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THE COMBINATION OF AIR FLOTATION AND A MEMBRANE BIOREACTOR FOR THE TREATMENT OF PALM OIL MILL EFFLUENT

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ABSTRACT

The combination of baffled air flotation and a membrane system for the treatment of palm oil mill effluent (POME) was studied. The POME was obtained from a palm oil factory in PTPN I Tanjong Seumantoh, Aceh, Indonesia. Operation variables and conditions, such as the hydraulic retention time and air flow rates, were varied to find the optimum process. The air flotation process is able to reduce the concentration of suspended solids and fats/ oils contained in the wastewater, which increases the performance of the membrane by reducing clogging. The results showed that this method was promising for POME treatment. The optimum organic removal efficiency of the air flotation pretreatment was obtained at HRT = 5 days and at an air flow rate of 11 L/min. The effluent was subsequently passed through an anaerobic membrane system to achieve the highest removal efficiency treatment. The removal efficiency of chemical oxygen demand (COD), total suspended solids (TSS), turbidity, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), and fats/oils after passing through the membrane system were 97%, 93.9%, 99.8%, 94.5%, 96.2%, and 99.9%, respectively. The results also showed that the pH could be neutralized to 6.18, while a dissolved oxygen (DO) level of 1.60 mg/L could be achieved. A high quality of effluent was obtained, which met the standards for POME effluent.

Keywords: Air flotation; COD; Membrane; POME; Removal efficiency; Wastewater

1. INTRODUCTION

The palm oil industry in Indonesia has grown significantly in the last few decades. As an agrarian country, Indonesia has significant potential for palm plantations and has become the world's biggest palm oil producer since 2006. Along with Malaysia, Indonesia controls almost 90% of the world's palm oil production. As the palm oil processing industry in Indonesia's agroindustry continues to expand, the pollution issue also increases. Pollution resulting from POME could degrade water quality and indirectly harm the environment and human health. This is due to the high content of organic materials in POME, including a biochemical oxygen demand (BOD) of approximately 10,250–43,750 mg/L and chemical oxygen demand (COD) ranging from 15,000 to 100,000 mg/L. It is also fairly acidic, with pH ranging from 4.0–5.0 and has a high content of fats/oils, including high levels of suspended solids and other dissolved substances (Baranitharan et al., 2013; Ahmad et al., 2003).

In general, POME is processed conventionally using aerobic and anaerobic ponds (Harsono et

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al., 2014; Basri et al., 2010; Kusrini et al., 2016). This process requires a large area and prolonged retention time. Such processing can reduce BOD and COD of wastewater by 85%–95% (Thanh, 1980). Many palm oil mills in Indonesia and Malaysia have employed a ponding system to treat their effluents. The method requires a prolonged retention time of the liquid to reduce the organic content of the effluent and the suspended solids to approximately 95%, making the process inefficient. In addition, anaerobic ponds also come with several disadvantages, such as the release of unpleasant odors, the possibility of groundwater contamination around the pond, unusable methane as a by-product of the process, and the need for periodic maintenance to discharge the sludge accumulated at the bottom of the pond (Azmi & Yunos, 2014; Liew et al., 2015; Budhijanto et al., 2015; Sunarsih et al., 2015). Thus, it is necessary to seek an alternative processing unit for use in the medium-scale industry that is economically feasible but that still maintains the expected effluent quality. Researchers have developed a POME processing method that includes drying and adsorption (Ahmad et al., 2005a,b), crop irrigation, animal fodder, decanting, skimming, coagulation evaporation, photocatalytic degradation (Cheng et al., 2015), and various aerobic and anaerobic biodegradation methods (Poh & Chong, 2009; Vijayaraghavan et al., 2007; Faisal & Unno, 2001).

