Jurnal
Teknologi

Full Paper

TREATING PALM OIL MILL EFFLUENT BY ACTIVATED SLUDGE PROCESS USING SUBMERGED MECHANICAL AERATOR/AGITATOR REPLACING SURFACE AERATOR

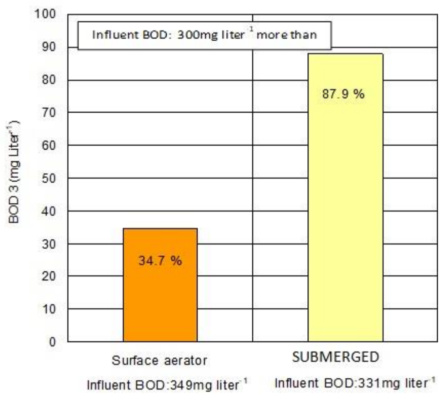
Yahaya Hawari[a*], Wira Jazair Yahya[b], Ikuma Sonda[c], Hirotaka Kawashima[c], Zahari Mohamad[b], Muhammad Aiman Abu Bakar[b], Hasannuddin Abd Kadir[b]

[a]Malaysian Palm Oil Board (MPOB), 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia
[b]Vehicle System Engineering, Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
[c]Hanshin Engineering Co., Ltd., 2-26-7 Shikanjima, Konohana-ku, Osaka 554-0014, Japan

Article history
Received
12 September 2018
Received in revised form
4 March 2019
Accepted
5 March 2019
Published online
18 April 2019

*Corresponding author
yayahawari@mpob.gov.my

Graphical abstract



Abstract

Activated sludge process (ASP) is gaining recognition as a process technique for the control of biological oxygen demand (BOD) in palm oil mill effluent (POME). Surface aerators or diffusing plates are often used in aeration tanks serving as core of the ASP. For consistent improvement in water quality within the aeration tank utilising the ASP and in particular, mitigating its BOD effluent stream, this study replaced the surface aerator with submerged mechanical aerator/agitator incorporating separate "agitation function" and "agitation diffusing function" intended for use in aeration tank of polishing plant that contains surface aerators. In order to confirm the activated state of the sludge in the aeration tanks, sludge was observed by microscopy (magnification 600 × or lower). The water analysis, POME, BOD, ammonium, and total nitrogen were analsyed. As a result of the study, improvement in water quality criteria including the agitation state in the aeration tank, mixed liquid dissolved oxygen, and BOD were observed. The BOD has improved from 34.7% to 93.1% at a maximum removal rate.

Keywords: Activated sludge method, aeration, agitation, palm oil, palm oil mill effluent

Abstrak

Proses enapcemar yang diaktifkan (ASP) semakin mendapat pengiktirafan sebagai teknik proses untuk mengawal keperluan oksigen biologi (BOD) di dalam cecair buangan (efluen) kilang kelapa sawit. Pengayun permukaan atau plat penyebaran sering digunakan di dalam tangki pengudaraan yang berfungsi sebagai teras ASP. Bagi peningkatan mutu air yang konsisten dalam tangki pengudaraan yang menggunakan ASP khususnya dalam mengurangkan BOD dalam aliran effluent, kajian telah dijalankan melalui demonstrasi menggantikan pengayun permukaan dengan pengayun/penyebaran mekanikal terendam yang menggabungkan fungsi pengadukan dan pengadukan penyebaran secara asing, bertujuan untuk penggunaan di dalam tangki pengudaraan kilang penggilap yang mempunyai pengayun permukaan. Untuk mengesahkan keadaan enapcemar yang diaktifkan dalam tangki pengudaraan, enapcemar diperhatikan oleh mikroskopi (pembesaran 600 x atau lebih rendah). Analisis air, POME, BOD, jumlah ammonium, dan nitrogen dianalisis. Keputusan kajian mendapati terdapat penambah baikan di dalam kualiti kriteria air termasuklah keadaan adukan di dalam tangki pengudaraan, oksigen terlerai cecair campuran, dan BOD. BOD lebih baik daripada 34.7% kepada 93.1% pada kadar pembuangan maksima.

Kata kunci: Kaedah enapcemar aktif, pengudaraan, pengadukan, kelapa sawit, efluen kilang kelapa sawit

1.0 INTRODUCTION

With the expansion of palm oil consumption in global market, the palm oil industry has grown to be a key industry in Malaysia, especially in export which makes up 23.29 million tonnes of the total export value of the primary industry in the year 2016 [1]. Meanwhile, the environmental problems caused by the expansion of the palm oil industry, especially water pollution in rivers, are due to deforestation and biodiversity of the river basin. The administrative authority, Department of Environment (DOE), which is under the control of the Ministry of Natural Resources and Environment, had employed the execution policies for the advancement in processing and circulative utilisation of Palm Oil Mill Effluents (POME), the enhancement of the Environmental Quality Act (1974) (tightening of the effluent standard), enhancement of control activities (legal compliance monitoring), and improvement in water quality (improvement in water quality in rivers, etc.). In the Environmental Quality (Prescribed Premises) (Crude Palm-Oil) Regulations 1977, tightening of regulations of the Biological Oxygen Demand values which is a representative index in the environmental regulations regarding POME has been considered [2].

