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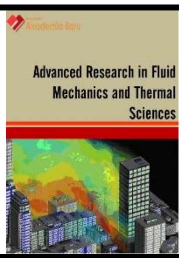

Effect of Filtered Palm Oil Mill Effluent (POME) via Close Loop In-Line Microbubbles Treatment Chamber for Biochemical Oxygen Demand (BOD) Treatment

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ABSTRACT

Palm oil mill effluent (POME) is wastewater that has brought major impact due to its high content of organic pollutant. Thus, a stringent regulation has been imposed by Malaysia's Department of Environment (DOE), where the biochemical oxygen demand (BOD) value have to be less than 20 mg/L before it is discharged into the water stream. The novelty of this research was to treat POME via a combination of closed-loop in line microbubbles treatment chamber and filter papers to reduce the BOD value. The treatment chamber was made up of translucent PVC pipe with two units of microbubbles diffuser attached under the pipeline. The air compressor and water pump were installed to supply air and to make sure the consistency the flow of water. Microbubbles were used due to great oxygen transfer coefficient at lower air flow rate. POME sample was treated based on APHA standard for 120 minutes with certain time intervals, with and without using filter paper to compare the efficiency of the treatment. Throughout the study, the smallest flow rate (1.0 L/min) has the highest BOD removal efficiency for both conditions (filtered and unfiltered). Almost 50.1%-64.2% of BOD removal efficiency can be achieved by applying filter paper for flow rate 1.0-3.0 L/min. The applications of filter papers were also one of the main reasons for BOD reduction due to rapid elimination of impurities.

1. Introduction

Palm oil, which is scientifically known as *Elaeis guineensis* was originated from West Africa. Later, the oil palm has spread throughout to South East Asia such as Malaysia, Indonesia and Thailand and considered as top commodities in these countries. Palm oil industry is considered as important agricultural industries which bring huge economic value in some tropical countries [1] .The global production of palm oil is expected to grow to around 73.5 million metric tons in the marketing year 2018/2019,

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up from approximately 70.5 million metric tons in 2017/2018. In that period, Indonesia and Malaysia were the leading exporters of palm oil worldwide. In 2017, the Roundtable on Sustainable Palm Oil (RSPO) certified area planted with palm trees in Indonesia reached 1.7 million hectares, up from 1.54 million hectares in 2016 [2].

Figure 1 shows the brownish liquid mixture of POME. Generally, POME is a brownish semi-liquid mixture and can be considered as a non-toxic waste because there are no chemicals added during the processing of oil extraction. Due to its non-toxic nature, it able to provide essential nutrients for microbes to live [3] and it can be utilized as fertilizer and animal feed substitute to provide adequate nutrients that they required. The pH of POME is approximately pH 4.5 due to organic acids produced during fermentation. As a consequence, it commonly used as organic and inorganic compounds [4]. Table 1 below shows the general properties of POME and its discharge limit according to DOE.

Fig. 1. Brownish liquid POME

Raw POME causes a lot of environmental issues due to its highly polluting wastewater. Generally, when each ton of FFB (fresh fruit bunches) are processed, a palm oil mill produces approximately 27 kg, 62 kg, 35 kg and 6 kg of BOD, COD, SS and oil and grease, respectively. Moreover, the empty fruit bunch (EFB), palm kernel shell (PKS) and mesocarp fibre are one of the examples of the wastes produced that need to be well treated, so that it does not bring negative effect towards the environment [5].

Due to the negative impact of POME, some palm oil millers treat POME and transform into methane gas that further can generate methanol [6]. Besides that, POME has a very high value of BOD and COD, which is 100 times more than the municipal sewage [7]. Thus, the DOE has imposed stringent rules on the final discharge where the BOD is decreased from 100 to 20 mg/L [8], [9]. Therefore, any technologies related to POME treatment must comply with the latest standard discharge gazetted by the DOE [10].

