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Sequencing Batch Reactor for Treatment of Palm Oil Mill Effluent.

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ABSTRACT

Oil palm is commonly used in commercial agricultural activities as the second leading export in Malaysia. The main by-products and wastes that are produced from oil palm includes empty fruit bunch (EFB) and palm oil mill effluent (POME) generated from sterilizer condensate, palm fibre and palm kernels. Due to its high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations, POME has been recognized to be one of the main sources for environmental pollution. In this study, sequencing batch reactors (SBRs) namely experimental reactor R1 and control reactor R2 have been used at height to diameter (H/D) ratio of 17 for optimal granulation process. R1 and R2 were operated on a sequential cyclic processes comprehended of anoxic fill, react, settle, decant and idle period while simultaneously removing COD, BOD and color at organic loading rate (OLR) of 2.5 kgCOD $m^{-3}d^{-1}$. Good COD removal of up to 85% was achieved in R1 as compared to 70% in R2 indicating efficient COD removal in SBR when operated with seeding sludge. However, color removal for R2 was higher than R1 at 85% as compared to 72% which was presumably due to contributions of phenolic content in the influent.

Keywords: oil palm; aerobic granular sludge; POME; SBR; phenolic content

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INTRODUCTION

Oil palm is one of the most important crops in Malaysia due to several valuable attributes such as high productivity and adaptability to tropical weather and environmental conditions. Oil palm is also regarded as an important generation of work opportunities in a year-round cycle in Malaysia. The production of palm oil is a rewarding return to investment, due mainly to the strong growth of world demand for palm oil [1]. The industry has been identified as one of the key drivers towards achieving the national key economic aspiration. However, by year 2020, world population would likely to have grown to 8 billion people increasing the demand for food and energy resources, concerns on global climate change and managing diminishing earth resources especially water, air and arable land. As such, issues relating to environmental sustainability are to be considered more objectively with recognition on the importance of palm oil in the coming years to ensure supply is adequate in the global food equation. The risks of pollution generated from the industry have been escalating following the rapid expansion of palm oil industry in Malaysia. The risks mainly found in surface water pollution are due to either insufficient or improper disposal of solid and liquid wastes originating from palm oil production including palm oil mill effluent (POME). These have given justification for further assessment towards the potential contribution of cleaner palm oil industry to improve the environmental performance of the sector in Malaysia. In addition, life cycle assessments (LCA) of waste treatment in the palm oil industry have been recently introduced to identify the potential use of palm oil residues [2]

The benefits in terms of energy requirement for biodiesel production using palm oil were also quantified [2]. For example, when 520 kg fibers and 170 kg shells were used for steam generation per ton CPO, 8.7 GJ per ton CPO of energy input is produced resulted in an average energy requirement of 80 kg shells per ton CPO. Besides that, LCA tools is one of the significance technology on the greenhouse gas (GHG) balance to handle the residues from palm oil production compared to conventional practices. Moreover, the extraction process of the oil requires large quantities of water for steam sterilizing of the fruit bunches resulting in the production of wastes in the form of POME.

Aerobic granular sludge have been widely developed for the treatment of industrial wastewaters in a sequencing batch reactor (SBR) [3-6]. SBRs have been used for simultaneous COD and phosphate elimination from various types of wastewater following recent regulations on nutrient discharge limitation [7]. According to Umble and Ketchum (1997) [8], SBRs are commonly used for removal of biological nutrient from municipal wastewater. By using SBR, 98% of BOD_5, 90% of total solid suspension (TSS), and 89% NH_3-N were removed effectively with a 12 hour cycle time.

POME was treated in an SBR at OLR 2.5 kgCOD $m^{-3}d^{-1}$ using POME as the main substrate. In this study, the efficiencies of modified laboratory scale SBRs were identified based on COD, BOD and color removals. The MLSS content was also monitored to determine the biomass concentration in SBRs.

