million m^3 for one year of production. Thus, the expenditure costs for producing palm oil will be significant for the water supply to the palm oil mills.

In addition to the large water requirement, the palm oil mill also produces a large amount of waste because nearly 70% of the processing of palm oil into CPO is waste [5]. One of the wastes generated in processing palm oil into CPO is palm oil mill effluent (POME). The most extensive content in this liquid waste is

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Received : July 17, 2023
Accepted : November 2, 2023

90% water, 4% to 5% dissolved solids, and 2% to 4% oil, with the content of chemical oxygen demand (COD) ranging from 25,000 to 78,290 mg/L [6,7].

Regarding water quality standards, the POME waste produced cannot be disposed of directly because it can pollute the environment, mainly if used as water for CPO processing. Thus, POME must be treated first with a waste treatment plant to reduce the content of harmful pollutants in it [8]. Various conventional methods have been widely studied for POME treatment, including biological treatment [9,10], membrane technology [11], coagulation and flocculation [12], and electrocoagulation [13]. However, processing using conventional methods is often insufficient or expensive to implement [8].

In research recent years, sequencing batch reactor (SBR) has been used as an effective technology for wastewater treatment [14,15] due to its simple single tank configuration and performance in degrading COD of 95-96% and total suspended solid (TSS) of 98-99% [15]. Several stages occur gradually in a single tank: fill, idle, aeration, settle, and effluent discharge [14,16,17]. Aerobic granular sludge on sequencing batch reactor (AGS-SBR) is a version improved of the activated sludge system. Various redox layers inside the granule create optimal conditions for removing carbon and nutrients in one reactor [18]. There are denitrifier microorganisms and facultative phosphate accumulators (PAOs) in the anoxic/anaerobic zone of the granule core [19], while the AGS (aerobic) surface zone is dominated by aerobic heterotrophs and autotrophs, especially nitrifier microorganisms [18–20]. Process control strategies are needed to maintain the performance of AGS-SBR [21]. The oxidation-reduction potential (ORP) parameter has been extensively studied as a monitoring and control process for AGS-SBR [22,23]. The ORP value is used to detect nitrogen and phosphorus degradation processes by controlling the length of the phase duration of anoxic and aerobics in SBR [21,23,24]. The parameter of ORP can be used to evaluate a system based on the reduction and oxidation (redox) reactions involved [25]. Based on previous research, the ORP value can regulate the desired biological response [26–28]. Lackner and Horn have conducted a study to determine the relationship between ORP pattern and nitrogen reduction in AGS-SBR [22]. This research will focus on optimizing cycle patterns and degradation efficiency of pollutant parameters for variations in feed concentrations by applying ORP as an indicator parameter.

2. RESEARCH METHODS

2.1. Reactor Feed and Inoculum (Seed Sludge)

The reactor feed used in this study was divided into two: feed for the preparation stage (start-up) granular sludge using synthetic wastewater and performance test using POME. Synthetic wastewater was used for sludge to adapt to operating conditions and form granules during the phased start-up before using POME. Composition of synthetic wastewater was used 1000 mg-COD/L, 100 mg-N/L, 5 mg-Fe/L, 10 mg-O/L, 10 mg-Ca/L, and 300 mg-HCO_3/l. Making synthetic wastewater carried out by dissolving 256.7 g of Na-acetate (HCOONa), 75.72 g of ammonium chloride (NH_4Cl), 10.3 g magnesium sulfate heptahydrate ($MgSO_4.7H_2O$), 5 g iron (II) sulfate heptahydrate $(FeSO)_4.7H_2O)$, 8.8 g potassium dihydrogen phosphate (KH_2PO_4), 7.4 g of calcium chloride ($CaCl_2$), and 82.62 g sodium bicarbonate ($NaHCO_3$) in 200 L distilled water. POME waste and seed sludge were obtained from Palm Oil Mill X in Lampung. POME influent varied in concentrations 600 mg sCOD/L, 300 mg sCOD/L, and 100 mg sCOD/L.

2.2. Research Tools

Sequencing batch reactor volume of 8 L with a diameter of 10 cm with an L/D ratio (length per diameter) 10, exchange ratio 0.5, cycle time for 6 hours with filling influent phase for 3 minutes, idling phase for 57 minutes, aeration phase for 270 to 295 minutes with increments according to granule growth, and discharge phase for 3 minutes. The aeration process was carried out with the help of a 40 W air compressor and a speed superficial of 1.5-3 m/s. The series of tools in detail is shown in the illustration Figure 1.

