Performance Evaluation of Industrial Effluent Treatment Systems (IETSs) - An Insight for Biotechnology Advances in Agro-Based Wastewater Treatment

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Abstract: Seven Industrial Effluent Treatment Systems (IETSs, IETS1-IETS7) were evaluated to identify the most effective biological treatment for palm oil mill effluent (POME) and their compliance to the prevailing national discharge standard. Two main groups of IETSs were selected, comprising the conventional secondary biological treatment (G1) and biotechnologically advanced tertiary treatment processes (G2). G1 IETSs treated POME with an organic content equivalent to raw domestic sewage from a population of 175,799 to 480,558 persons (PE) while G2 IETSs in the range of 136,986 to 406,392 PE. Removal efficiency of aggregate organic constituents in terms of the biochemical oxygen demand (BOD), chemical oxygen demand (COD) and oil & grease (OG) as well as the physical properties in terms of the suspended solids (SS) and volatile suspended solids (VSS) in the IETSs was evaluated. Results indicated that the most efficient system was IETS6 with BOD, COD and OG removal of 99.7%, 98% and 99.6% respectively. It comprises the open-top anaerobic tank digesters, lagoon system and a polishing plant (extended aeration, coupled with fixed packing in activated sludge aeration tank), with large amount of biological agent. The biological treatment efficiency of POME for IETSs was described. All IETSs showed compliance to the national discharge standard except IETS1.

Key words: Attached growth - Biological wastewater treatment - Palm oil mill effluent (POME) - Plant design - Suspended growth

INTRODUCTION

Palm oil mill effluent (POME) is a wastewater resulted from the palm oil milling process and is considered as a high polluting wastewater due to its high biochemical oxygen demand (BOD), chemical oxygen demand (COD), oils and suspended solids (SS). The high temperature and acidic nature of raw POME made the necessity for pretreatment processes before a subsequent biological or other means of treatment. POME itself in untreated form is a high strength waste which depends on the operation of the process such as informal, semi-formal and formal processes. It has about 94% of water and its BOD ranges from 25,000 to 35,000 mg L⁻¹ [1].

The characteristic of POME is dependable on the quality of the raw material and palm oil production processes in palm oil mills. An enormous amount of water is needed to extract crude palm oil from FFB which is about 5 to 7.5 tonnes of water to produce 1 tonnes of crude palm oil and more than 50% of water eventually becomes the POME [2]. Land application of the POME is practiced in mills with sufficient land area opting for zero discharge. This approach however was reported to cause clogging and water logging of the soil and destroys the vegetation on contact [3]. There is a cheapest way to dispose POME which is discharging it into river. Though, the effluent to be discharged into public waterways need to be treated to meet the discharge regulation standards.

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POME is a non-toxic oily waste but however discharging effluent into river can cause water quality depletion and thus causing aquatic pollution [4].

The organic nature of POME makes biological treatment approaches applicable and preferred in most palm oil mills. In biological treatment system, physical pretreatment of POME consist of stages such as screening, sedimentation and oil removal prior to the secondary treatment [3]. Solvent extraction was attempted in laboratory scale to remove residual oil from POME as a pretreatment process. As the mixing time, solvent or feed ratio and mixing rate for all solvents increase, the percentage of extraction of oil from the POME too will increase [5]. Anaerobic biological process is a suitable treatment method because of the organic characteristic of POME [6]. Thus, this makes ponding system the most conventional method for treating the wastewater [7]. Palm oil mills in Malaysia have adopted ponding system since 1982 to treat POME [8]. In Malaysia, the open pond system is the most popular treatment method and is utilized by more than 85% of mills [9]. The popularity of open pond system is due to its low capital and operating cost. Majority of palm oil mills which is more than 85% have used ponding system due to their low cost [8]. However, ponding systems face some disadvantages such as occupying a vast amount of land mass, long retention time (HRT) of 45-60days for effective performance, foul smell and a hard time to maintain the liquor distribution and biogas release which causes detrimental effect on the environment [8]. Anaerobic process has its advantages over other processes such as less energy demands, minimum sludge formation, no bad odor and production of methane [10]. With the rapid disintegration of organic matter in the anaerobic digestion process, biogas can be generated to be applied in electrical generation and thus save fossil energy [11]. Due to the nature of POME which is non-toxic, the use of composting by integrating vermicomposting is an efficient waste management option. By using vermicompost, it benefits in recycling the plant nutrients and prevent soil to degrade. Thus, this can reduce the use of inorganic fertilizer, boost the economy and maintain the ecosystem [3].