In the 1978 environmental regulation regarding POME, BOD in unprocessed POME was required to be lowered from 25,000 mg liter^{-1} to BOD 5,000 mg liter^{-1} as the first generation regulation, and to BOD 100 mg liter $^{-1}$ presently. Improvement efforts to reduce BOD to 50 mg liter^{-1} are in progress. In places where wastes are discharged into rivers, a progress in research and development to achieve the target BOD 20 mg liter^{-1} is expected. The oxidation pond (lagoon) method, whereby facility and operation management expenses are low, has been employed as the BOD processing technique for POME of biological origin for many years [3]. Along with the reduction in discharge standard, the effluent standard cannot be met by the oxidation pond process; therefore, transition to the aerobe / ASP is taking place. When POME is processed by ASP, it is processed until it has an inflow BOD of about 500 to 1000 mg liter^{-1} by anaerobic lagoon or the like in the preceding stage, and is then further subjected to BOD reduction with aerobic organisms (activated sludge). Therefore, in the BOD reduction by ASP, efficient aeration and agitation in the aeration tank where aerobic reactions occur are essential.

A diffuser or a surface aerator has been normally employed as air diffuser in the aeration tank. These air diffusers are considered to be the cause that prevents the BOD reduction from being continuously stabilised due to instability of the aerobic organisms caused by excessive or insufficient aeration, or deposition of sludge caused by insufficient agitation [4]. A diffuser generates minute air bubbles and has high aeration efficiency in clean water. However it is known to have a low vapour-liquid oxygen transfer rate in sewage [5]. This is because the agitation stream of the diffuser is only upward and the oxygen retention time in the aeration tank is insufficient. The oxygen supply function is halted due to the blockage of bubble generating sludge, which does not occur in clean water. Continuous stable processing in the aeration tank becomes difficult due to sludge deposition at the bottom of the tank (see Figure 1). The surface aerator performs oxygen dissolution by agitation on the surface of the water. When the water is deep, the agitation does not reach the bottom of the aeration tank, and sufficient aeration cannot be formed. In addition, the agitation flow velocity is uneven, which causes a concentration gradient of activated sludge within the tank and forms sludge deposition at the bottom of the tank. Since actual aeration capacity (reaction capacity) decreased due to sludge deposition, stable aeration in the aeration tank and formation of agitation became difficult, as with the diffuser (see Figure 2).

Figure 1 Clogging of diffuser

Figure 2 Scattering wastewater/sludge of surface aerator

Air diffusers have the same aeration and agitating functions thus efficient processing functions cannot be performed in the aeration tanks. Therefore, even if they employ ASP, the aeration tank used as the key device becomes unstable, and ASP does not fully function, thereby continuous BOD processing cannot be expected. As a solution for these problems, we conducted an investigation on the aeration and agitation states by a diffuser and surface aerator, for the purpose of realising stable BOD processing in aeration tank of ASP. In order to realise efficient aeration and agitation, any improvement in an aeration tank using a submerged mechanical aerator and agitator which has separate "agitating function" and "agitating diffusing function" were examined.

2.0 METHODOLOGY

The process flow and specification of the polishing plant in which a surface aerator is installed in the ASP is shown in Figure 3 and Table 1. The POME production of the target polishing plant is 54 m^3 hour^{-1} (1296 m^3 day^{-1}), and the hydraulic retention time (HRT) of the same plant is 1.8 days. The aeration system served as a process flow of a standard ASP having three aeration tanks, and each aeration tank has one surface aerator installed therein.

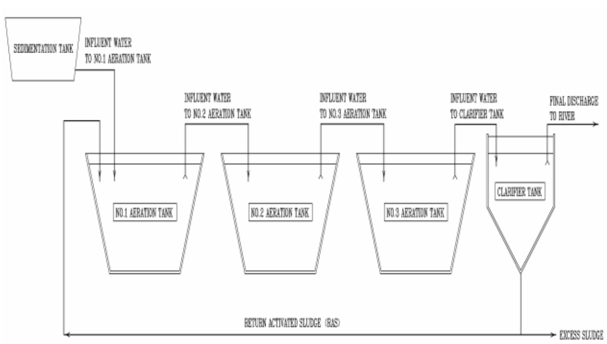


Figure 3 Specification of activated sludge method (ASM) for polishing plant

2.1 BOD and COD

Various water analytical results on the processing state of POME from the polishing plant are shown in Table 2. Herein, the water quality analysis of POME was conducted just before replacing the surface aerator with the submerged mechanical aerator/agitator, and the analysis is based on [6]. The influent has BOD of 349 mg liter^{-1} and COD of 1320 mg liter^{-1}, while the final effluent reading were 228 mg liter^{-1} and 843 mg liter^{-1}, respectively. This state indicates that the biological activities by ASP was not functioning and the values were left at high levels. As for ammonium, nitrification reaction was inadequate indicating insufficient oxygen supply for the nitrification process in the aeration tank. The total amount of nitrogen content has been reduced, due to denitrification reaction that could have occurred as a result of insufficient agitation, adsorption caused by deposition of sludge, and other reasons. Mixed liquid dissolved oxygen value was as low as 0.39 to 0.13 mg liter^{-1}. Since it is 0.1 mg liter^{-1} or lower especially at the bottom of the tank, deposition of sludge can be predicted [7].