MATERIALS AND METHODS

Reactor set-up

Two modified laboratory scale SBRs with a working volume of 2 L each was setup following Niloufar et al. (2014) [9]. The first SBR was termed R1 containing POME activated sludge while the second SBR was termed R2 which was operated as control reactor without the activated sludge. The top of the column was utilized as influent and effluent ports. Influent was fed from a 5 L storage canister at an organic loading rate (OLR) of 2.5 kgCOD $m^{-3}d^{-1}$. Aeration was provided by means of air bubble at a superficial air velocity of 2.5 cms^{-1}. The reactor was operated based on Khouni et al. (2011) [10] in successive cycles of 24 h comprehended a feeding period of 30 min, a reaction period consisting an anaerobic and aerobic condition of 6 h, a settling period of 16 h, an effluent withdrawal period of 1 h and an idle period of 30 min.

POME and seed sludge preparations

Raw undiluted POME was collected from a local mill at Felda Bukit Besar Palm Oil Mill, Kulai, Malaysia. Raw POME was centrifuged at 15,000 rpm for 40 min following Abdullah et al. (2011) [11] to eliminate suspended solids and debris which can cause clogging to the influent tubes. A suitable amount of tap water was added to the POME to produce feed composition at OLR 2.5 kgCOD $m^{-3}d^{-1}$. Prior to feeding the pH of the mixed liquor was adjusted to a level of between 6.5 and 7.0 using 2M NaOH. The sludge was sieved with a mesh of 1.0 mm twice to remove large debris before inoculation. Reactor R1 was inoculated with 250 mL of seed sludge resulting in an initial MLSS concentration of 500 mg L^{-1} while R2 functions as control reactor without the addition of seed sludge.

General Analytical Procedures

Parameters such as COD, MLSS and BOD and color were carried out according to Standard Methods 5220-D, 2540-D and 5210, respectively [12]. Color was analyzed using the American Dye Manufacturers Institute (ADMI) weighted–ordinate spectrophotometric method (2120-F) [12]. The percentage of color removal can be determined by comparing the initial and final ADMI value of influent and effluent as given in Equation 1.

$$\frac{\text{ADMI value of influent} - \text{ADMI value of effluent}}{\text{ADMI value of influent}} \times 100\% \qquad \text{(Equation 1)}$$

EXPERIMENTAL RESULTS AND DISCUSSION

Dynamics of SBR

Generally, SBR is a single reactor that undergoes continuous fill and draw activated sludge system for treating wastewater. After the wastewater is added into a single reactor, all the undesirable components are removed biologically and the wastewater is ready to discharge. The performance of an activated sludge system highly depends on the quality of sludge formed in the reactor. Good quality sludge should be easily separated from the liquid and retained in the reactor. In this study, aerobic granulation has been successfully achieved in a modified SBRs referred as R1. The SBR was designed by taking several important parameters facilitating aerobic granular sludge formation using POME including good settling conditions, ability to withstand high organic loading rates and suitable ratio of height to diameter (H/D) for a compact sized reactor.

POME is treated aerobically in a successive 24-h cycle as depicted in Figure 1. Five basic SBR cycles comprehended fill-react-settle and draw-idle phases were continuously operated for R1 and R2 according to timed hours. Each cycle was carried out for 8 hours prior to settling of 16 hours. The biomass in R1 consisted of diluted raw POME and POME seeding sludge whilst R2 was operated without the activated sludge. At the beginning of every cycle, 250 mL of diluted POME is added to both R1 and R2. When aeration was provided, the organic biodegradation took place in the reactors. At the end of each cycle, the aeration is switched off allowing settling of the biomass. Upon settling, the supernatant is removed as the effluent whereby COD removal and activated sludge settling accommodate the same operating reactor. The repetition of these SBR processes resulted in a single reactor operation with a high concentration of aerobic granular sludge and therefore high volumetric conversion rates. Besides, the dynamic process conditions enable the SBR activated sludge to withstand fluctuating wastewater streams [13].