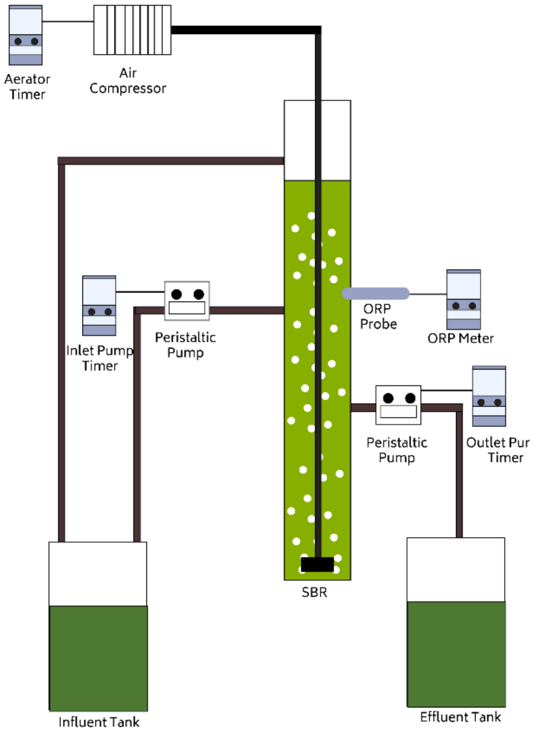


Figure 1. Series of sequencing batch reactor (SBR) equipment.

2.3. Observation of Research Data

This type of research in this study uses an empirical approach. Sampling on influent and effluent was first filtered using a syringe filter of 0.45 µm before analysis. The observed daily data is the pH using a pH meter Lutron pH-208 and calibrated with buffer solution pH 7.0 and 4.0. The ORP is measured using the equipped ORP meter probe (Digital Instruments, ORP-213). Sampling sludge, influent fluids, and effluents were carried out every three days. Parameters analyzed included settled sludge volume (SSV), sludge volume index (SVI), mixed liquor volatile suspended solid (MLVSS), mixed liquor suspended solid (MLSS), and COD analysis method according to analysis using the APHA method [29]. Total phosphorus was analyzed using the Phosphorus total reagent HR kit (HI 93758C-50) with the Vanadomolybdo Phosphoric Acid method. Nitrate measurements were analyzed using the LR reagent kit (HI 93766-01) with the Chromotropic Acid method. The Nessler method analyzed Ammonia measurements using the LR reagent kit (HI 93700-01). The morphology of sludge was observed using an image analysis system (Image-Pro Plus, V4.0, Media Cybernetics) with the Olympus SZX9 microscope. The percentage value of removal of sCOD is determined using equation 1.

$$\%\mathrm{sCOD}_{\mathrm{removal}} = \frac{\mathrm{sCOD}_{\mathrm{in}} - \mathrm{sCOD}_{\mathrm{out}}}{\mathrm{sCOD}_{\mathrm{in}}} \mathrm{x}100\% \quad (1)$$

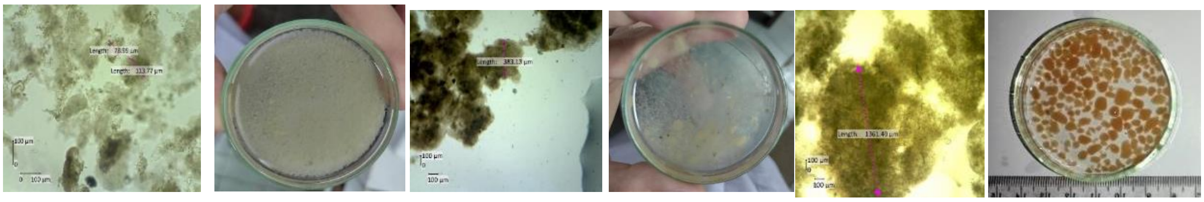
3. RESULTS AND DISCUSSION

3.1 Granule Start-Up Stages

At the start-up stages, seed sludge is taken from PTPN 7 Bekri, acclimatized for three months, then put into the reactor as sludge. During the 70-day cycle, sludge slowly forms filaments and then forms Aerobic Granular Sludge (AGS). It can be seen in Figure 2 that there is a change in the shape and size of the observed granules becoming larger. The summary of the characteristics of AGS on the 70th day of the start-up is shown in Table 1.