Table 1 Specification of aeration system for polishing plant using surface aerator

Material	Value
POME to Aeration tank	54 m^3 hr^{-1} (1296 m^3 day^{-1})
Treatment system	Activated sludge method(ASM)
Aeration tank (AT)	
Number of aeration tank	3 tanks
Tank size	Upper : Length 1 = 18.5 m Width 2 = 18.5 m Lower : Length 2 =11.3 m Width 2 =11.3 m Water depth = 3. 6 m
Tank volumes	771 m3 tank^{-1}
Total tank volumes	2313 m^3 3tanks^{-1}
HRT	1.8 day (43 hr)
Existing aeration device	Surface aerator 15 kW 2 units 11 kW 1 unit (Total: 3 units)

Note: Upper: Surface area
Lower: Bottom of tank area
HRT: Hydraulic retention time
Note: Upper: Surface area
Lower: Bottom of tank area
HRT: Hydraulic retention time

Table 2 Parameter of water quality for polishing plant using surface aerator

Parameter	Unit	Value
Influent BOD	mg liter^{-1}	349
Effluent BOD	mg liter^{-1}	228
Influent COD	mg liter^{-1}	1320
Effluent COD	mg liter^{-1}	843
Influent Ammonium	mg liter^{-1}	125
Effluent Ammonium	mg liter^{-1}	21.5
Influent total nitrogen	mg liter^{-1}	157
Effluent total nitrogen	mg liter^{-1}	73
MLDO		
No.1 aeration tank	mg liter^{-1}	Upper 0.39 Lower 0.07
No.2 aeration tank	mg liter^{-1}	Upper 0.21 Lower 0.08
No.3 aeration tank	mg liter^{-1}	Upper 0.39 Lower 0.13
Operating temperature of waste water	deg C	28.1 to 29.5

Note: Upper: Surface area
Lower: Bottom of tank area

2.2 Design Parameter

A case study of submerged mechanical aerator and agitator was conducted using a surface aerator with ASP being employed. Submerged mechanical aerator/agitator was used as a submerged mechanical aerator and agitator (Figure 4). The aeration capability was examined from the POME parameter (see Table 3).

Table 3 Design parameter of case study for polishing plant

Parameter	Unit	Design value
Influent BOD	mg liter^{-1}	500
Effluent BOD	mg liter^{-1}	20
BOD removal rate	%	95
MLDO	mg liter^{-1}	2.0
MLSS	mg liter^{-1}	2500
Operating temperature of waste water	deg C	28
Aeration devise installation water depth (as water depth)	m	3.6

Note: Target tank specification is based on L1=18.5m W1=18.5m (L2=11.3m W2=11.3m) WD=3.6m for 1 tank.

Number of aeration tanks: 3 tanks
MLDO: Mixed Liquor Dissolved Oxygen
MLSS: Mixed Liquor Suspended Solid

The surface aerators in the polishing plant of Table 1 were replaced with three submerged mechanical aerator/agitator and installed therein. The features of the submerged mechanical aerator/agitator and their specifications for polishing plant are shown in Figure 4 and Table 4. Product is a submerged mechanical aerator/agitator installed in both aerobic tank and anaerobic tank. Bubbles were formed which mixed with the liquid through the aeration tank.

Advantages

1. The submerged mechanical aerator/agitator separates the power source for the 2 main functions for aeration which are supplying air and agitation/aeration.
2. The submerged mechanical aerator/agitator is able to operate with flexibility either for aerobic agitation or anaerobic agitation.
3. The simple design is suitable for ponding system.
4. No scattering of wastewater/sludge and free from noise/vibration.

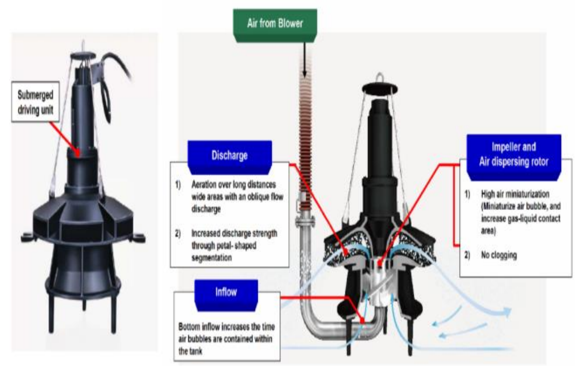


Figure 4 Appearance and feature of submerged mechanical aerator/agitator

The mixed liquor suspended solids (MLSS) and flow velocity were measured in the respective aeration tanks using the surface aerator and submerged mechanical aerator/agitator to investigate the actual states of agitation. The measurement parts in the aeration tanks were the surface, middle, and the bottom of the tank by using Yellow Springs Instruments YSI 58 membrane DO probe and Iijima Electronics Corporation IM 100 P probe.

Table 4 Specification of submerged mechanical aerator/agitator for polishing plant

Material	Value
SUBMERGED	
Type	F-75 (Motor power : 7.5kW)
Number of units	3 units (1 unit per aeration tank)
Air flow volumes from blower	6.7 m3 min (to each SUBMERGED)
Performance (SOTR)	21.7 kgO2 hr^{-1} per unit

Note: SOTR: Standard oxygen transfer rate

The aeration performance was determined by examining through comparison the ASP with the surface aerator. For the evaluation of ASP using the submerged mechanical aerator/agitator, inflow BOD of 200mg liter^{-1} or higher was used as targets, and comparative examination was performed with various analysis results of water qualities such as MLDO and other criteria such as BOD, COD, ammonium, and T-N. The measurement points of MLDO was one point which is the midway of the depth of water in each of the aeration tanks 1 to 3, and the measurement points of BOD, COD, ammonium, and total nitrogen were seven points: influent, aeration tanks 1 to 3, after clarifier, and the final discharge point of POME. The measurement points of SS were two points: after clarifier and the final discharge point of POME.