The possibility to obtain aerobic granular sludge using POME and to find good operational parameters leading to good granulation was observed in terms of SBR design parameters. Therefore, the SBR design is primarily made based on the basic assumption that aerobic granular sludge will be formed if lighter bioflocs are washed out. Hence, the settling time allocated in the reactor became the main design parameter for the SBR in this study as a short settling period selects for biomass particles with a high settling velocity [13]. In addition, according to Beun et al. (1999) [13], a high H/D ratio is advantageous for aerobic granular sludge formation. The combination of a high H/D ratio and elimination of external settlers results in a reactor with a small footprint leading to providing a more compact alternative and/or post-treatment method for POME treatment.

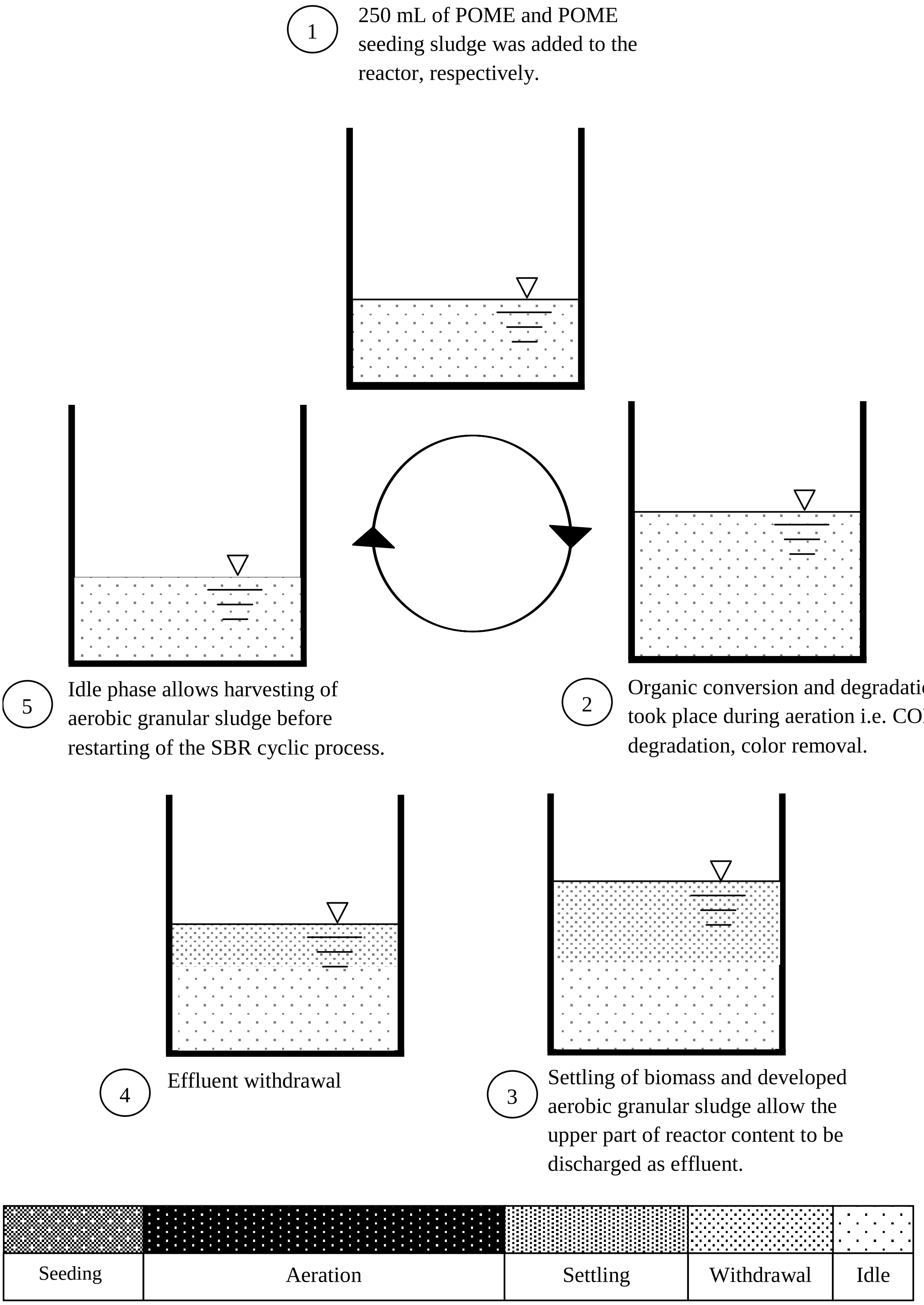

Figure 1: Dynamic process conditions of the SBR used in a successive 24-h cycle

Biomass Concentration in SBR

In this study, activated sludge taken from a local palm oil mill was seeded directly into the reactors without any acclimation due to fungal growth and foaming conditions associated with POME. At the end of the reactor operation on day-40, samples of bioflocs and/or granules were collected from the reactors and the reactor effluents and analyzed for MLSS concentrations.

Previous study has shown that aerobic granules was successfully developed using POME after 60 days of SBR operation [14]. Compact structured granules were not detected in R2 on day-40 of experiments which was operated as control reactor. In R1, unsteady biomass accumulation was observed until about day-30 of experiments. The fluctuation of biomass content was presumably due to excessive foaming condition which is commonly associated with POME characteristics. On day-30, the MLSS concentrations in R1 improved from 140 gL^{-1} to 340 gL^{-1}, indicating good accumulation and settleability of biomass. The MLSS concentrations in R2 which was the control reactor remained low at 20gL^{-1} until the end of experiments period. The settling ability of biomass content determined the solid-liquid separation that was important for the successful formation of aerobic granular sludge. Good biomass settling ability will enhance accumulation of solids in the mixed liquor to promote healthy growth of aerobic granules in the reactor.

Removal Efficiencies

The capabilities of granulation SBR in industrial wastewater treatment have been reported in the literatures [15], [11], [16]. Figure 2 depicts the profiles of COD throughout the granulation process and control in R1 and R2, respectively.