In 1908, biochemical oxygen demand (BOD) was selected for biological testing to determine the level of organic pollutants in the water stream by the U.K. Royal Commission on River Pollution. The reason behind the 5 days BOD test was due to the time needed to assess the requirement of the water river of to flow from upstream to downstream in United Kingdom [11]. Later on, BOD test was officially chosen by the APHA Committee as the measurement for biochemical degradation assessment [12] whereas, in 1917, this parameter was classified as Standard Methods [13]. BOD test can be defined as a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific period. It is not a precise quantitative test, although it is commonly used to test the characteristic of the organic water. It is usually expressed in milligrams of oxygen consumed per litre (mg/L) of the sample during 5 days (BOD_5) of incubation at 20°C. It also plays a vital role in assessing treatment efficiency [14].

Table 1
Characteristics of POME and standard discharge requirements of POME by DOE

Parameters	Average concentration value (Raw POME)	Average concentration value (Final discharge of POME)	Current standard discharge limit (DOE, 1982)	Future standard discharge limit (DOE, 2015)
COD (mg/L)	51 000	800	100	NA
BOD_3 (mg/L)	25 000	200	100	20
pH	9.0	4.2	5.0–9.0	5.0–9.0
Temperature (°C)	85	25	45	45
Colour (ADMI)	10 000	500	200	100
Total suspended solids (TSS) (mg/L)	18 000	130	400	200
Total nitrogen (mg/L)	750	127	200	150
Ammoniacal nitrogen (mg/L)	35	–	NA	NA
Total volatile solids (TVS) (mg/L)	34 000	–	NA	NA
Oil and grease (OG) (mg/L)	4 000–6 000	–	50	5
Manganese (mg/L)	2.0	–	10	10
Zinc (mg/L)	2.3	–	10	10
Copper, (mg/L)	0.8–0.9	–	10	10
Iron (mg/L)	46.5	–	50	50
Phosphorus (mg/L)	180	–	NA	NA
Potassium (mg/L)	2 270	–	NA	NA
Magnesium (mg/L)	615	–	NA	NA
Boron (mg/L)	7.6	–	NA	NA
Calcium (mg/L)	439	–	NA	NA
Chromium (mg/L)	10.2	–	NA	NA

Notes: There is no standard discharge for COD after 1984; BOD denotes biochemical oxygen demand; COD denotes chemical oxygen demand; ADMI denotes American Dye Manufacturers Institute; POME denotes palm oil mill effluents; NA denotes not available. Sources: [15]

Production of microbubble can be divided into three ways which are i) air is compressed to high pressure and liberating it via customized nozzle ii) ultrasonic and iii) via fluidic oscillator [16]. Microbubble mostly can eliminate a huge amount of pollutants in many types of wastewater such as oily, laundry and fishpond wastewater [17]. Moreover, microbubbles treatment is capable to increase the rate of mass transfer coefficients and improved mixing efficiency due to smaller bubble have much larger surface area compared to larger bubbles [16]. Microbubbles can generate small and tiny size bubbles as small as 50 µm in high pressure.

Filtration separates constituents dissolved in the water from detritus and other solids that may alter the chemistry of the sample before it can be analyzed. However, filtration in the field adds the possibility of sample contamination if not done carefully. Therefore, the nature of the water being sampled determines whether the greater risk is from field filtration or sample degradation before filtration at the laboratory. Samples containing large amounts of suspended solids or organic matter are the most likely to degrade before filtration at the laboratory [18].

A rapid and cost-effective technique to treat POME to generate clean and safe water before discharging into the environment for daily use is still not available to be applied on site. Very few investigations have been conducted on the aerobic digestion process for the treatment of organic pollutants present in POME [19]. Before further experiments were carried out, there are also no specific literature existed on how this fabricated close-loop in-line microbubbles treatment chamber would reduce the BOD value in treating POME. Thus, the main objective of the present study was to design a close-loop in-line microbubbles treatment chamber for POME treatment and to determine the optimum setting of the treatment chamber for maximum reduction of BOD at the shortest time. Therefore, this work represents one of combination approach on the aerobic treatment technology of POME in Malaysia.