The aeration tanks in the polishing plants using ASP employing a diffuser or a surface aerator were measured for MLDO, MLSS and Flow velocities to investigate their aeration and agitation. The measured parts of each of the aeration tanks were divided into two portions: the surface and the bottom of the tank (see Table 1) by using Yellow Springs Instruments YSI 58 membrane DO probe and Iijima Electronics Corporation IM 100 P probe. Yellow Springs Instruments YSI 58 membrane DO probe was used for measuring MLDO. Iijima Electronics Corporation IM 100 P probe was used for measuring MLSS. JFE Advantech Co., Ltd. ACM3-RS was used for measuring flow velocity. In order to confirm the activated state of the sludge in the aeration tanks, sludge was observed by microscopy (magnification 600 × or lower). The water analysis, POME, BOD, COD, SS, ammonium, and total nitrogen were analysed in accordance with [6-9].

3.0 RESULTS AND DISCUSSION

3.1 MLDO and MLSS, and Flow Velocity

The results of MLDO, MLSS, and flow velocity of the aeration tank are shown in Table 5. In the measurement of M1 using a diffuser, the following results were obtained: MLDO: 4.5 to 6.0 mg liter^{-1}, MLSS: 500 to 600 mg liter^{-1}, and flow velocity: 0.179 to 0.576 m sec^{-1}. Although the oxygen required for aerobic biodegradation was efficiently maintained when MLDO was within the range from 1 to 3 mg liter^{-1} by ASP, it was confirmed that the aeration state of M1 such that excessive aeration was performed and the aeration state was inappropriate. As a result, MLSS concentration showed that the concentration of the activated sludge was too low [8, 10, 11] which supposedly indicate that the sludge balance was disturbed by the shortage of aerobic organisms. It was confirmed that there was a gap of flow velocities, which possibly showed that stirring by the diffuser was not fully performed.

In the measurement using the surface aerator, the results were as follows: MLDO: 1.44 to 5.46 mg liter^{-1}, MLSS: 1170 to 1200 mg liter^{-1}, and flow velocity: 0.185 to 0.281 m sec^{-1}. The MLSS concentration and flow velocity were generally in the appropriate ranges, indicating that the agitating state was good. However, the MLDO distribution revealed that excessive aeration was performed as in M1. These results seem to show that a proper aeration state cannot be controlled by the surface aerator if there is a variation in concentration of the inflow BOD [5]. The results of the measurement at M3 that used the surface aerator were as follows: MLDO: 4.7 to 5.96 mg liter^{-1}, MLSS: 6120 to 6500 mg liter^{-1}, and flow velocity: 0.097 to 0.243 m sec^{-1}. The MLDO results revealed that, as in M1 and M2 locations, excessive aeration was performed; therefore, the aeration state was excessive. MLSS concentrations were too high in general, which showed that appropriate control in the sludge concentration was not achieved. In addition, it was confirmed that sludge deposition was formed in the lower part of the tank, which prevented sufficient agitation in the entire aeration tank [5].

Table 5 Results on different aeration tank conditions

Location	Aeration device	Items		
		MLDO (mg liter^{-1})	**MLSS (mg liter^{-1})**	**Average flow velocity (m sec^{-1})**
M1	Diffuser	6.5 (Upper) 4.6 (Lower)	600 (Upper) 500 (Lower)	0.576 (Upper) 0.179 (Lower)
M2	Surface aerator 15 kW 3 units	5.46 (Upper) 1.44 (Lower)	1200 (Upper) 1170 (Lower)	0.185 (Upper) 0.281 (Lower)
M3	Surface aerator 15 kW 3 units 5.5 kW 2 units	5.96 (Upper) 4.7 (Lower)	6500 (Upper) 6160 (Lower) 27500 (One part of lower)	0.243 (Upper) 0.097 (Lower)
M4	Diffuser	7.42 (Upper) 0.11 (Lower)	120 (Upper) 40000 and more (All parts of lower)	0.143 (Upper) 0.091 (Lower)
M5	Surface aerator 15 kW 2 units 11 kW 1 unit	0.87 (Upper) 0.17 (Lower)	1350 (Upper) 40000 and more (All parts of lower)	0.386 (Upper) 0.070 (Lower)

Note: Location: Polishing plant
Upper: Surface area
Lower: Bottom of tank area

The results of the measurement at M4 using the diffuser were as follows: MLDO: 0.11 to 7.42 mg liter^{-1}, MLSS on the surface: 200 mg liter^{-1}, and flow velocity: 0.091 to 0.143 m sec^{-1}. As in the other locations (M1 to M3), it was confirmed that excessive aeration was performed. The results of excessively low MLSS concentration revealed to be an appropriate value as ASP was not maintained. In addition, sludge decomposition of MLSS 40000 mg liter^{-1} or higher was confirmed, and no agitation flow velocity was observed at the bottom of the tank. It was therefore confirmed that stirring was not sufficiently performed and that aeration capacity (reaction capacity) was reduced.

The results of the measurement at M5 using the surface aerator were as follows: MLDO: 0.17 to 0.87 mg liter^{-1}, and MLSS on the surface: 1350 mg liter^{-1}, wherein at the bottom of the tank, MLSS value higher than 40000 mg liter^{-1} was observed. The result of the flow velocity was 0.070 to 0.386 m sec^{-1}. Value measured at the bottom of the tank for MLDO was 0.11 mg liter^{-1}, lower than MLDO on the surface, and therefore it was revealed that the aeration in the tank was insufficient. The sludge deposition at the bottom of the tank was confirmed from the high MLSS concentration and low flow velocity at the bottom of the tank. This means that the aeration capacity (reaction capacity) had reduced as in M4.