During the first week of operation, the COD removal was below 70% and the effluent quality was unsatisfactory. Stable COD removal was observed in the experimental reactor R1 after 10 days of operation although bioflocs were still dominating the reactor content. As bioflocs grew and developed into bioflocs, the COD removal in R1 improved to between 70% and 85% which is comparable to previous observation by Wang *et al.* (2007) [5] in brewery wastewater treatments using aerobic granular sludge. Reactor performance stabilized during the remainder of the experimental period with an average of 86% of COD being removed. This was attributable to both microbial aerobic degradation of POME and acquisition of good settling properties as mentioned earlier. In another study by Liu *et al.* (2011) [16], the COD removal efficiency of a granule-based reactor treating mixed wastewater rich in toxic organics could reach around 80%. However, COD removal in control reactor R2 averaged at only 35% until the end of the experimental period as illustrated in Figure 2. Significant fluctuations in COD removal in R2 also indicated that successful treatment of POME must be supported with addition of activated sludge into the SBR system. The fluctuations may presumably due to extreme foaming condition of POME in R2 which was operated without the addition of activated sludge. The prolonged aeration of up to 6 h may also have resulted in the COD removal fluctuations.

BOD is the amount of oxygen, usually expressed in mgL^{-1} that microbes take from water when they oxidize the organic matter. The success of POME treatment also depends on the ability of the microorganism to degrade the organics content in POME. Both R1 and R2 gave increased BOD removal concentrations from 20% to 37% and 9% to 31%, respectively. The BOD removal efficiencies were below 50% presumably due to several interferences during the incubation period. The instability of reactor condition may also cause the ununiformed mixing during the aeration phase of the reactors resulting in low BOD removal efficiencies.

Figure 3 gives the percentage of color removal in R1 and R2. Based on Figure 3, the percentage of color removal of POME slightly fluctuated until the end of the experimental period. The percentage of color removal in experimental reactor R1 was 72%. The phenolic compounds is thought to have contributed to the lower percentage of color removed in R1 and R2. The fluctuation of removal efficiencies in both reactors between 40% to 78% throughout the experimental period may be due to adaptation of POME and activated sludge to the reactor’s environment and operational conditions. Although many studies have been undertaken into POME treatments, good color removal is rarely observed.