2. Methodology

2.1 Sample Collection

Untreated POME has been collected from Palm Oil Mill Effluent Zero Discharge Green Technology Centre (POMTEC) located at Labu, Negeri Sembilan. After that, it is kept in a clean container and was brought back to the laboratory in a conveyable freezer with the temperature maintained at 4°C so that the process of biodegradation of POME and chemical reaction can be minimized [20].

2.2 Experimental Methods

The experiment was conducted at Vehicle System Engineering (VSE) Laboratory, University Technology Malaysia (UTM). Figure 2 shows the closed-loop in line microbubbles treatment chamber that was build up using translucent PVC pipe with a nominal pipe size of 12" in diameter. The chamber would be able to handle 0.292 meter cubic (approximately 292 litres) of effluent per treatment. Two units of microbubbles diffuser model 1DMBDC100 with 14.5” x 1.75” in size that has the capability to produce fine bubbles in the range size of 100-500 microns at the bubbling pressure rate of 25 to 35 psi (1.7 to 2.4 bars) are connected to Swan SVP202 2HP 85 Liter 8 Bar Air Compressor as air supplier of the system. The microbubbles diffuser it was attached to both sides of the PVC pipeline.

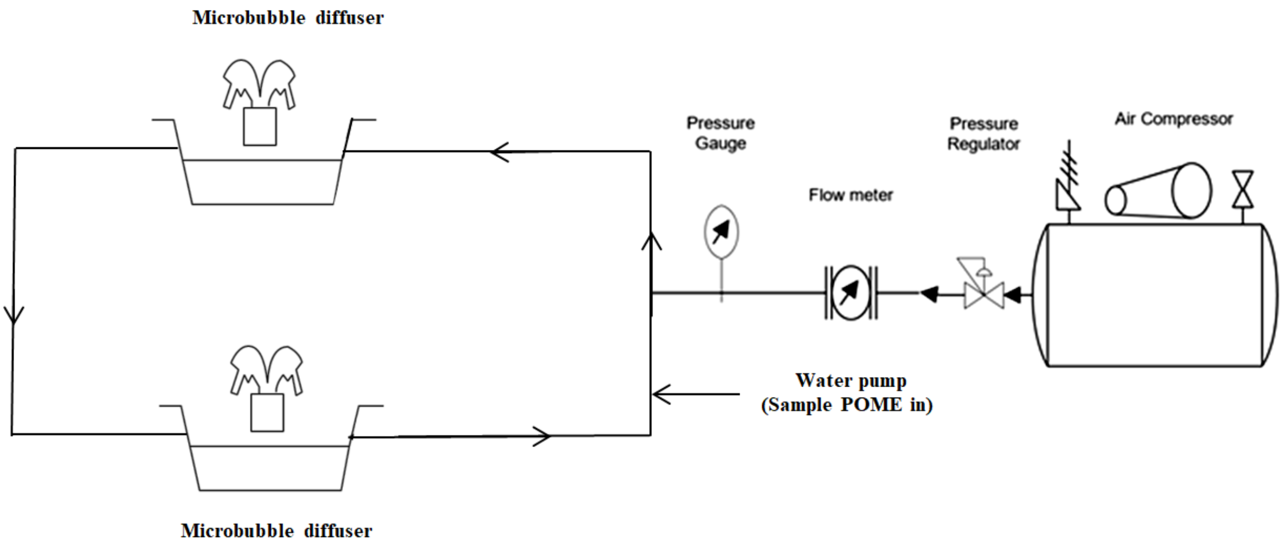

Fig. 2. Schematic diagram of a closed-loop in-line microbubbles treatment chamber

A pressure regulator is used to reduce the input pressure of air to the desired value at its output. The allowed pressure of the microbubble is set to 50 psi because it will give an impact on the size of the bubble generated. The airflow meter is also used to control the airflow measurement in L/min. Apart from that, the pressure gauge was installed with the unit of psi. Okazawa 0.5 HP 370W

Peripheral Clean Water Pump was connected at the convergence-divergence section of the chamber to ensure the flow is consistently and continuously circulated along with the chamber.