Seldom literatures reported performance monitoring of IETSs treating POME. The wastewater is difficult to treat and continue being listed as a major threat to the environment in Malaysia although tremendous researches have been conducted on the feasibility of various treatment technology. Performance monitoring of other IETSs treating other kinds of wastewater is vastly reported, on the other hand. Sim et al. in [12] has mentioned that they have tested 25 pharmaceuticals in ten municipal effluent treatment systems, one hospital effluent treatment system and five rivers in Korea. The study suggested positive results where the pharmaceutical concentrations were decreased via the biological treatment processes. However, the decrease of pharmaceuticals was little except for some cases via the physico-chemical processes. Another study by Gracia-Lor et al. [13] suggested that conventional treatment processes did not remove the micro-pollutants completely. The micro pollutants included the analgesics and anti-inflamatories, lipid regulators as well as quinolone. Barat et al. in [14] also conducted performance monitoring on the IETS to study the precipitation problems during anaerobic digestion. Next, another IETS was studied and was suggested to efficiently operate the disinfection unit and/or include the facility into the IETS in order to reuse the effluent in irrigation [15]. Last but not least, Mahvi et al. [16] survey the effluent treatment system for a hospital and highlighted that the activated sludge system was not efficient. The average COD and BOD values were found higher than WHO standards. All these studies on IETSs identified the operational problems and suggested ways for system improvement.

Since there are lack of studies on the performance monitoring of POME IETSs, this study was conducted with the aim of identifying the most effective POME treatment approach. Seven IETSs with different PE utilizing different technologies were selected for the study. Their compliance to prevailing national discharge limit (both water and land) was selected and the role of biotechnology in POME treatment is emphasized in this paper.

**MATERIALS AND METHODS**

**IETSs Description:** Seven wastewater treatment processes are divided into two groups which are the conventional secondary biological treatment (G1) and G2 with the addition of biotechnologically advanced tertiary treatment processes. Fig. 1 and 2 presented the entire treatment processes for all IETSs. G1 IETSs included the IETS 1, IETS 4 and IETS 7 while G2 IETSs included the IETS 2, IETS 3, IETS 5 and IETS 6. The symbol “*” denotes locations where effluent samples were taken.
In Fig. 1, the entire treatment processes for IETS 1 which practiced watercourse discharge in addition to the IETS 4 and IETS 7 which practiced land discharge were presented along with the sampling locations. Two sampling locations were selected in IETS 1 to evaluate the ponding system efficiency while only one sampling location is selected in IETS 4 and 7 because we are only interested to examine their compliance to the regulation prior to disposing the semi-treated POME onto the oil palm plantations in this study. Hence, no efficiency on the IETS will be assessed on the IETS 4 and IETS 7. Their treatment systems are simple and only involve the use of several ponds. IETS 1 had the most ponds when compared to the other two IETSs and indeed to all other IETSs in this study. A total of 28 ponds were employed in IETS 1 which accounted for a large area of land in the palm oil mill. Take IETS1 for example, its treatments started from oil recovery pit and ended at facultative ponds. Each of IETS’s process ended at different processes which are IETS 1: facultative pond, IETS 4: aerobic ponds and IETS 7: anaerobic ponds. IETS 1 has a PE of 251,141, IETS 4 has a PE of 480,558 and the PE of IETS 7 was 175,799.

From Fig. 2, another four IETSs which involved more treatment processes are presented. More sampling locations were selected to assess the treatment processes involved and the overall IETS performance. IETS 2 had the most processes which were 10 process altogether. All these IETSs started with pretreatment processes and then the ponding system. The processes that follows were more advanced biotechnologies such as the SBR and extended aeration in IETS 2, the activated sludge system with suspended packing materials in IETS 3, the SBR and activated carbon adsorption in IETS 5 and the activated sludge system with fixed packing materials in addition to the extended aeration in IETS 6. The PE for IETS 2, IETS 3, IETS 5 and IETS 6 were 406,392, 136,986, 308,219 and 256,724 respectively.