From the above investigation, aeration could not be controlled since the surface aerator and diffuser performed aeration and stirring simultaneously and sludge deposition was formed at the bottom of the tank due to insufficient stirring in the tanks. This could have made the BOD reduction process unstable. In order to realise appropriate aeration and agitating state for POME, it was considered desirable to separate the agitating function and the diffusing function. As earlier mentioned, the Standard Oxygen Requirement (SOR) required for the BOD process in the aeration tank of M5 was 74.5 kg O_2 / hour (see Table 2). The optimal model of submerged mechanical aerator/agitator which satisfied this SOR and its aeration performance are shown below. When the blowing operation of the F-75 was performed from a blower at an air flow volume of 8.3 m^3 min^{-1}, the treated water of BOD removal rate was 95 %, i.e., BOD effluent of 20mg liter^{-1} was obtained.

Suitable model for submerged mechanical aerator/agitator:

- Model: F-75 (7.5kW)
- Range of air flow volumes: 3.2 to 12.9 m^3 min^{-1}
- Quantity: 3 units (1 unit per tank)

Surface aerator and submerged mechanical aerator/agitator both on the surface and the middle layer were agitated in the range from MLSS 1350 to 1630 mg liter^{-1}. However, values as high as 40000 to 44000 mg liter^{-1} were detected at the bottom of the tank in the surface aerator which revealed that with sufficient agitation, the deposition of sludge within the tank occurred continuously [11](see Figure 5). It was confirmed that with the submerged mechanical aerator/agitator, the interior of the aeration tank were entirely agitated since the concentration distribution at the bottom of the tank (MLSS 1460 mg liter^{-1}) were similar to those of the surface and middle layers.

3.2 Flow Velocity

The average flow velocity distribution of the surface aerator is shown in Figure 6. The average flow velocity was 0.386 m/sec on the surface, 0.162 m/sec in the middle layer, and 0.07 m/sec at the bottom of the tank, which indicates that the deeper the water depth became, a great difference in the flow velocity was created in the tank. Since the flow velocity was especially low at the bottom of the tank, it is presumed that sludge had accumulated as indicated by the MLSS concentration distribution.

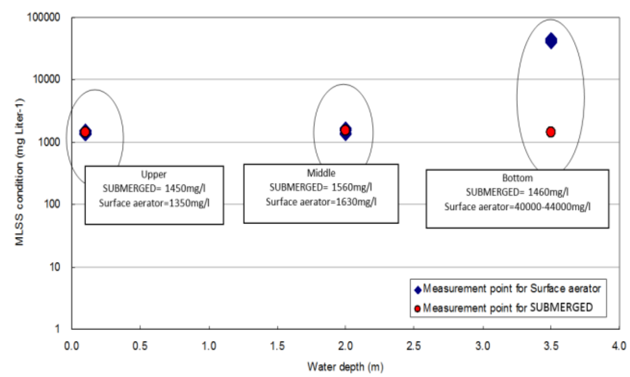


Figure 5 Comparison of MLSS condition in aeration tank

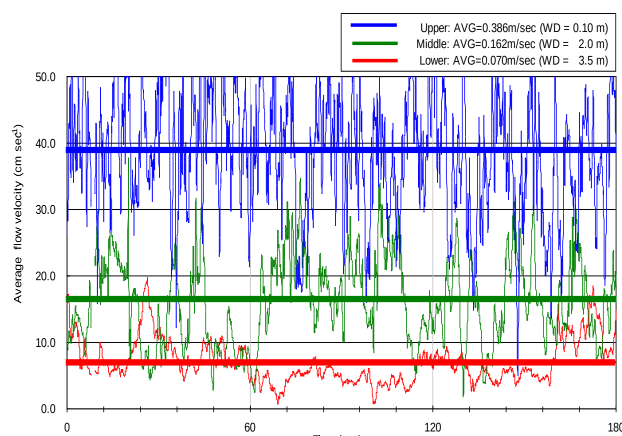


Figure 6 Flow velocity for surface aerator in aeration tank

Meanwhile, the flow velocity distributions of the submerged mechanical aerator/agitator (see Figure 7) were 0.296 to 0.320 m/sec on the surface, in the middle layer and at the bottom, respectively, with no significant difference. Therefore, it was found that the entire liquid in the tank were agitated to cause turbulence from the waveform of each velocity. It was therefore confirmed that there was no deposition of sludge at the bottom of the tank due to sufficient agitation [11, 12]. The above investigation on the agitation state by determining MLSS and flow velocity showed that the surface aerator provided good agitation state on the surface layer, but it reduced the aeration capacity (reaction capacity) as the agitation flow failed to reach the bottom of the tank, resulting in the formation of sludge deposition. It was confirmed that the submerged mechanical aerator/agitator which causes a turbulent flow state by underwater agitation was effective in solving agitation problem [12].