One of the new waste treatment methods uses membrane technology (Mutamim et al., 2013; Wu et al., 2010; Zhang et al., 2008; Kartohardjono et al., 2015). A pilot study on POME treatment, which includes an anaerobic process for biogas production followed by membrane removal, was carried out and produced significant results with a BOD effluent level of 20 mg/L (Tabassum et al., 2015). The membrane method treatment provided some advantages. For example, a higher quality of waste could be recovered in the process, and it involved a shorter period and required a smaller area. Yet the method also had some disadvantages, such as a short membrane life, the high possibility of clogging, and a high maintenance cost (Ahmad et al., 2006; Metcalf & Eddy, 2003).

To address these issues, a modification of the membrane process was necessary. A previous study that used micro-bubble flotation combined with a coagulation system was able to reduce the level of COD to 93% (Poh et al., 2014). The use of dissolved air flotation for POME treatment was more efficient than chemical flocculation (Ho & Tan 1989). Pretreatment with the air flotation system was required to extend the life and improve the membrane performance, which could bring optimal results. The flotation process was selected because it was suitable for wastes with a high content of fats and oils. Some researchers have reported that the dissolved air flotation method has been widely used in industrial and domestic waste treatment with significant results (Zhang et al., 2014; Oliveira & Rubio, 2012; Edzwald, 2010; Palaniandy et al., 2010; Zlokarnik et al., 1998).

So far, only a few studies have been conducted on CPO waste treatment with a combination of flotation and a membrane process. Various membrane materials have been used to treat CPO waste. The use of anaerobic digestion and aerobic biodegradation in combination with ultrafiltration (UF) and reverse osmosis (RO) membrane units could result in COD efficiency reductions up to 93% (Zhang et al., 2008). Other studies using polysulphone, polyethylsulphone, polyvinylidene, and UF membranes (Ahmad et al., 2005c, Ahmad et al., 2003) to treat POME have also been carried out. This study focused on POME treatment using a chlorinated polyethylene (PE) sheet membrane combined with air flotation.

2. MATERIALS AND METHODS

POME was taken from the effluent unit of PTPN I palm oil mill in Tg. Seumantoh, Aceh Tamiang, Aceh. The characteristics of the waste were analyzed before it was used in the processing. The parameters tested included pH (HI-98128, Hanna Instrument, UK), turbidity (HACH 2100P, USA), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), total suspended solids (TSS), chemical oxygen demand (COD) (HI-839800, Hanna Instrument, UK and HACH DR-2800,USA), DO (HI-98193, Hanna Instrument, UK), and oils/fats content (OCMA 310, Horiba, Japan). The parameters were measured according to the standard method for industry disposal quality analysis (APHA, 2005). The parameters were analyzed at the output of the air flotation reactor and after passing the membrane unit.

The air flotation tank was a baffled tank made of glass with dimensions of 80 cm long, 16.5 cm wide, and 16 cm high. A schematic diagram of the flotation and membrane process is shown in Figure 1. The screen separates the reactor into several rooms. The effluent in the first room overflows to the next room in stages. The first and the second rooms were aerated to float the suspended solids that had a density lighter than that of the liquid, and the oils/fats contained in the effluent. The floating suspended solids and oils/fats were then separated. The solids with higher densities than the liquids precipitated to the third, fourth, and fifth rooms by gravitation. The retention times of the liquid in the flotation reactor were three, four, and five days. The air flow rates of the flotation were 11, 8, and 5 L/minute without aeration. The output from the flotation tank was then pumped into the membrane unit.