Table 1. Characteristics of AGS on the 70th day (start-up)

Parameter	Value	Unit
Granule size	3.95	mm
SVI 5	32	ml/g.MLSS
SVI 30	27	ml/g.MLSS
MLSS	10	g/L
MLVSS	5	g/L
COD influent	1000	mg-COD/L



(a) (b) (c)

Figure 2. Microscopic observations for granule development on days (a) 14th, (b) 21th, and (c) 70th with zoom 10x.

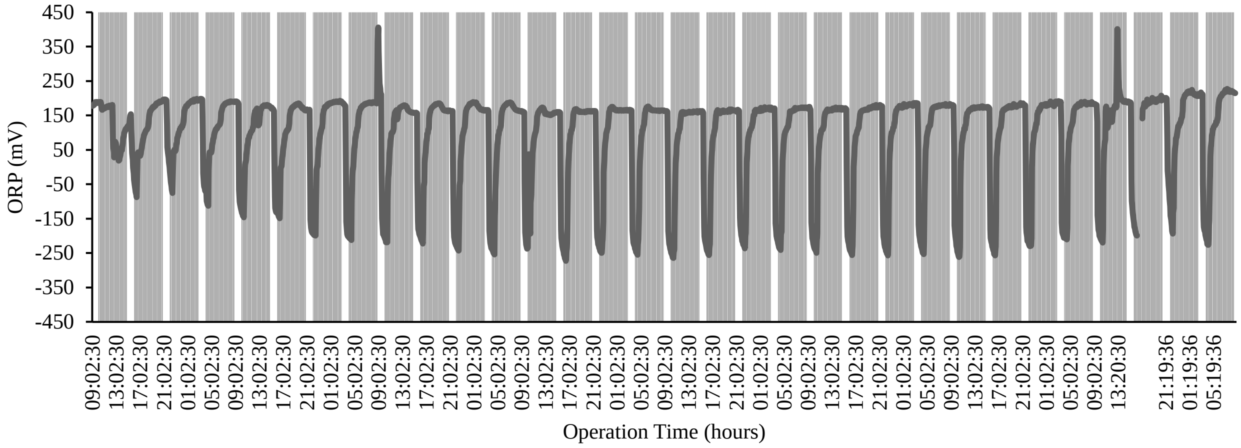


Figure 3. ORP value pattern at the start-up stage.

Figure 2 shows that the shape of the granules is quite large, with an average diameter of 150 µm granule samples in SBR of 3.95 mm. These results are by the literature, which states that the diameter of AGS is expected to be in the range of 0.1-5 mm [30–33]. Therefore, AGS is ready to be used to test its performance using POME waste.

This research will study the trend ORP on the degradation of nutrient content, then at the stage start-up trend. The ORP will be recorded to determine the pattern for each executed SBR cycle. It can be seen from Figure 3, the trend ORP on one cycle tends to be the same on all experimental dates. The condition decreases during the idling phase and rises during the aeration phase. This observation demonstrates an anaerobic phase, known as the idling phase, wherein oxygen supply is absent, particularly at the lower region of the reactor. This lack of oxygen is primarily attributed to the sole source of oxygen, namely air, which is unable to diffuse to the bottom of the reactor. In this condition, the system will act as a reducing agent where there will be a transfer of electrons from the system to the electrodes so that the ORP meter will read a negative ORP value due to the high electrons around the probe (-200 to -250 mV) [34]. In the aeration phase, oxygen will be continuously introduced into the reactor through the aerator. Due to the nature of oxygen, which has a high electronegativity, it was causing the system to experience reduction or act as an oxidizing agent where electrons will be transferred from the electrode to the system so that the ORP meter will read positive (150 to 200 mV) [21]. According to Nghiem et al., the ORP value is also greatly influenced by the concentration of waste fed [35]. The presence of 2 spikes at 9 and 13 hours was caused by the time that fresh influent with a higher concentration of waste was pumped into the reactor.

3.2 The Cod, N, and P Removal on Variations in Influent Concentrations

SBR performance testing with POME feed using SBR operates independently batch in various concentrations. Data collection was carried out without changing the SBR phase for different concentrations. Figure 4 shows the sCOD removal of the various concentrations carried out.