**Sampling Conditions:** POME samples were collected from seven local palm oil mills. IETS 1 is located in Seri Ulu Langat in the Selangor state. IETS 2 to IETS 7 are located in several locations in the Johore state, which included Kota Tinggi, Kulai, Paloh, Kahang, Penggeli and Segamat. Raw samples were obtained from the pipe located after the pump in condensate sump. For samples from the ponds, approximately 1000 mL of effluent were taken into the containers. No sampling points should be located near to drains as moss and irrelevant dirt may enter the sampling containers. Grab samples collected were brought back to the laboratory and stored in a sealed container. The samples were also preserved in a cold temperature at 4°C prior to analysis, to prevent the deterioration of wastewater quality which caused by the microbial activity.
Table 1: List of parameters examined and their respective methods referred.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Methods</th>
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<tbody>
<tr>
<td>Aggregate Organic Constituents</td>
<td></td>
</tr>
<tr>
<td>BOD (3-days in 30°C)</td>
<td>APHA 5210B</td>
</tr>
<tr>
<td>COD</td>
<td>HACH METHOD 8000 (HACH, 2013)</td>
</tr>
<tr>
<td>OG</td>
<td>APHA 5520B (Semi-treated samples); APHA 5520D (Raw samples)</td>
</tr>
<tr>
<td>Physical Properties</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>APHA 2540D</td>
</tr>
<tr>
<td>VSS</td>
<td>APHA 2540E</td>
</tr>
<tr>
<td>Biological Properties</td>
<td></td>
</tr>
<tr>
<td>TBC</td>
<td>Cappucino and Sherman, 1991</td>
</tr>
</tbody>
</table>

**Analytical Procedures:** During sampling events, measurements on the dissolved oxygen (DO) and pH of the POME were carried out ‘in situ’. In the laboratory, several monitoring parameters were evaluated, including the aggregate organic constituents in terms of the BOD, COD and oil & grease (OG), as well as the physical properties in terms of the SS and volatile suspended solids (VSS). The analytical methods were strictly executed according to the Standard Methods [17]. Apart from that, evaluation on biological property of the wastewater in terms of total bacteria count (TBC) was also conducted. The exact methodology used is described in Table 1.

**RESULTS AND DISCUSSION**

**Removal Efficiencies:** The proficiency of each IETSs treating the POME was evaluated on two levels, whereby the first was an evaluation on the entire IETS and subsequently on every stage in the IETS in order to gain an insight for which technology contributed to the high pollutant removal in that IETS itself. Generally, all IETSs discharged the treated effluent into their nearby waterways except for IETS 4 and IETS 7 which were granted the license on land disposal. These two IETSs were only examined on their final discharge quality to evaluate their compliance to the discharge limit. Some of the common systems of land application of POME being adopted in most of the palm oil mills in Malaysia including the sprinkler/pipe irrigation system, flatbed/longbed system, furrow/gravity flow system and the tractor/tanker/pump system [2]. Prior to land application of the effluent, these palm oil mills need to obtain permission from the authority and there is a requirement to monitor their subsurface water quality. For IETS 2, IETS 5 and IETS 6, more stages in the respective IETS were examined as these systems have more interesting biotechnology applications adopted.

From Table 2, IETS 6 has the highest BOD, which is 5,833 mg L⁻¹ which is taken at the last mixing pond. The lowest BOD, is taken at IETS 6 in the discharge from tertiary treatment plant which is 23 mg L⁻¹. As for the COD parameter, IETS 6 has the highest COD which is 72,567 mg L⁻¹ which is taken at the last mixing pond. Also, IETS 6 has the highest OG which is 3,299 mg L⁻¹. As for physical properties, IETS 2 has shown the highest content for SS and VSS which is taken from the last acidification pond. IETS 5 has the lowest SS contents which is 127 mg L⁻¹. It also has the lowest VSS content which is taken from the discharge from the tertiary treatment plant. IETS 2 has the highest TBC with 76,700,000 mg L⁻¹.

Fig. 3a shows IETS 6 has the highest removal efficiency which is 99.6% in BOD, while IETS 1 has the lowest BOD removal efficiency. As for COD removal efficiency, IETS 2 and 6 have high percentages which are 98.44% and 98.23% respectively. IETS 2 and 6 in Fig. 3c too have high COD removal efficiency while IETS 1 shows the lowest value. In SS removal efficiency, IETS 2 has the highest percentage which is 99.62%, followed by IETS 6; 98.72%, IETS 5; 93.46%, IETS 3; 59.39% and lastly IETS 1 with 7.50%. VSS parameter too shows that IETS 2 and 6 have high percentage compared to others. IETS 1 has the lowest percentage and showed slightly increase in concentration instead of reducing the pollutant.