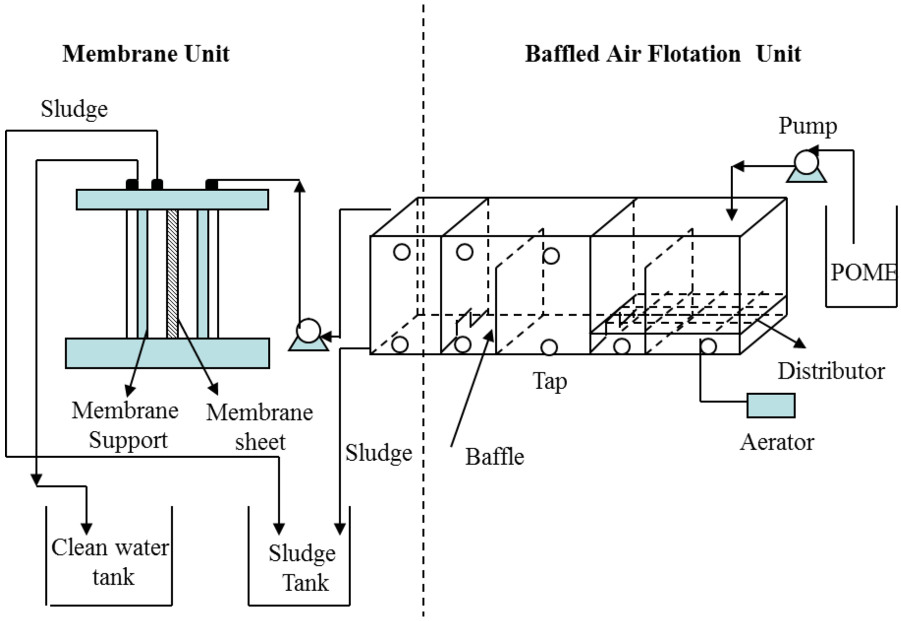

Figure 1 The schematic diagram of the flotation and membrane process

The membrane module used in this research was a flat sheet membrane made of chlorinated polyethylene with a nominal pore size of 0.4µm, which was produced by Kubota, Japan (Kubota Corp., 2005).

3. RESULTS AND DISCUSSION

3.1. Removal Efficiency at the Flotation Stage

3.1.1. COD removal efficiency

One of the criteria for success of the flotation process was by measuring the COD removal efficiency. The removal of COD contained in POME was highly influenced by the retention time of the liquid and air flow rates. Table 1 shows the influence of liquid retention time on the efficiency of the removal of waste parameters at various air flow rates in the flotation tank. The initial COD content in POME entering the flotation tank was approximately 20,000 mg/l. The

COD removal efficiency achieved from the retention time of five days with air flow rates of 11 L/min, 8 L/min, 5 L/min, and without aeration were 35.5%, 36.1%, 26.8%, and 26.6% respectively. These results were lower than that obtained using micro-bubble flotation, where the COD removal efficiency reached 53.7% (Poh et al., 2014). The air flow rate of 8 L/min produced higher removal results because the particles that increased COD in the waste were floated and discharged during the collection of fats/oils. However, higher air flow rates led to liquid turbulence in the flotation tanks, resulting in complete contact between the air and the particles. On the contrary, when the air flow was too low, only a few particles floated.

Table 1 The efficiency of the removal of waste parameters at various air flow rates and liquid retention time at the flotation stage

Retention time (day)	Air flow rate (L/min)	Removal Efficiency					
		COD (%)	TSS (%)	Turbidity (%)	MLSS (%)	MLVSS (%)	Fats/Oils (%)
3	11	30.1	63.2	55.2	61.7	64.1	35.4
	8	31.0	36.7	50.3	66.2	67.8	28.5
	5	25.4	27.9	43.5	48.5	50.8	23.8
	0	21.1	13.7	14.1	28.8	32.4	10.3
4	11	31.8	54.7	54.7	60.6	60.8	30.1
	8	33.6	37.3	53.7	63.3	63.6	21.6
	5	25.9	24.7	47.0	55.1	56.5	19.3
	0	24.6	20.5	20.6	42.8	44.3	10.3
5	11	35.5	86.4	57.7	57.3	59.7	52.6
	8	36.1	40.6	60.3	69.0	69.8	47.3
	5	26.8	35.5	48.2	58.8	59.9	38.8
	0	26.6	29.2	30.6	47.2	47.7	12.7

3.1.2. Fats/oils removal efficiency

One way to remove or minimize the fats/oils content in the effluent is by flotation, where the air is aerated into the waste. Since fats/oils have a lower density, contact with the air makes them float easily. Fat is classified as a fixed organic material and is difficult to be decomposed by bacteria. Fats/oils are one of the main compositions in palm oil mill effluents, in addition to essence, sugar, carbohydrate, and lignin. Biodegrading fats/oils through the use of bacteria is most difficult, since not all bacteria produce the lipase enzyme that can decompose fats/oils. Thus, the hydrolysis reaction of fat/oil decomposition is slower than other substances.