2.3 Apparatus / BOD Measurement and Characterizations

After a certain time interval, POME is then filtered using NICE Qualitative filter paper Model 101 (Fast). After that, the sample will be collected and to be handled under 5210B method (APHA standard). Time and flow rate will be monitored and recorded from the beginning of the experiment until the end. The dissolved oxygen (DO) level was consistently tested on the 0, 30, 60, 90, 120 minutes interval by using the YSI ProODO optical dissolved oxygen meter (Model 626281) at flow rate 1.0, 2.0 and 3.0 L/min, which is equivalent of 11.2, 22.4, 33.6 psi respectively (Figure 3). After measuring initial DO of the sample at an interval, the sample was left incubated in 300 ml BOD bottles for 5 days before the reading was taken for a final measurement of DO for all the intervals.

Fig. 3. YSI ProODO Dissolved Oxygen Meter

2.4 Analytic BOD Calculation

The general equation for the determination of a BOD5 value is

$$BOD_5 \text{ (mg/L)} = D_i - D_f \quad (1)$$

The BOD removal efficiency can be measured as below

$$\text{Percentage of removal of BOD (\%)} = \frac{D_i - D_f}{D_i} \times 100\% \quad (2)$$

where D_i = initial DO of the sample, D_f = final DO of the sample after 5 days of incubation

3. Results and Discussion

3.1 BOD Values

A test to study the effect of microbubbles on the reduction of biochemical oxygen demand (BOD) of palm oil mill effluent (POME) treatment has been performed at different flow rates and at several retention times. Results obtained are as per illustrated in Figure 4 and 5. The graph shows the BOD against time.

Figure 4 and 5 show the trend of BOD is decreasing against time. The lowest flow rate used for the test which is 0.5 L/min decreasing abruptly for the first 60 minutes of retention time compared to the other flow rates, 2.5 L/min and 4.5 L/min. The test observation is assumed that flow rates which also affect the bubble size imposed significance effects to the removal of BOD and this was proved in the experiment where lowest flow rate of microbubbles performed better in reducing the BOD with reduction of 26% of BOD at 60 minutes retention time. An experiment using the treatment chamber on BOD reduction of POME has been conducted at varies flow rates and at certain time intervals. As the time flow, the temperature is increasing due to the pump friction and cavitation from the treatment chamber. Thus, it is one of the reasons for BOD reduction. For filtered samples in Figure 5, the BOD values decreased significantly at 30th minutes whereas, for unfiltered samples as seen in Figure 4, the BOD reduction occurs at the first 60th minute. As we can see, 1.0 L/min gave the highest BOD reduction for both filtered and unfiltered samples, rather than flow rates 2.0 and 3.0 L/min. Generally, the sizes of microbubble are affected by the internal pressure of the bubble itself [21]. This can be described in Young-Laplace's law as below, where the change of pressure in the bubble decrease, the diameter of the bubble increases, and vice versa [22].

$$\Delta p = \frac{2\gamma}{r} \tag{3}$$

where r = local radius of curvature of the surface, γ = surface tension, and Δp = the change of pressure across the gas-liquid interface.

However, this is not applicable since the bubbles in question do not have a single liquid-gas interface, but instead have 2 (one "inside" the bubble and another "outside" the bubble). In the case of this thin-film barrier, the Young-Laplace equation becomes

$$\Delta p = \frac{4\gamma}{r} \tag{4}$$

This equation is part of what governs the shape and size of bubbles. Besides that, the characteristics and performance of microbubbles in water can be described by some other equations as such as Henry's Law and Stokes Law [23].

Moreover, the smaller size of the bubble with a large surface area produces high flotation efficiency due to high mass transfer flux [24]. This shows that the size of the microbubble is affected by the flow rates used and for an effective BOD reduction. But in this case, the minimum flow rate used gave the highest removal efficiency for both filtered and unfiltered sample. Thus, it is presumed that the impact of surface area on the BOD reduction was more significant by the impact of increasing of velocities, where the smaller size of bubbles are able to remove more BOD, but due to low rising velocities, it causes a low quantity of bubble to outreach the surface in a certain period of time. Consequently, the removal efficiency of BOD is low [25].