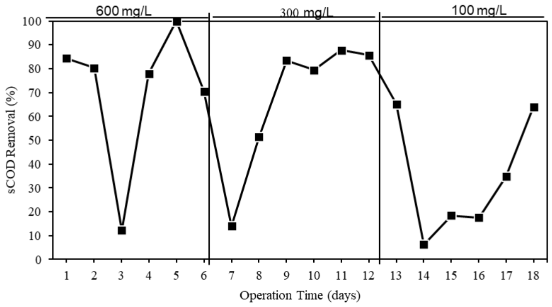
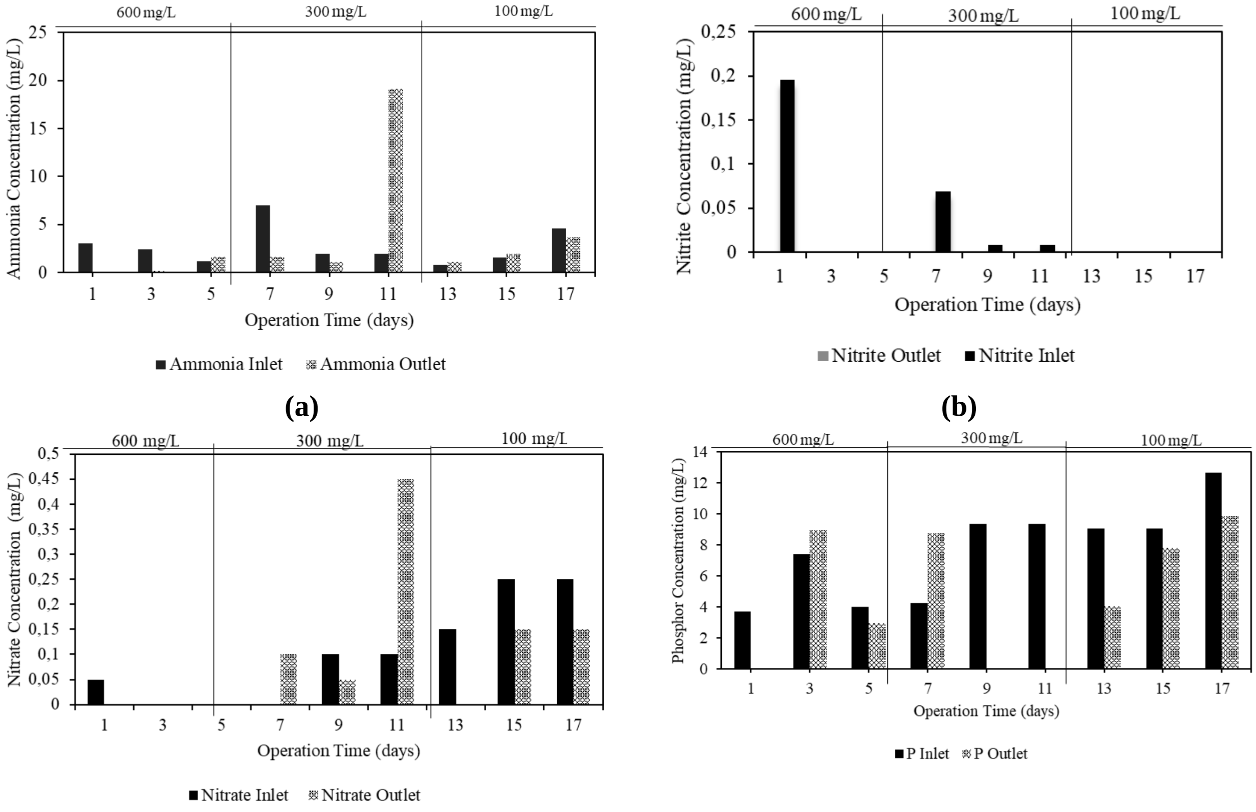


Figure 4. Profile of sCOD removal on variation of influent concentration.



(a) **(b)**

(c) **(d)**

Figure 5. Nutrient concentrations (a) Ammonia, (b) Nitrite, (c) Nitrate, and (d) Phosphorus at variations in influent concentrations.

Significant differences in sCOD removal parameters are shown in Figure 4. The substrate concentration fed into the SBR strongly influences the high-value removal. At the time of variation of 100 mg sCOD/L, removal decreased significantly but began to increase when varying concentrations of 300 mg sCOD/L and stabilized at 600 mg sCOD/L. This is because the composition of the waste affects the growth of microorganisms, so it will end in the performance of microorganisms in decomposing the waste. Removal of sCOD can occur due to the role of heterotrophic and autotrophic bacteria by using a carbon source read as the concentration of sCOD [36,37]. Figure 4 also shows the profile of sCOD removal on variation of influent concentration on days 3, 7, and 14. There is a sharp decrease in the value of sCOD removal;

because microorganisms must adapt to the concentration of waste being fed, this situation is typical. Hamzah et al. also mentioned that the performance of AGS-SBR is also determined by nitrogen removal [35].