For this study, the correlation of retention time and air flow rate in fat/oil removal efficiency is shown in Table 1. It can be seen that with a retention time of five days and an air flow rate of 11L/min, the highest result of 52.6% was obtained, where the initial content of fats/oils in POME was about 3,780 mg/L. The result achieved was far lower than that with micro-bubble flotation, which could separate fats/oils to 74.5% (Poh et al., 2014). Meanwhile, effluent treatment using flotation without the aeration method with a retention time of five days reached only 12.7% in fat/oil removal efficiency. This was due to higher air flow rates for the fats/oils contained in the waste, resulting in more fat/oil floating on the surface of the flotation tank and making it easy to separate. Effluent treatment without aeration would only float a small amount of fats/oils.

3.1.3. MLSS removal efficiency

The MLSS removal in the effluent was influenced by the retention time and the air flow rates applied. The influence of the retention time on MLSS removal efficiency at various air flow rates is shown in Table 1. The initial MLSS value in POME was approximately 1,150 mg/L. The MLSS removal efficiency at five days reached 69.0% and 57.3% at air flow rates of 8 L/min and 11 L/min, respectively. High air flow rate resulted in incomplete contact of air and solids. The efficiency for a retention time of five days with an air flow rate of 5 L/min and without aeration resulted in 58.8% and 47.2% of MLSS removal, respectively. Low air flow rates only floated small amounts of solids and reduced the removal efficiency.

3.1.4. MLVSS removal efficiency

In general, Table 1 shows that the longer the retention time of the effluent in the flotation tank, the higher the removal efficiency obtained (except at 11 L/min). With a retention time of five days and an air flow rate of 8 L/min, the removal efficiency was 69.8% (the initial MLVSS value was approximately 900 mg/L). Additionally, the air flow rate applied to the flotation tank highly influenced MLVSS removal, as high air flow rates led to incomplete contact between the air and the solid that the percentage of removal decreased, as shown in Table 1. With a retention time of five days and an air flow rate of 11 L/min, the efficiency reached 59.7%.

3.1.5. TSS removal efficiency

The flotation process was carried out by introducing air bubbles into the effluent to float the suspended solids. Table 1 shows the relationship between the retention time and airflow rates on TSS removal efficiency. A high TSS removal efficiency of 86.4% was achieved with a retention time of five days and an air flow rate of 11 L/min from the initial TSS value of 2,150 mg/L. The removal efficiency was quite significant when compared to the use of the micro-bubble from a venture tube, as reported by Poh et al. (2014). This was due to a significant amounts of air applied, leading to significant amounts of floating suspended solids that were easy to separate. Meanwhile, a retention time of five days without aeration resulted in a removal efficiency of 29.2%. This was due to the absence of the air supply, as only a small amount of suspended solids floated.

3.1.6. Turbidity removal efficiency

Turbidity in the effluent was caused by suspended solids contained in the waste. Turbidity removal was necessary because it could become a burden in the receiving water body. The percentage of turbidity removal depended largely on the air flow rate applied to the liquid waste, which allowed it to float the suspended solids for removal. Table 1 shows the percentage of removal efficiency from a retention time of five days with an air flow rate of 8 L/min reaching 60.3%. Meanwhile, with a retention time of five days and an air flow rate of 11 L/min, the percentage decreased to 57.7%. In five days of retention time and without aeration, the removal only reached 30.6%.

3.1.7. The influence of retention time and air flow rates on dissolved oxygen

DO was an important parameter of water quality that was considered. Oxygen entered the water through air diffusion that was helped by aeration. Aeration could increase DO concentration in the water. High concentrations of DO could contribute to water biota life. POME treatment by flotation could increase concentrations of DO in the wastewater, as aeration in the flotation process could transfer oxygen from the air to the wastewater. The increase of DO concentration was also affected by the retention time in the flotation tank, which prolonged the contact between air and the wastewater. Figure 2 shows the correlation of retention time and air flow rates to the DO output. It showed that the concentration of the DO increased with a retention time of five days with an air flow rate of 11 L/min (i.e., 1.48 mg/L), where the initial DO of the wastewater was 0.57 mg/L. Although this represented a threefold increase compared to the initial DO, the increase in DO was still insignificant because of the higher amount of organic content in the wastewater (initial COD of 20,000 mg/L).