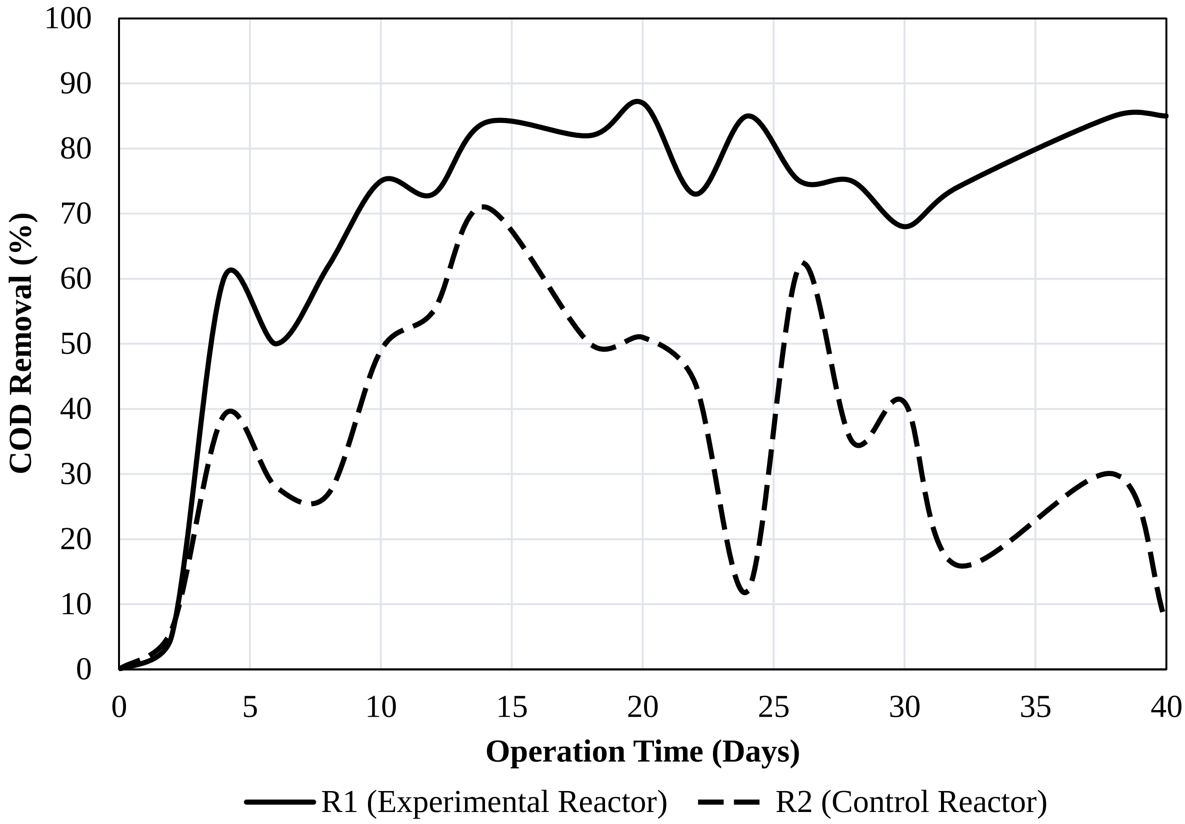

Figure 2 Profile of COD removal performances of the SBR systems in both R1 (Experimental reactor) and R2 (Control reactor)