Nitrogen in wastewater is nitrogen in the form of ammonia. Ammonia decomposition is needed to meet environmental quality standards because it will cause eutrophication. Nitrogen decomposition has two mechanisms in this SBR process: nitrification and denitrification. Nitrification (Equation 2) is a process in which ammonia is converted to nitrite, then the nitrite formed is converted to nitrate [36]. Nitrification has two process pathways: converting ammonia to nitrite (nitridation) and converting nitrite to nitrate (nitration). Denitrification is when nitrate is converted to nitrite and reduced to nitrogen gas [38].

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O \quad (2)$$

Microorganisms that play a role in the nitridation process are ammonia-oxidizing bacteria (AOB), where there is a conversion of ammonia to nitrite so that the ammonia concentration, which was initially high in the influent, becomes low in the effluent. In general, Figure 5 (a) shows that a good nitrification process has occurred in all variations. The increasing ammonia concentration on day 11 expresses incomplete nitrification, or the nitrification reaction has not reached the optimum condition and can also be affected by the too-long anaerobic time (ammonia formed in anaerobic zone). The anaerobic zone is not only in the idle cycle; it might happen on other cycles because there is no mixing in this AGS-SBR [39].

The following process mechanism is the nitridation process, where it is simultaneously directly converted by nitrite-oxidizing bacteria (NOB*)* to be suitable nitrate (Equation 3) [36].

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \quad (3)$$

Figure 5 (b) shows the role of NOB in the nitration efficiency at all concentration variations well.

If nitrate is not converted into nitrogen gas, eutrophication will still occur in the waters when released into the environment. Therefore, the AGS-SBR process carries out a nitrification mechanism and a denitrification process to convert nitrate into nitrogen gas discharged into the air. Denitrification occurs because of the role of phosphate-accumulating organisms (PAOs) related to phosphorus removal [40]. Denitrification has a mechanism according to (Equation 4) [36].

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (4)$$

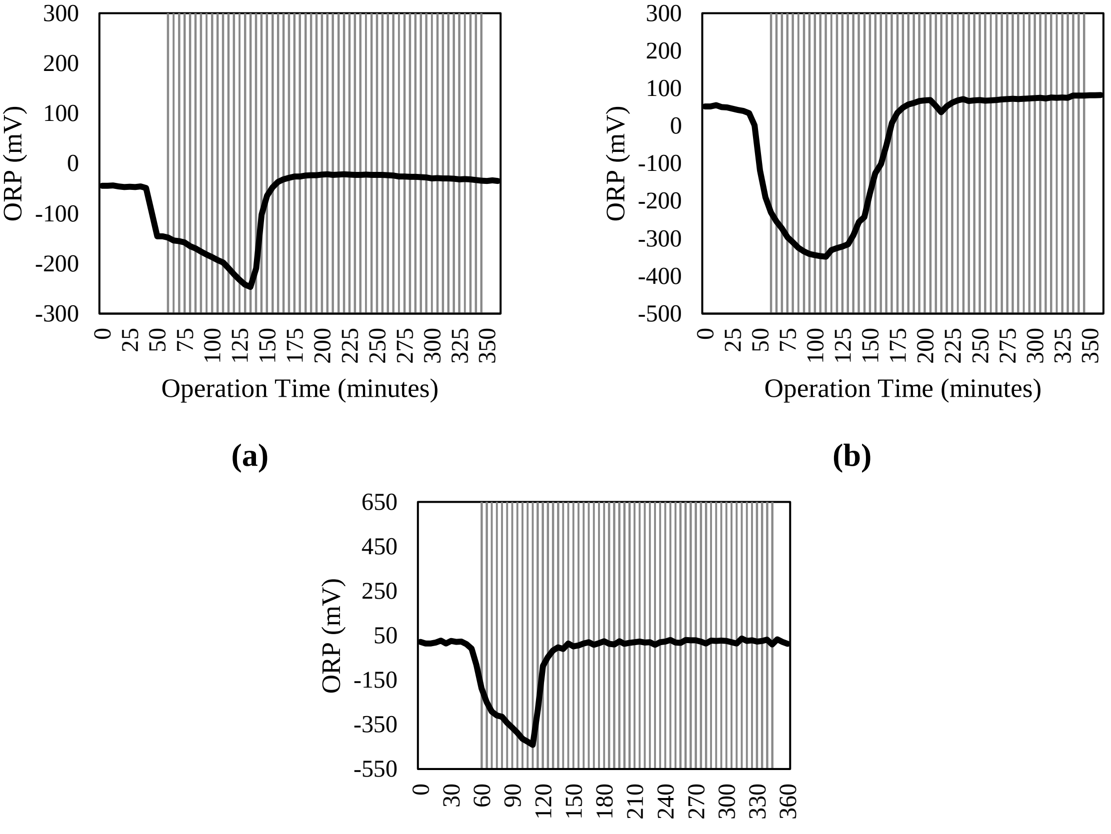
In this study, the nitrification and denitrification processes went quite well, although there was a slight anomaly because nitrite was not converted to nitrate. This can be seen in Figure 5 (c). Nitrogen removal is not optimally influenced by organic content, which is already very small at a 100 mg sCOD/L concentration.