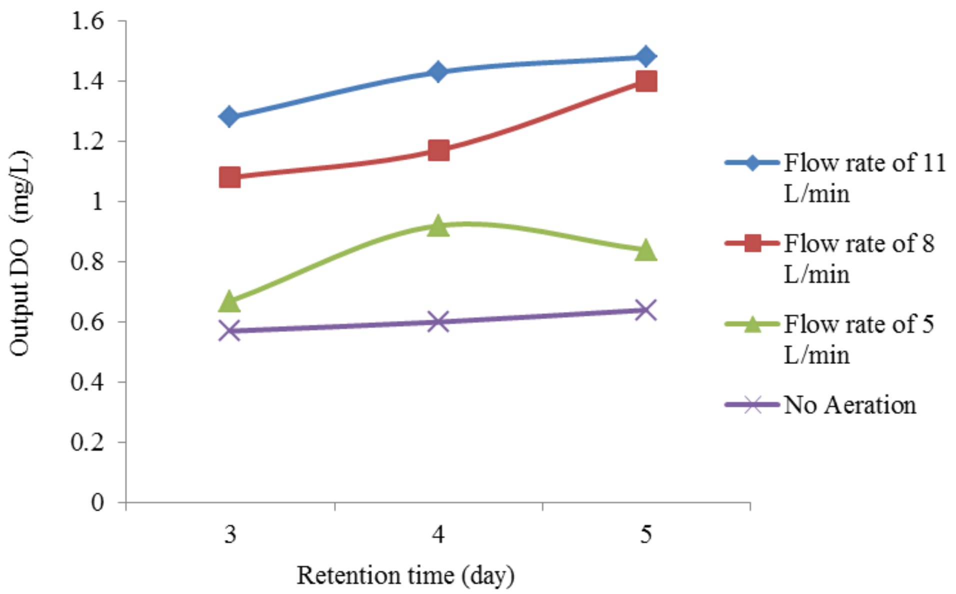

Figure 2 The change of DO at various air flow rates and retention times

3.2. Removal Efficiency with a Combination of Flotation and Membrane

The POME treatment with the membrane was performed from the flotation output involving five days of retention time and at air flow rates of 5 and 11 L/min.

3.2.1. COD removal efficiency

After passing through the membrane, the removal percentage of the organic contents in the waste was far beyond that of the flotation process. Table 2 shows some waste removal efficiency parameters using the flotation and membrane modification with air flow rates of 5 and 11 L/min. It can be seen that the flotation treatment of effluent resulted in COD removal efficiency rates of 26.8% and 35.5% for air flow rates of 5 and 11 L/min, respectively. The effluent from the flotation treatment was then passed through the membrane reactor, which reduced the COD content in POME up to 97.1% and 97.0% for each air flow rate. This result was higher than in the previous study by Wu et al. (2010), which used a polysulphone membrane. Abdurrahman et al. (2011) reported that by using a membrane anaerobic system, a higher COD removal efficiency of 99% was obtained at the very long hydraulic retention time of 600 days. The flotation pretreatment was performed to improve the COD removal percentage in the membrane. The efficiency achieved was slightly lower than when using a combination of coagulation, ultrafiltration membrane, and reverse osmosis, where about 99% of COD could be removed (Ahmad et al., 2006).