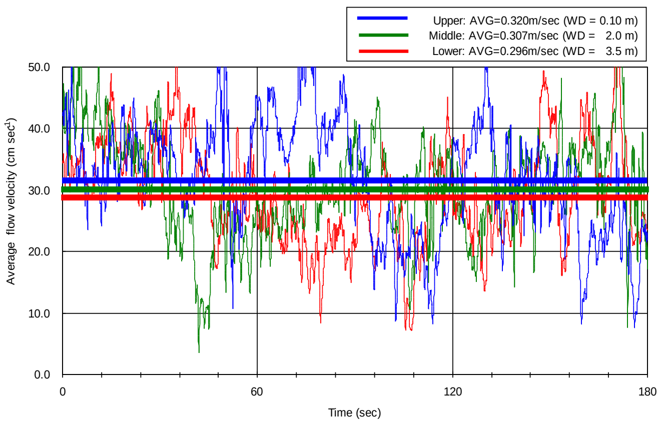


Figure 7 Flow velocity for submerged mechanical aerator/agitator in aeration tank

The analysis results for MLDO were 0.3 to 0.98 mg liter-1 in Aeration tank 1, 3.5 to 6.51 mg liter-1 in Aeration tank 2; 6.0 to 7.59 mg liter-1 in Aeration tank 3 (see Figure 8). In Aeration tank 1, since oxygen consumption by biodegradation and nitrification reaction were in progress [13] a value as low as 0.3 to 0.98 mg liter-1 were obtained. The changes in MLDO in Aeration tanks 2 and 3 presumably resulted from oxygen consumption by respiration of the activated sludge in the tanks and the decomposition of organic matters [13, 14] with low reaction rates in Aeration tank 3. With the aeration by the surface aerator, the values were 0.39 to 0.13 mg liter-1 in the respective aeration tanks and in particular, 0.1 mg liter-1 or lower at the bottom of the tank, which showed that MLDO was improved by aeration in the submerged mechanical aerator/agitator. Herein, the standard control ranges of MLDO by ASP were usually 3.0 mg liter-1 or lower [15]. Therefore, the surface aerator cannot control MLDO, but it is thought that the submerged mechanical aerator/agitator can be managed by controlling the amount of air blown by the blower.

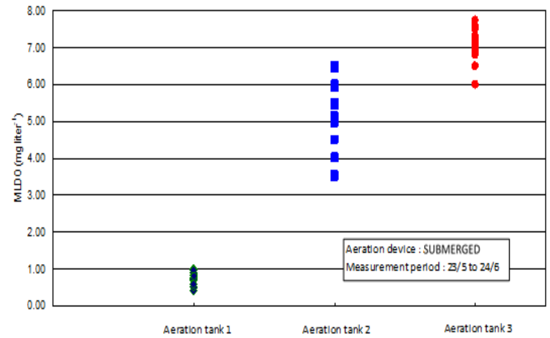


Figure 8 Variation of MLDO concentration in aeration tank 1 to 3

3.3 BOD and COD

The analytical results of BOD and COD are shown in Figures 9 and 10. From the BOD and COD concentration distributions, the biological process of POME by ASP was found to be primarily reduced over time. Although the concentration of the influent was not constant, the results for BOD were 21 to 48 mg liter-1, and for COD they were between 74 to 231 mg liter-1 for the final effluent. The comparisons of concentration variation and removal rate of influent BOD (more than 300 mg liter-1) between surface aerator and submerged mechanical aerator/agitator are shown in Figures 11 and 12. The removal rate was greatly improved between submerged mechanical aerator/agitator (84.1 to 93.1%), and the surface aerator was (34.7%). It was confirmed from these results that stable BOD process can be performed by replacing the surface aerator with the submerged mechanical aerator/agitator.

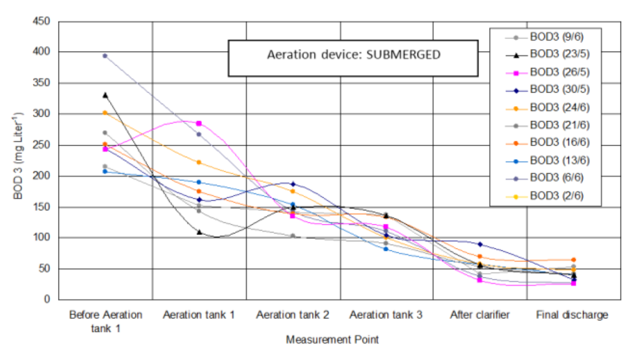


Figure 9 Variation of BOD concentration in aeration system

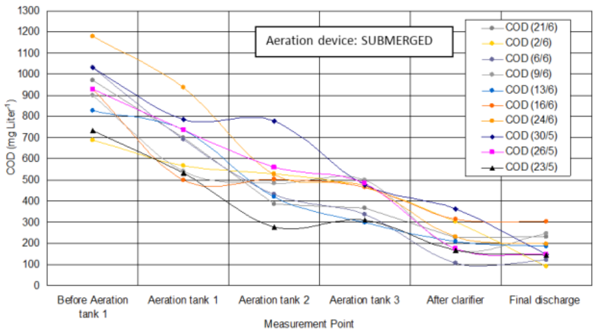


Figure 10 The variation of COD concentration in aeration system

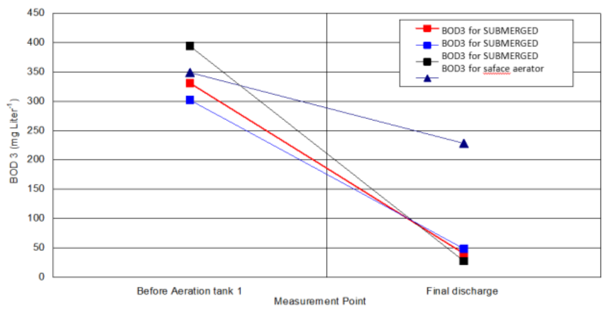


Figure 11 Comparison of the variation of BOD concentration between surface aerator and submerged mechanical aerator/agitator