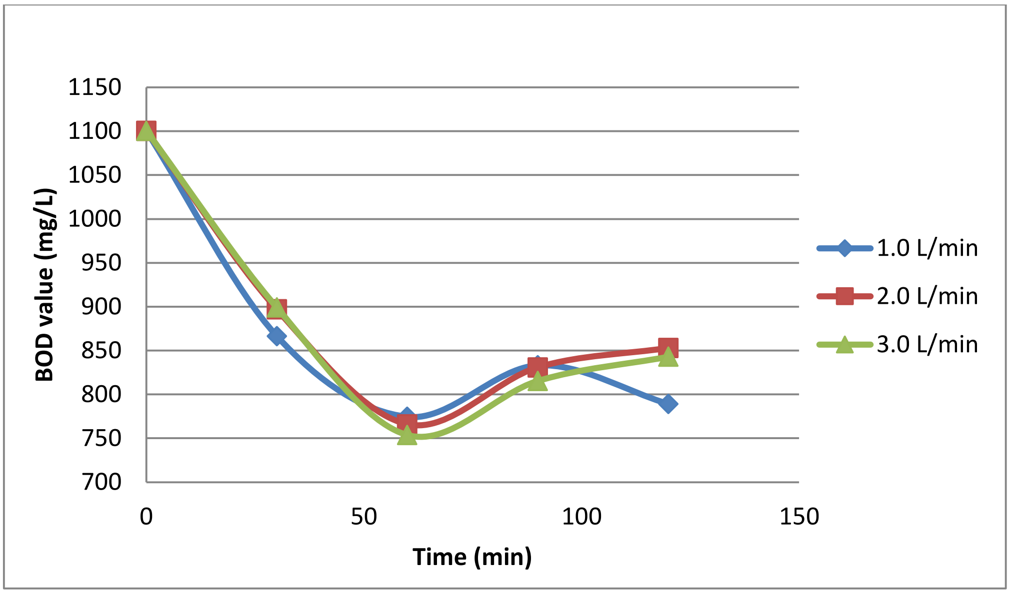

Fig. 4. BOD values of unfiltered POME against Retention Time

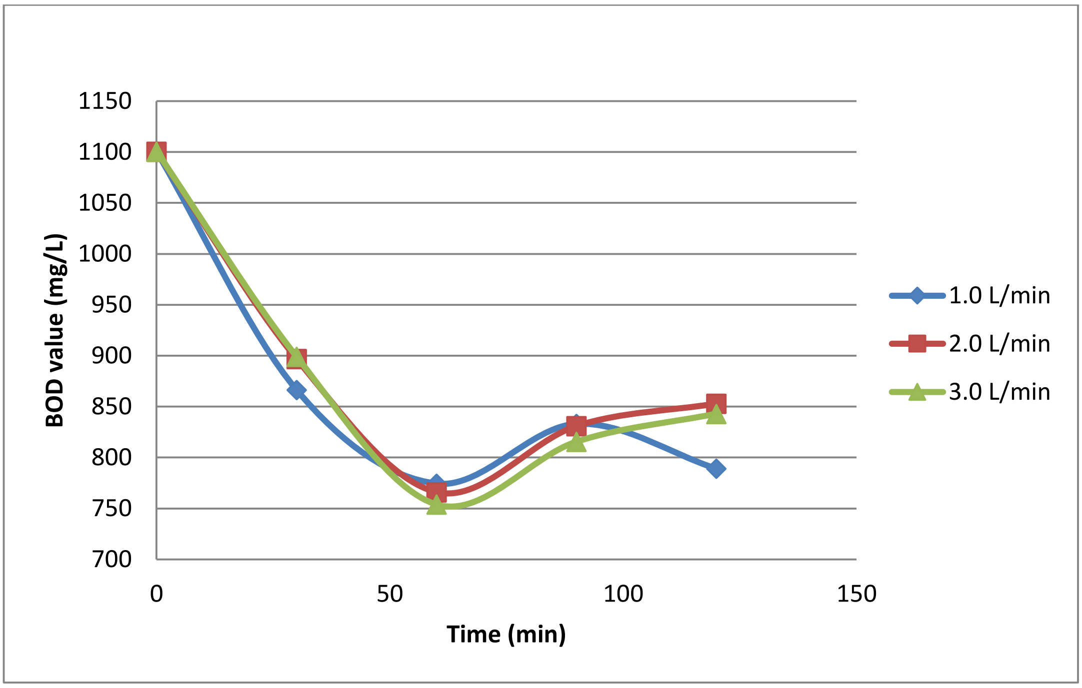

Fig. 5. BOD values of filtered POME against Retention Time

3.2 BOD Removal Efficiency

The trend of the graph in Figure 7 shows that the BOD removal efficiency of filtered POME at 30th minute can reach up to 50.1%-64.2% for the entire flow rate. Furthermore, the BOD reduction is kept constant for all flow rates from 60th to 120th minute. Apart from that, in Figure 6, the BOD reduction of unfiltered POME was increasing significantly at the first 60th minute for all flow rate and decrease after 60th minute. Thus, when using 1.0 L/min flow rate, filtered samples have a higher BOD reduction at 30th minute, which is 64.67%, whereas unfiltered samples, the BOD removal efficiency was 29.64%.