Table 2 Removal efficiency of waste parameters after membrane treatment

Flotation retention time (day)	Air flow rate (L/min)	Removal Efficiency					
		COD (%)	TSS (%)	Turbidity (%)	MLSS (%)	MLVSS (%)	Fats/Oils (%)
5	5	97.1	98.0	99.8	90.2	92.4	99.5
	11	97.0	93.9	99.8	94.5	96.1	99.9

3.2.2. Oil/fat removal efficiency

As shown in Table 1, the percentages of oil/fat removal efficiency after the flotation treatment with air flow rates of 5 and 11 L/min were 38.8% and 52.6%, respectively. After passing the membrane reactor, almost all (over 99.5%) the oil/fat content in POME could be significantly removed (see Table 2). The PE membrane pore size (0.4μm) allowed filtering of the remaining oils or fats contained in the liquid waste, leading to high oil/fat removal efficiency. However, the use of a combination of ultrafiltration and reverse osmosis, coupled with coagulation/flocculation as a pretreatment could remove all oils and fats in the waste (Ahmad et al., 2006).

3.2.3. MLSS removal efficiency

POME contained a high level of MLSS, which made pretreatment necessary to support the membrane performance. It can be seen in Table 1 that the percentages of MLSS removal efficiency after the flotation treatment with air flow rates of 5 and 11 L/min were 58.8% and 57.3%, respectively. The result of the flotation treatment was then passed through the membrane reactor, which increased the removal efficiency of the MLSS up to 90.2% and 94.5% for each air flow rate, as seen Table 2.

3.2.4. MLVSS removal efficiency

The MLVSS removal efficiency percentages using the flotation and membrane method with air flow rates of 5 and 11 L/min are shown in Table 2. The MLVSS removal efficiency after flotation treatment was about 59%. The use of the membrane increased the MLVSS removal efficiency in POME waste up to 96%. Thus, the membrane capability was good enough to separate and filter the remaining dissolved and suspended solids contained in the effluent after the flotation pretreatment.

3.2.5. TSS removal efficiency

The TSS removal efficiency reached 98%, as seen in Table 2. Almost similar results were obtained using a polysulphone membrane (Wu et al., 2010). This was due to higher air flow rates supplied in the flotation pretreatment that could separate suspended solids in the effluent and the capability of the micro-filtration membrane to separate or filter the remaining suspended solids contained in the effluent in the flotation result. The membrane removal was an effective method to achieve the complete removal of solids from the liquid, and this method could also be employed in high sludge rates (Saddoud et al., 2007).

3.2.6. Turbidity removal efficiency

POME comes with quite high turbidity, which necessitated the pretreatment. Table 1 shows that the percentages of turbidity removal efficiency after the flotation treatment with air flow rates of 5 and 11 L/min were 48.2% L/min and 57.7%, respectively. The effluent from the flotation treatment was then passed through the membrane reactor, and increased removal efficiency percentages of up to 99.8% and 99.8% were observed for each air flow rate (Table 2). The efficiency achieved from this study was higher than that of previous studies using the polysulphone ultrafiltration membrane, which had a removal efficiency of 88.5%. (Wu et al., 2010).

3.2.7. Change of pH

The hydrogen ion (pH) concentration was an important parameter of water quality and wastewater that was considered. The pH was determined by the high or low concentration of hydrogen ion in the liquid. POME is acidic in nature, with a pH of approximately 4.05–4.6. This meant that the palm oil effluent contained a high level of hydrogen ions. If not treated, or if disposed directly into the receiving water body, the POME could lead to pipe corrosion or the destruction of water biota. The flotation treatment brought only a slight increase to the pH of the POME, and further treatment was necessary to increase the pH to between 6 and 9. The pH could be increased slightly by increasing the retention time of the liquid in the flotation tank, meaning that the longer it settled in the tank, the higher the pH achieved. This could be due to the removal of the volatile fat acid contained in the liquid.

Figure 3 shows that the flotation pretreatment with air flow rates of 5 and 11 L/min resulted in pH values of 4.79 and 4.97, respectively. After passing the membrane reactor, the pH of the effluent reached 6.14 and 6.18 for each air flow rate. This was due to the capability of the microfiltration membrane to separate volatile fatty acid particles contained in the effluent so that it increased the acidity (pH) of the effluent to a near neutral level. These results were comparable with that obtained by Yuniarto et al. (2013).