Despite the good performances as shown by the IETS 2, IETS 5 and IETS 6, which process in these IETSs essentially accomplished better was also evaluated. Based on Fig. 4a, stage 2b to 2c shows high percentage in removal efficiencies. Parameters SS and VSS have high percentages which are 97.36% and 97.32% respectively. However, in stage 2a to 2b has the lowest removal efficiency which is 19.72% when compared to other removal efficiencies. In IETS 2 from Fig. 4b, the lowest percentage of removal efficiency is taken from stage 5b to 5c where increment of concentration occurred.
Table 2: Quality of the wastewater at the respective sampling locations (mean ± standard deviation, n = 3).

<table>
<thead>
<tr>
<th>Aggregate Organic Constituents</th>
<th>Physical Properties</th>
<th>Biological Property</th>
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<tbody>
<tr>
<td></td>
<td>BOD&lt;sub&gt;c&lt;/sub&gt;</td>
<td>COD</td>
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<td>--------------------------------</td>
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<td>---------------------</td>
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<tr>
<td>IETS1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a - The last aerobic pond</td>
<td>340± 101.98</td>
<td>6178± 2903.55</td>
</tr>
<tr>
<td>1b - The last facultative pond</td>
<td>327± 66.00</td>
<td>6672±1397.75</td>
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<tr>
<td></td>
<td>180± 33.24</td>
<td>209±53.67</td>
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<tr>
<td></td>
<td>675±463.22</td>
<td>625±484.26</td>
</tr>
<tr>
<td></td>
<td>320±177.31</td>
<td>332±176.98</td>
</tr>
<tr>
<td></td>
<td>18233±3560.99</td>
<td></td>
</tr>
<tr>
<td>IETS2</td>
<td>4200±653.20</td>
<td>52233±1249.89</td>
</tr>
<tr>
<td>2a - The last acidification pond</td>
<td>2800±588.78</td>
<td>22056±13667.78</td>
</tr>
<tr>
<td>2b - Discharge from the closed-tank anaerobic digesters</td>
<td>257±30.91</td>
<td>4400±2512.30</td>
</tr>
<tr>
<td>2c - The aerobic pond</td>
<td>83±26.56</td>
<td>817±543.65</td>
</tr>
<tr>
<td></td>
<td>127±12.47</td>
<td>1294±644.46</td>
</tr>
<tr>
<td></td>
<td>64±25.33</td>
<td>369±145.64</td>
</tr>
<tr>
<td></td>
<td>150±28.71</td>
<td>182±84.32</td>
</tr>
<tr>
<td>IETS3</td>
<td>127±12.47</td>
<td>9928±7555.15</td>
</tr>
<tr>
<td>3a - The last algae pond</td>
<td>700±150.00</td>
<td>4907±2623.50</td>
</tr>
<tr>
<td>3b - Discharge from the tertiary treatment plant</td>
<td>207±115.85</td>
<td>257±1084.73</td>
</tr>
<tr>
<td></td>
<td>35±14.72</td>
<td>3558±1620.58</td>
</tr>
<tr>
<td></td>
<td>15±61.82</td>
<td>358±38.03</td>
</tr>
<tr>
<td>IETS4</td>
<td>87±20.55</td>
<td>9928±7555.15</td>
</tr>
<tr>
<td>4a - The last aerobic pond</td>
<td>700±150.00</td>
<td>4907±2623.50</td>
</tr>
<tr>
<td></td>
<td>207±115.85</td>
<td>257±1084.73</td>
</tr>
<tr>
<td></td>
<td>35±14.72</td>
<td>3558±1620.58</td>
</tr>
<tr>
<td>IETS5</td>
<td>500±120.00</td>
<td>5007±2623.50</td>
</tr>
<tr>
<td>5a - The anaerobic pond</td>
<td>1900±1134.31</td>
<td>15411±5920.38</td>
</tr>
<tr>
<td>5b - The last facultative pond</td>
<td>123±54.37</td>
<td>1639±188.76</td>
</tr>
<tr>
<td>5c - Discharge from the tertiary treatment plant</td>
<td>23±4.71</td>
<td>1264±447.83</td>
</tr>
<tr>
<td></td>
<td>150±28.71</td>
<td>156±51.41</td>
</tr>
<tr>
<td>IETS6</td>
<td>5833±1312.33</td>
<td>72657±4402.84</td>
</tr>
<tr>
<td>6a - The last mixing pond</td>
<td>1900±1134.31</td>
<td>15411±5920.38</td>
</tr>
<tr>
<td>6b - Discharge from the open-tank anaerobic digester</td>
<td>123±54.37</td>
<td>1639±188.76</td>
</tr>
<tr>
<td>6c - The last algae pond</td>
<td>23±4.71</td>
<td>1226±447.83</td>
</tr>
<tr>
<td>6d - Discharge from the tertiary treatment plant</td>
<td>15±61.82</td>
<td>358±38.03</td>
</tr>
<tr>
<td></td>
<td>15±61.82</td>
<td>358±38.03</td>
</tr>
<tr>
<td>IETS7</td>
<td>24±72±24.78</td>
<td>2872±519.55</td>
</tr>
<tr>
<td>7a - The last anaerobic pond</td>
<td>123±378.09</td>
<td>602±136.56</td>
</tr>
<tr>
<td>Notes: All parameters are in mg L&lt;sup&gt;-1&lt;/sup&gt; except for TBC is in CFU mL&lt;sup&gt;-1&lt;/sup&gt;.</td>
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</table>