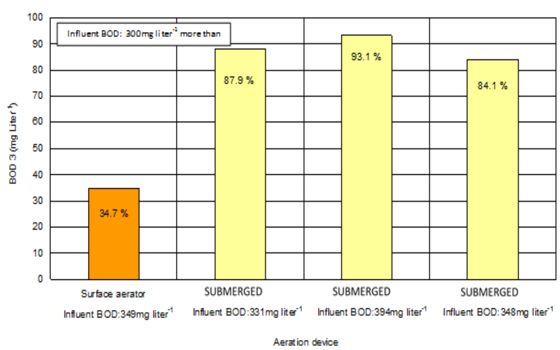


Figure 12 Comparison of the removal rate of the BOD concentration between surface aerator and submerged mechanical aerator/agitator

Since 97 to 99% of nitrification reaction was completed in Aeration tank 2, it was believed that oxygen supply necessary for a reaction was adequate [16] (see Figures 13 and 14). As a result, the concentration of total nitrogen was lower in the aeration tanks although it was under aerobic conditions. This is presumably due to denitrification reaction from partial anaerobic conditions caused by long HRT simultaneously taking place even under aerobic conditions. The partial anaerobic condition mentioned herein means that MLDO turned into anaerobic atmosphere in the process of biological degradation immediately after BOD flowed into Aeration tank 1, and that the inside of the floc of the activated sludge was partially under anaerobic conditions so that denitrification reaction can occur. These were inferred from the MLDO concentration in Aeration tank 1. These results showed that oxygen required for nitrification reaction of ammonium content was insufficient with the surface aerator, but ammonium was greatly reduced from the viewpoint of oxygen supply. With the submerged mechanical aerator/agitator, and separation of the "agitation function" and the "agitation diffusing function"; formation of a denitrifying atmosphere depending on the state of water quality was possible, while it was uncontrollable with the surface aerator. Therefore, it was considered that aeration performance suitable for the respective process purposes could be produced.

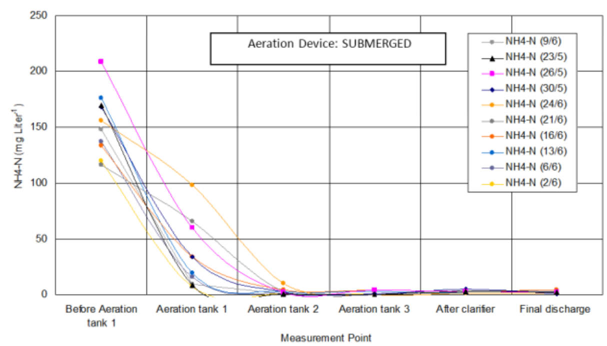


Figure 13 Variation of ammonium concentration in aeration system

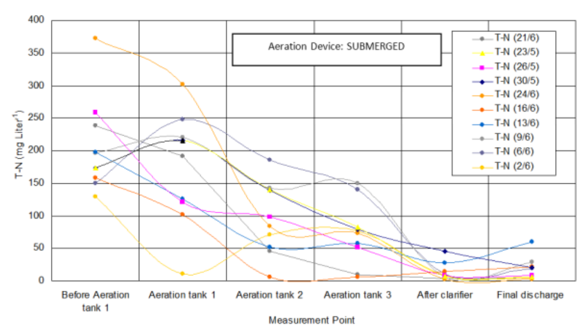


Figure 14 Variation of total nitrogen concentration in aeration system

It was confirmed from the SS concentration of treated effluents result of 100 mg liter^{-1} or lower that sedimentation separation was performed satisfactorily as well as functioning as clarifier (see Figure 15).

3.4 Microscopic

In order to confirm the activated state of the sludge in the aeration tanks, sludge was observed by means of microscopy (see Figure 16). Although the floc was rather small, protozoa such as Vorticella, Arcella, Trochilia, Euglypha were found to be present, and the results showed favourable conditions for these protozoa. With the presence of a variety of microorganisms which usually appeared when the process was successful, it was confirmed that sufficient degradation of organic matters took place along with nitrification. As the examination of improvement in aeration was conducted by replacing the surface aerator with the submerged mechanical aerator/agitator in which the "agitation function" and the "agitation diffusing function" were separated, focusing on various water quality criteria. The surface aerator was unable to perform various water quality processes since it has low MLDO and insufficient function as an aeration tank. However, by adding a "agitation diffusing function" to the "agitation function" of the submerged mechanical aerator/agitator and MLDO in the aeration tank, various water quality criteria, especially BOD improved.