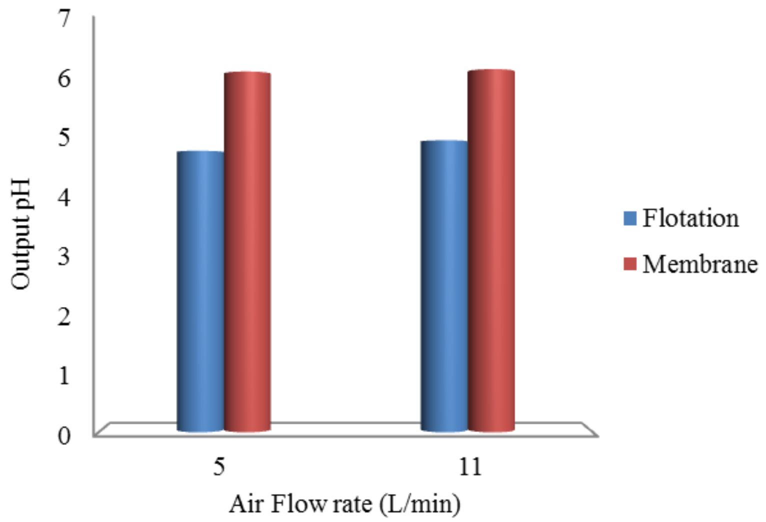

Figure 3 The change in pH after the flotation and membrane treatment

3.2.8. Change of DO

The air flow rate of 11 L/min applied to the flotation pretreatment could increase the DO of the output to 1.48 mg/L. After passing the membrane and separating the remaining organic substances contained in the effluent, it resulted in a DO reading of 1.60 mg/L, as shown in Figure 4.

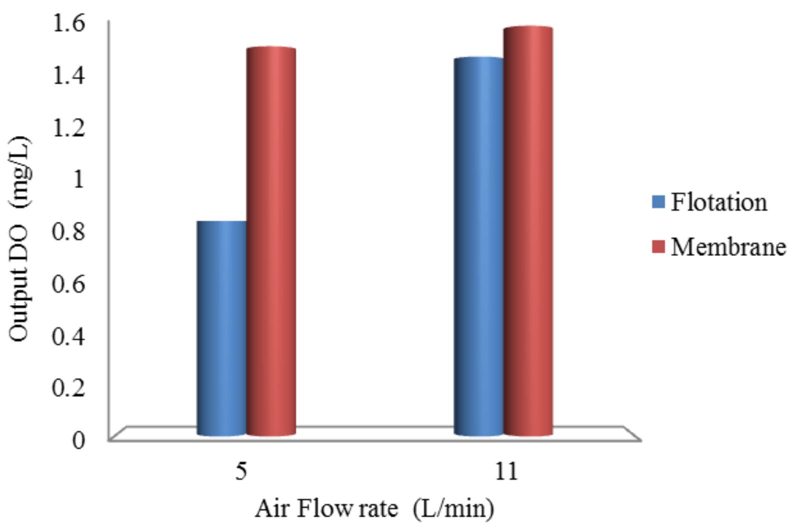

Figure 4 Change in DO after the flotation and membrane treatment

Based on the analysis in Tables 1 and 2 and Figures 1 through 4 above, the POME resulting from the current treatment could not be recovered yet as processed water. Further purification treatment was required before it could be used as processed water.

4. CONCLUSION

The percentage of organic content removal of the POME by air flotation was influenced by the retention time of the liquid and air flow rates. Pretreatment was necessary to support membrane performance. Further treatment using a PE membrane could result in higher removal efficiency. The removal efficiency rates of COD, TSS, turbidity, MLSS, MLVSS, and fats/oils from the effluent by the flotation treatment at a retention time of five days and an air flow rate of 11 L/min were 35.5%, 86.4%, 57.7%, 57.3%, 59.7%, and 52.6%, respectively. After passing through the membrane, the removal efficiency levels of COD, TSS, turbidity, MLSS, MLVSS and fats/oils reached 97.0%, 93.9%, 99.8%, 94.5%, 96.1%, and 99.9%, respectively.

5. ACKNOWLEDGEMENT

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