The highest percentage recorded is 83.06% at the 5b to 5c stage. From IETS 6, stage 6a to 6c shows quite favorable results when compared to other stages. The highest percentage recorded is 94.99% and then followed by 95.20%, 93.51%, 89.36% and lastly 78.14%. The lowest percentage of removal efficiency in IETS 6 is 21.66% at stage 6c to 6d.

From BOD<sub>c</sub> in Fig. 4c, stage 6b to 6c has the highest percentage in removing BOD, which is 93.51%. Then, the second highest BOD<sub>c</sub> removal is at stage 2b to 2c in Fig. 4a which is 90.83%. This shows that facultative ponds and algae ponds contribute to a high removal of BOD<sub>c</sub>. Indeed, these conventional ponding systems are a successful technology in the treatment of POME due to its high retention time. Anaerobic and facultative ponds are known being employed for BOD removal. A relatively low surface organic loading of the facultative ponds are design for the BOD removal, which allow for the development of active algal population [18]. 33.33% is the lowest percentage that IETS 2 can remove its BOD, at stage 2a to 2b.

As for COD, the highest percentage removal is at stage 6a to 6b with 89.37%. IETS 2 at stage 2b to 2c and 2c to 2d show high percentages which are 80.05% and 81.44% respectively. Based on the result in this study, the open tank anaerobic digester, the anaerobic ponds, the sequencing batch reactors as well as the holding and extended aeration ponds might contribute to a high COD removal efficiencies. Subbiah and Ahmad [19] in their study reported that open tank anaerobic digesters were built in subsequent developments mills with higher reduction of COD and BOD (70% - 80% of removal efficiencies) compared to ponds. Apart from that, Chan et al. [20] reported that COD removal efficiencies were range from 63.8% to 86.3% when utilizing sequencing batch reactors for POME treatment.

In Fig. 4c, IETS 6 especially at stage 6a to 6b has the highest percentage removal in OG which is 93.72%. It then followed by the second highest which is at IETS2 at stage 2b to 2c. IETS 6 shows 3 stages that have high OG removal efficiencies based on their high percentages. It can be said that the treatment systems applied by IETS 6
are efficient in reducing OG. Apart from that, anaerobic ponds also give a high value of OG removal based on IETS 2. In Igwe and Onyegbado [1] review, they stated that the digester tank and aeration pond resulted in 99.7\% of OG removal. Similar technology applied in IETS 6 indicated similar high OG removal capability.

In SS parameter, the highest removal efficiency is shown in IETS2 at stage 2b to 2c. Stage 6b to 6c shows high percentage too which is 95.20\% and it also recorded in the lowest percentage which is 25.24\%. It can be said that the anaerobic ponds were responsible in reducing the SS, ordinarily in the manner of sedimentation. VSS parameter has IETS 2 to remove the most in stage 2b to 2c with 97.32\%. The lowest percentage of VSS removal efficiencies is also at IETS 2 but is taken at stage 2c to 2d. Again, anaerobic pond shows that it also contributed in the high reduction of VSS.

National Standard: The palm oil mills in Malaysia need to comply to the Environmental Quality Act 1974 (EQA) and more specifically to the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1977. These regulations stated the conditions of the POME prior to discharge into a watercourse or onto land. The Regulation 12 described the increasingly stringent watercourse discharge limit with the latest amendment on 1984 until
now. Enforcing the regulation based on the approach of “polluter pays principle”, the palm oil millers have no choice but to ensure the treatment of POME is appropriate to conform to the regulation in order to be granted the license of operation [21].