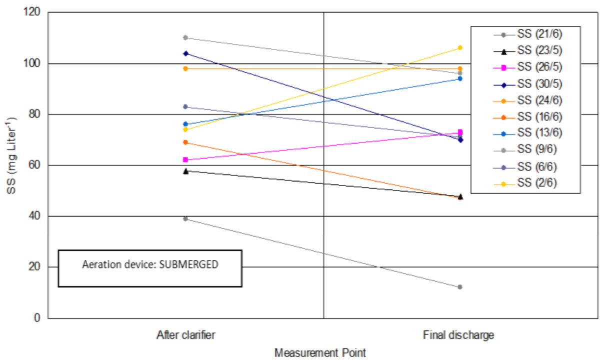


Figure 15 Effluent of *SS* concentration

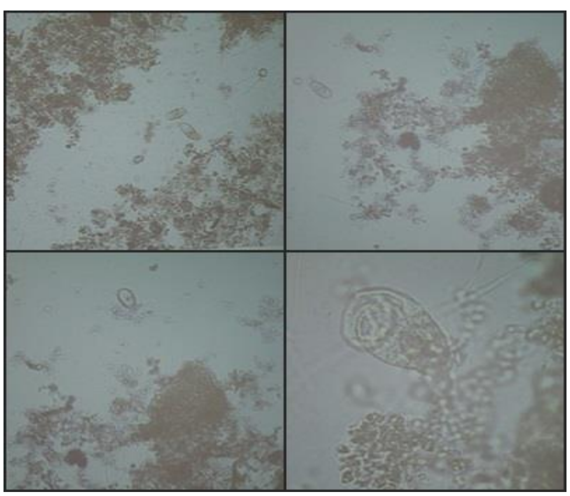


Figure 16 Microscopic image of activated sludge

4.0 CONCLUSION

For the purpose of realising consistent BOD processing in the aeration tank using ASP, aeration by a diffuser, and a surface aerator as well as agitating state were investigated. It was confirmed that the diffuser and surface aerator cannot control optimal aeration state. The agitating state had not attained a complete state of mixing in the tank with deposition of sludge observed at the bottom of the tank. Since these air diffusers had aeration and agitating functions performed by the same component, they cannot perform efficient processing capability in the aeration tank. It was inferred that the aeration tank used as the core device was unstable even if ASP was employed, and that continuous BOD process was not expected. Using the submerged mechanical aerator/agitator in which the "agitating function", and the "agitating diffusing function" were separated, a case study of aeration and stirring was performed.

As a result of the investigation of the MLSS and flow velocity by replacing the surface aerator with the submerged mechanical aerator/agitator, the agitation state in the aeration tank was found to have greatly improved, and the MLDO, various water quality criteria, especially the BOD reduction process improved from 34.7% to 93.1% at a maximum as a result of accelerated removal rate by adding the "agitation diffusing function". Although POME improvement was attempted targeting on the aeration tanks of ASP, stable POME process required controlling the operation flow of the whole ASP including the aeration tank which serves as a core. It is considered that submerged mechanical aerator/agitator which can control the "agitation function" and "agitation diffusing function" allowed construction of a stable ASP including variations in the inflow load change, and seasonal variations that can contribute to the POME treatment process.

References

[1] Kushairi, A. 2017. *Malaysian Palm Oil Performance 2016 and Future Prospects for 2017*. http:// www.mpob.gov.my/images/stories/pdf/2017/2017_Dr.Kus hairiPALMEROS2017.pdf, accessed in September 2017.

[2] Enforcement Division, Department of Environmental Malaysia. 2013. Malaysia's Requirements on Industrial Effluent Treatment Systems. The WEPA Workship and Annual Meeting 18th – 21st February 2013. 14-15.

[3] Soh, K., L. Mei, E., L. Muzzammil, N. Weng, S., L. Yuen, M., C. Zhenjia, Z. Jumat, S. 2013. Zero Discharge Treatment Technology of Palm Oil Mill Effluent. *Journal of Oil Palm Research*. 25(3): 273-281.

[4] Busby, S., J., W. Thomas, C., M., and Brown, N., L. 2013. *Molecular Microbiology*. Birmingham: UK-Springer.

[5] Kumar, S., R. 2007. *Efficiency of Aeration System in Wastewater Treatment Plants*. Universiti Teknologi Malaysia.

[6] American Public Health Association (APHA). 2005. *Standard Method for Examination Of Water And Wastewater*.

[7] Flanders, K., R. Reich, R. Himelreich, L., E. Gary, G., James, W., M. Harry, W. H. 1994. The Impact of Alpha on the Feasibility of Fine Bubble Diffusers in Industrial Wastewater. *Proceedings of the 49th Industrial Waste Conference*. Purdue University.

[8] Ma, A., N. Lee, K., M., and Choo, K., C. 1988. Full Scale Sequencing Batch Reactor Treatment of Palm Oil Refinery Wastewater. *PORIM Bulletin*.

[9] Ibrahim, A., H. Dahlan, I. Adlan, M., N., and Dasti, A., F. 2012. Comparative Study on Characterization of

Malaysian Palm Oil Mill Effluent. *Research Journal of Chemical Sciences*. 2(12): 3.

[10] Damayanti, A. Ujang, Z. Salim, M., R., and Olsson, G. 2011. The Effect of Mixed Liquor Suspended Solids (MLSS) on Biofouling in a Hybrid Membrane Bioreactor for the Treatment of High Concentration Organic Wastewater. *Water Science and Technology*. 63(8):1701-1706.

[11] Alam, M., Z. and Fakhru'l-Razi, A. 2002. Effect of Agitation an Aeration on Bioconversion of Domestic Wastewater Sludge in a Batch Fermenter. *Journal of Environmental Science and Health. Part A, Toxic/Hazardous Substances & Environmental Engineering*. 37(6): 1087-1097.

[12] Neyestanak, A., A., L. Tarybakhsh, M., R., and Daneshmand, S. 2017. Study on the Effect of Jet Velocity on Mixing Performance and Sludge Prevention in Large-Scale Crude-Oil Tanks by the CFD Technique. *Journal of Chemists and Chemical Engineers of Croatia*. 66(6): 229-239.

[13] Winconsin Department of Natural Resources. 2012. Advanced Activated Sludge Study Guide. *Wisconsin Department of Natural Resources: Wastewater Operator Certification*.

[14] Adonadaga, M. 2015. Effect of Dissolved Oxygen Concentration on Morphology and Settleability of Activated Sludge Flocs. *Journal of Applied & Environmental Microbiology*. 3(2): 31-37.

[15] MPOB. 2017. Economic and Industry Development Division. http://bepi.mpob.gov.my.

[16] Ecos Environment Consultants Limited. (2013, March 22). Wastewater Nitrification: How it works. [web log post] Retrieved from http://www.ecos.ie/wastewater-nitrification-how-it-works/.