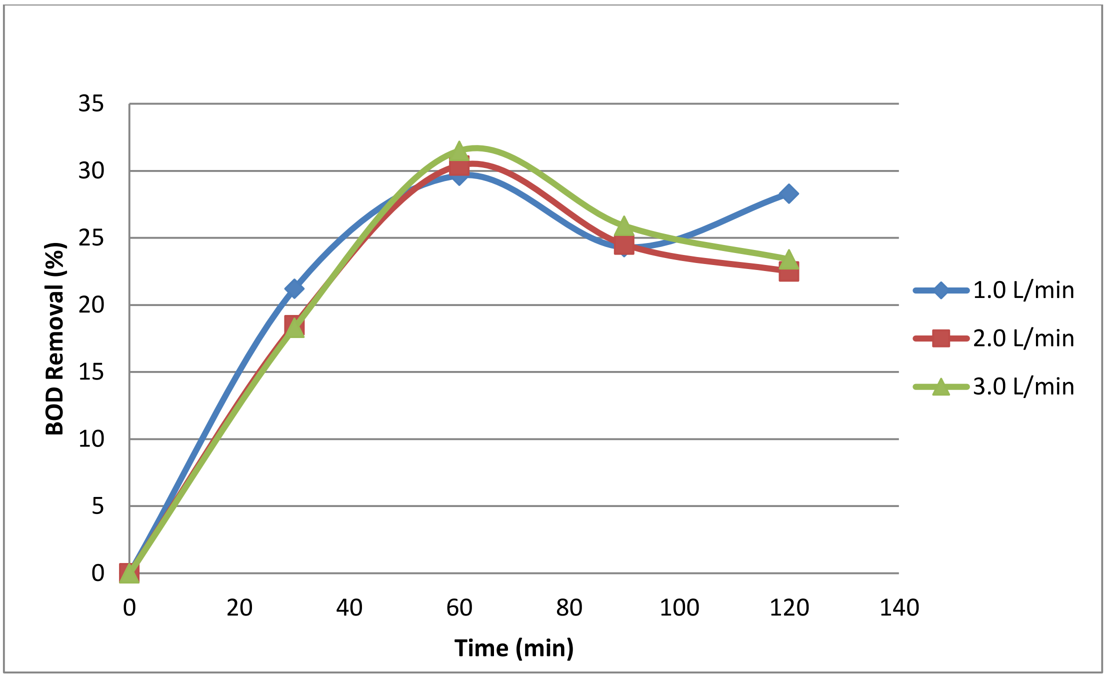

Fig. 6. BOD Removal% of unfiltered POME against Retention Time

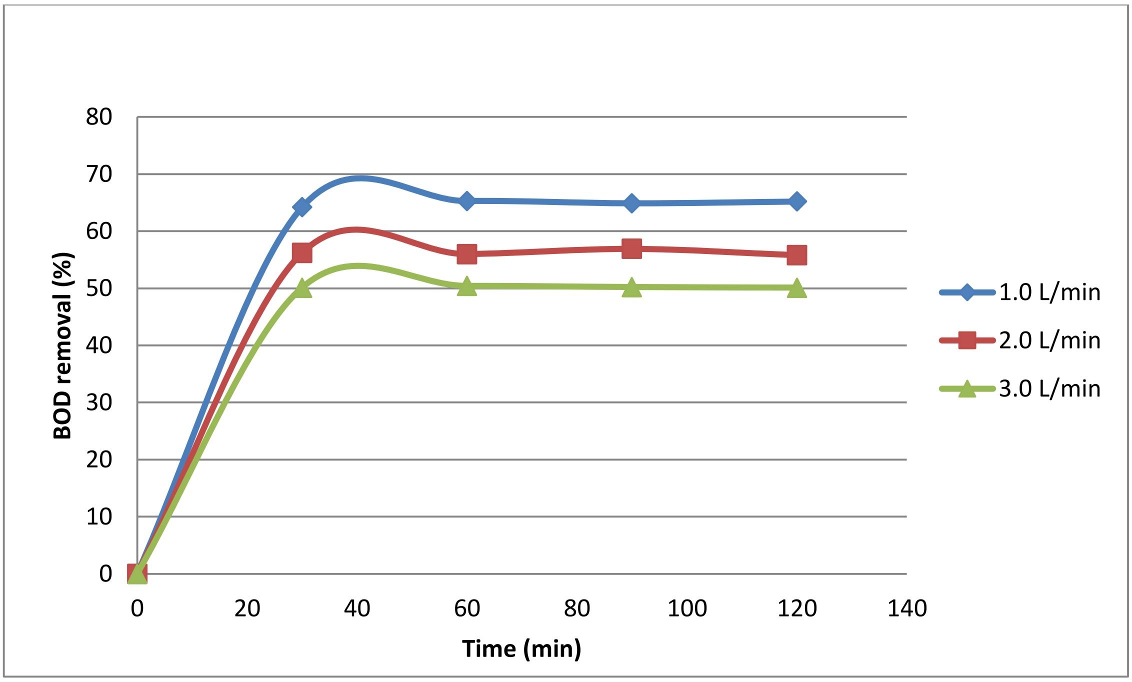

Fig 7. BOD Removal% of filtered POME against Retention Time

Different flow rates will generate various sizes of bubbles. Thus, the size of the bubble plays an important role in flotation. The smaller the bubble sizes, the more contaminant will be eliminated within a short time, and vice versa [22], [26]. Besides that, the mass transfer rate and mixing are vital for effective aeration. As a result, it gives a positive impact especially in treating wastewater [16]. The utilisations of filter paper are also one of the main factors for the rapid BOD reduction compared to unfiltered samples. Filtration can be used as pre-treatment or post-treatment in eliminating organic compound in wastewater. From the previous research, POME that was filtered by 2 layers of cheesecloth were capable to remove more dirt, fibres and other suspended solids before the main treatment were carried out [27].

4. Conclusions

Treating POME via a closed-loop in line microbubbles treatment chamber has been assessed with various air flow rates for a certain time intervals. Flow rate used is very essential to eliminate contaminant, where flow rate 1.0 L/min have the highest BOD removal efficiency for both conditions (filtered and unfiltered). The application of filter paper also plays a vital role in BOD reduction. Almost 50.1% - 65.3% of BOD removal efficiency can be achieved by applying filter paper for flow rate 1.0-3.0 L/min. Therefore, the small the size of a bubble, small flow rates and application of filter paper gave the highest BOD removal efficiency in POME. Thus, it is suggested to upgrade this treatment from bench scale to industrial scale, so that BOD and other pollutants can be removed in shorter times.

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