It can be seen from Figure 5 (d) that P-removal occurs in all variations. However, there are certain days where P-removal does not occur or is negative. This can happen because, during aeration, orthophosphate is not successfully absorbed by PAOs, so there is still phosphorus content in the mixed liquor, which will be detected in the effluent. Meanwhile, POME produces P-removal, which is not as good as on day 3 due to the diffuser's improper aeration because it happened to clog. Clogging causes not optimal aeration in SBR, so phosphorus absorption during aeration is not optimal. Phosphorus absorption will be more accessible when aeration is going well because phosphorus absorption during aeration is slower than the P-release moment idle [36].

3.3 Validation of Oxidation-Reduction Potential (ORP) Against Removal Nutrients

Measurements with the ORP value show that the reaction in the AGS-SBR system is like the reaction during the idle and aeration phase. Figure 6 shows the average ORP value of various concentrations. According to Higgins, the ORP value read on the system can be used as a reference to find out what biochemical reactions occur [41]. In the ORP range of +100 to +350 mV indicating a nitrification reaction, ORP +50 to +250 mV an sCOD degradation reaction occurs, and P-removal, +25 to -50 mV denitrification reaction, -50 to -250 mV Sulfide H formation reaction, -100 to -250 VFA formation, and at ORP -175 to -400 methane formation occurs [21,34].

In Figure 6(a), when idle, from the 1st to the 59th minute, the ORP slowly decreased to -145 mV. After entering the aeration phase, ORP still seems to fall from the trend until it slowly rises to -30 mV POME. Based on the ORP value, the idle phase indicates the formation of VFAs, P-release, and denitrification.



(a)

(b)

(c)

Figure 6. The ORP patterns at various sCOD concentrations of influent (a) 600 mg/L, (c) 300 mg/L, and (d) 100 mg/L

In Figure 6(b), when idle, from the 1st to the 59th minute, the ORP slowly decreased to -170 mV. After entering the aeration phase, from the trend, ORP still seems to decrease until it slowly rises to around 48 mV (POME). Based on the ORP value, the idle phase indicates the formation of VFAs, P-release, and denitrification. When aerated, POME waste reaches range nitrification, sCOD removal, and P-removal, which is still not good. Returns need to be confirmed with the data above. Overall nitrification occurs, sCOD removal, and P-removal (though still not good). So, in addition to the ORP indicator, it is necessary to ensure that judging from the P-removal, it still needs to be improved.

In Figure 6(c), when idle, from the 1st to the 59th minute, the ORP slowly decreased to -187 mV. After entering the aeration phase, ORP still seems to decrease from the second trend until it slowly rises to 18-36 mV. Based on the ORP value, the idle phase indicates the formation of VFAs, P-release, and denitrification. However, However, POME does not maximize its degradation during aeration because it does not reach that range.

4. CONCLUSION

The performance of AGS-SBR in processing the two wastes was quite good with sCODremoval. Stable POME was around 80% (around 100 mg sCOD/L); the unstable AGS-SBR process in this experiment in N-removal and P-removal; performance removal organic and nutrient content can be evaluated with the ORP indicator, which shows the biochemical reactions taking place in AGS-SBR which will be very useful if palm oil mills escalate mill.

ACKNOWLEDGMENT

The authors appreciate the research grant from the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia (KEMENDIKBUDRISTEK) (grant number 113/E5/PG.02.00.PL/2023).

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