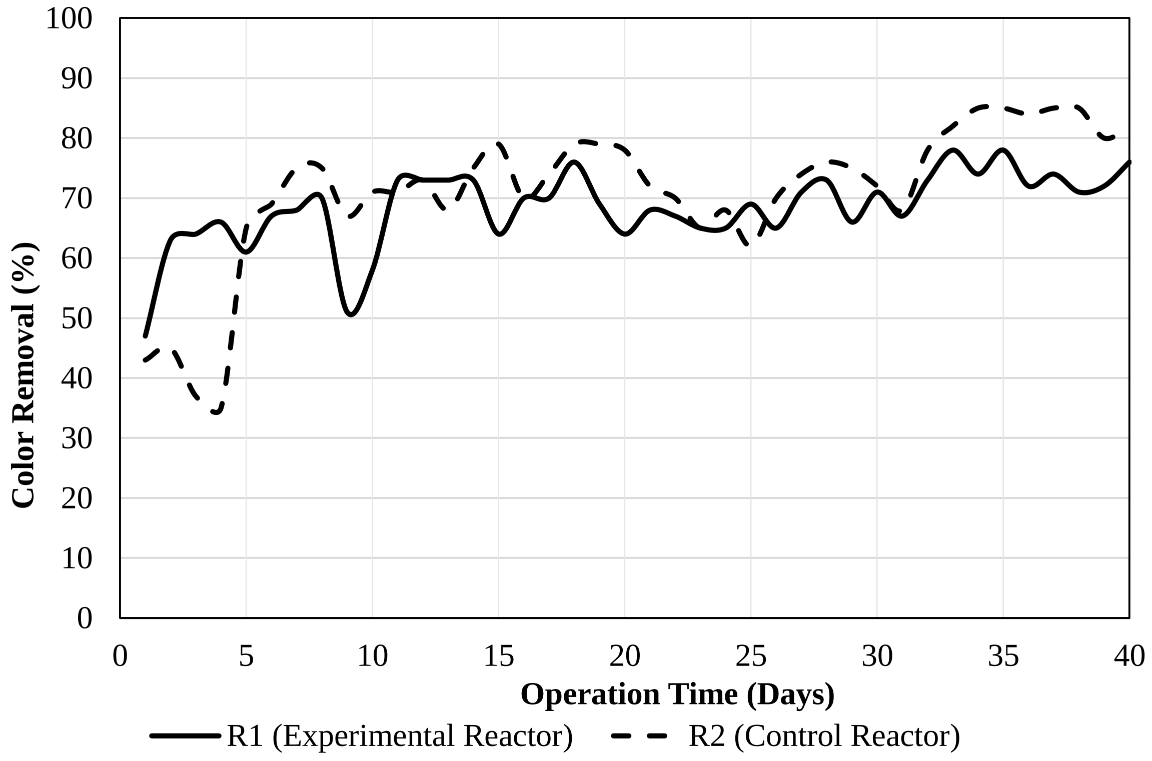

Figure 3 Profile of color removal efficiencies in R1 (Experimental reactor) and R2 (Control reactor) for SBR system in treating POME

Due to its viscous brown and grey appearance, the eradication of color from POME is becoming increasingly important from the environmental and aesthetic point of view. Colored effluents are moreover considered unacceptable by the public as they associated color with pollution. The colored effluent can cause depletion in photosynthetic activities, produce carcinogenic by-products in drinking water, chelate with metal ions, and are toxic to aquatic organism [17]. The effluent is colored due to the presence of lignin and its degraded products, tannin, and humic acids from crushed palm nut and also lipids and fatty acids released during steam extraction process [18].

Generally, the brownish color of molasses wastewater is mostly from organic compound known as melanoidin pigment, the complex biopolymer formed by the reaction between amino acid and carbohydrate occurs via the Millard's reaction [19], [20]. Whereas, the brownish color present in POME contain unknown composition of high organic matter. Related to olive mill wastewater (OMW), the present of dark brown color of POME most likely from the polymerization of tannins and low molecular weight phenolic compounds [21]. In addition, the colored wastewater receive a great concern from the public on the environmental effect compared to harmful wastewater that is colorless. Consequently, it is necessary that the color present in the effluent is removed before discharge into water stream [22].

CONCLUSION

SBRs were successfully used for treating complex agro-industrial wastewater such as POME. Good reactor performance was observed in R1 with 85% COD removal while R2 recorded lower COD removal at only 70%. The BOD removal efficiencies were below 50% presumably due to several interferences during the incubation period. However, color removal was 72% indicating good color removal. R1 has shown good solid-liquid separation based on stable MLSS concentrations despite fluctuations and suspended solid washout at the beginning of experiments. This study indicated that SBR may be used for efficient treatment of POME.

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