IETS 1, 2, 3, 5 and 6 discharged the treated effluent into watercourse. Hence, these IETSs need to produce POME at lower than 100 mg L\(^{-1}\) BOD, 400 mg L\(^{-1}\) SS and 50 mg L\(^{-1}\) OG. According to Fig. 5, IETS 1 exceeded the discharge limit for BOD and OG. As for other IETSs, the treated POME was found to be far lower than the discharge limit. The IETS 1 only applied conventional secondary biological treatment (the ponding system) in the palm oil mill. However, IETS 2, IETS 3, IETS 5 and IETS 6 which adopted the biotechnologically advanced tertiary treatment processes can produce effluent of good quality and can easily comply with the current discharge limit. On the other hand, IETS 4 and IETS 7 which discharged their treated POME onto land have much relax discharge limit. The condition limiting the BOD
concentration to 5,000 mg L\(^{-1}\) is meant for this approach of POME disposal. Other parameters such as the SS and OG are not relevant. Both IETSs 4 and 7 have very low BOD concentrations compared to the national discharge limit. However, these semi-treated effluent are still high in SS and OG concentrations.

**Biological Agents and IETSs Performances:** Based on the data obtained in this study, the highest content for TBC is at IETS 2 with 151,000,000 CFU mL\(^{-1}\), followed by IETS 1 with 2,700,000 CFU mL\(^{-1}\) and IETS 5 with 1,170,000 CFU mL\(^{-1}\). Notice that for IETS 2, the VSS has the highest value at 58, 454 mg L\(^{-1}\) as well. This means IETS 2 have the highest amount of biological agent coupled with the highest COD removal percentage (98%). Since VSS was tested to determine the level of organic “microbial mass” that will be available to treat dissolved organic waste in incoming waste [22-24], therefore we can say that as the TBC value increases, VSS value also increases, and this correspond to a high removal of organics.

However, IETS 1 too has a high value for TBC which is 2,700,000 CFU mL\(^{-1}\) but its VSS is quite low with only 558 mg L\(^{-1}\). The COD removal is poor too which showed an increased in COD concentration instead of removal. Hence, although both TBC and VSS should represent the amount of bio-agent present in the wastewater, only VSS appeared to be correlated to the performance of organics removal. This might be due to the presence of various types of microorganisms in the effluent tested. Some of the microorganisms might not be able to resist the environment during the TBC analysis. The colonies might not grow, too tiny, or require several days to be examined from the agar surface. Apart from that, error during the TBC techniques might also contributes to the end data as the experiment is fairly challenging.

IETS 2 and IETS 6 have high COD removal percentage which is 98% respectively. They both too have high VSS values of 58,454 mg L\(^{-1}\) and 19,116 mg L\(^{-1}\). Hence, we suggest that VSS is a better representative parameter to indicate the performance of organics removal. Contreras et al. [25] supported the result by reporting the observation of a linear relationship between VSS values and COD for samples obtained from the laboratory-scale activated sludge treatment system.

The presence of several bacteria in the effluent samples perform positive roles in the treatment of the wastewater which contributed to high removal efficiencies of the parameters evaluated. Floc-forming bacteria such as Aerobacter, Citromonas and Pseudomonas initiate floc formation in most stages of IETSs and are able to remove fine solids and heavy metals from the waste stream. Apart from that, floc-forming bacteria also oxidize soluble carbonaceous BOD and resulted in high removal of BOD. Nutrients such as nitrogen, phosphorus and trace elements allow nitrifying bacteria to multiply and led to the efficient oxidation of nitrogenous BOD [26]. Methane-forming bacteria such as actaeoelastic methanogens, hydrotrrophic methanogens and methyltrophic methanogens stabilize waste through methanogenesis in anaerobic digesters and anaerobic ponds [27].
CONCLUSIONS

The experimental results from the present study indicated that IETS 6 has the most effective biological treatment for POME. The removal efficiencies for BOD₅, COD and SS in IETS 6 were 99.60%, 98.23%, 98.72% respectively. Evaluation on stages to stages removal efficiency also proved that IETS 6 has the best treatment performance. Apart from that, IETS 6 also complied with the prevailing national discharge standard in terms of BOD₅, OG and SS limit. The processes that make up the IETS 6 were the mixing ponds, the open-tank anaerobic digesters, the ponding system and the extended aeration, coupled with fixed packing in activated sludge aeration tank. The study too further suggested that VSS is a good indication for COD removal from the POME.

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1. Missing.


