UNIVERSITI PUTRA MALAYSIA

PALM OIL MILL EFFLUENT TREATMENT BY USING INTEGRATED MICROBUBBLE TREATMENT COMBINED WITH MEMBRANE ULTRAFILTRATION

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ABSTRACT

Palm oil production contribute significantly to the national economies, encouraging rapid economic growth and minimizing rural poverty. However, palm oil production produce a large amount of waste water known as palm oil mill effluent (POME) and was identified as one of the major sources contributed to the pollution across all water stream in Malaysia. The treated POME can be reuse and recycle back to the mill as a general purposes and boiler feed water if the characteristic match the standard and indirectly reduce the discharging of the POME. The treatment proposes in this study involve two stages of treatment which are microbubble pretreatment and ultrafiltration (UF) membrane separation.

In microbubble separation, the raw POME was poured in the 2 m^3 tank and operated for 5 hours. Sample was collected every hour and analysed for parameter such as BOD, COD, total solid, turbidity and color and then shows reduction up to 69%BOD, 27% COD, 81% total solid, 27% turbidity and 2% color respectively. This microbubble separation was used prior to reduce major fouling in the UF membrane separation. In UF membrane separation, pretreated POME undergo UF membrane separation at different operating pressure which is 0.5, 1.0, 1.5, 2.0 and 2.5 bar using different type of regenerated cellulose (RC) membrane, 5 kDa molecular weight cut-off (MWCO) and 10 kDa MWCO. The results showed that microbubble separation coupled with UF membrane separation produce significant reduction up to 99% of all parameter. Finding shows the parameter reduction achieve the standard discharged limit of POME wastewater but not achieve the standard for water reuse and recycle.

ABSTRAK

Pengeluaran minyak kelapa sawit adalah penyumbang ketara kepada ekonomi negara, menggalakkan penumbuhan ekonomi dan mengurangkan kemiskinan luar bandar. Walaubagaimanapun pengeluaran minyak kelapa sawit menghasilkan kuantiti sisa yang tinggi yang dikenali sebagai efluen kilang kelapa sawit dan merupakan salah satu faktor terbesar yang menyumbang kepada pencemaran air di Malaysia. Efluen kilang kelapa sawit terawat boleh diguna kembali dan dikitar semula kembali ke kilang untuk kegunaan asas dan sumber air dandang jika ciri-ciri tersebut menepati kawalan yang ditetapkan dan secara tidak langsung mengurangkan pelepasan efluen kilang kelapa sawit. Kaedah rawatan terbaru ini terdiri daripada dua jenis rawatan iaitu pemisahan buih mikro prarawatan dan pemisahan ultrafiltrasi (UF) membran.

Dalam proses pemisahan buih mikro, efluen kilang kelapa sawit mentah dimasukkan ke dalam 2 m^3 tangki dan beroperasi selama 5 jam. Sampel diambil setiap satu jam dan parameter dianalisis seperti permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), jumlah pepejal, kekeruhan dan warna dan kemudiannya menunjukkaan penurunan sehingga to 69%, 27%, 81%, 27% and 2%. Pemisahan buih mikro ini digunakan untuk mengurangkan sekatan sebelum melalui proses pemisahan UF membrane. Dalam proses pemisahan UF, prarawatan efluen kilang kelapa sawit dijalankan pada tekanan yang berbeza seperti 0.5, 1.0, 1.5, 2.0 and 2.5 bar dengan menggunakan dua jenis membrane selulosa yang dijana semula (RC) pada 5 kDa dan 10 kDa had berat molekul (MWCO). Keputusan ujian menunjukkan gabungan antara pemisahan buih mikro dan pemisahan UF membrane menunjukkan penurunan ketara sehingga 99% pada semua parameter.

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BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
MWCO	Molecular Weight Cut-Off
POME	Palm Oil Mill Effluent
RC	Regenerated Cellulose
TS	Total Solid
UF	Ultrafiltration

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is one of the country that has large amount of oil palm production in the world. The demand of the crude palm oil keep increasing over the years due to its uses as cooking oil and biodiesel production. The large production of oil palm generates waste water which is called palm oil mill effluent (POME). POME is a mixture of water and oil which is the results of several processes during the milling activity such as sterilization process. According to Lawrence et al., in 2006 the emulsion can be separated by methods such as microbubble, adsorption, coagulation, electro-coagulation and membrane filtration. Among these methods, microbubble treatment for the separation of residual oil has attracted attention from many researchers. The large production of palm oil in Malaysia results in high production of POME and it is difficult to dispose due to their characteristic that very harmful to the surrounding if it is not treated properly.

POME is a thick brownish viscous liquid waste which is nontoxic but has unpleasant odor which contains soluble materials that may have a significant impact on the environment. Therefore, treatment of POME is required and for this purpose, various technologies have been conducted and are being developed. The treatment has been shifted from conventional aerobic POME treatment for example ponding system, open digester tanks and closed digester tanks. These anaerobic digesters could reduce only 70% of BOD in POME. (Tan, Bahar, Yahya, & Ithnin, n.d.)

Figure 1.1 below shows the mass flow in palm oil process and also the source of water that will be generated as a POME. From the figure below, the excessive amount of water is used during sterilization process, threshing and pressing process. The waste water from milling process later will be treated by some treatment such as ponding system and anaerobic digestion.

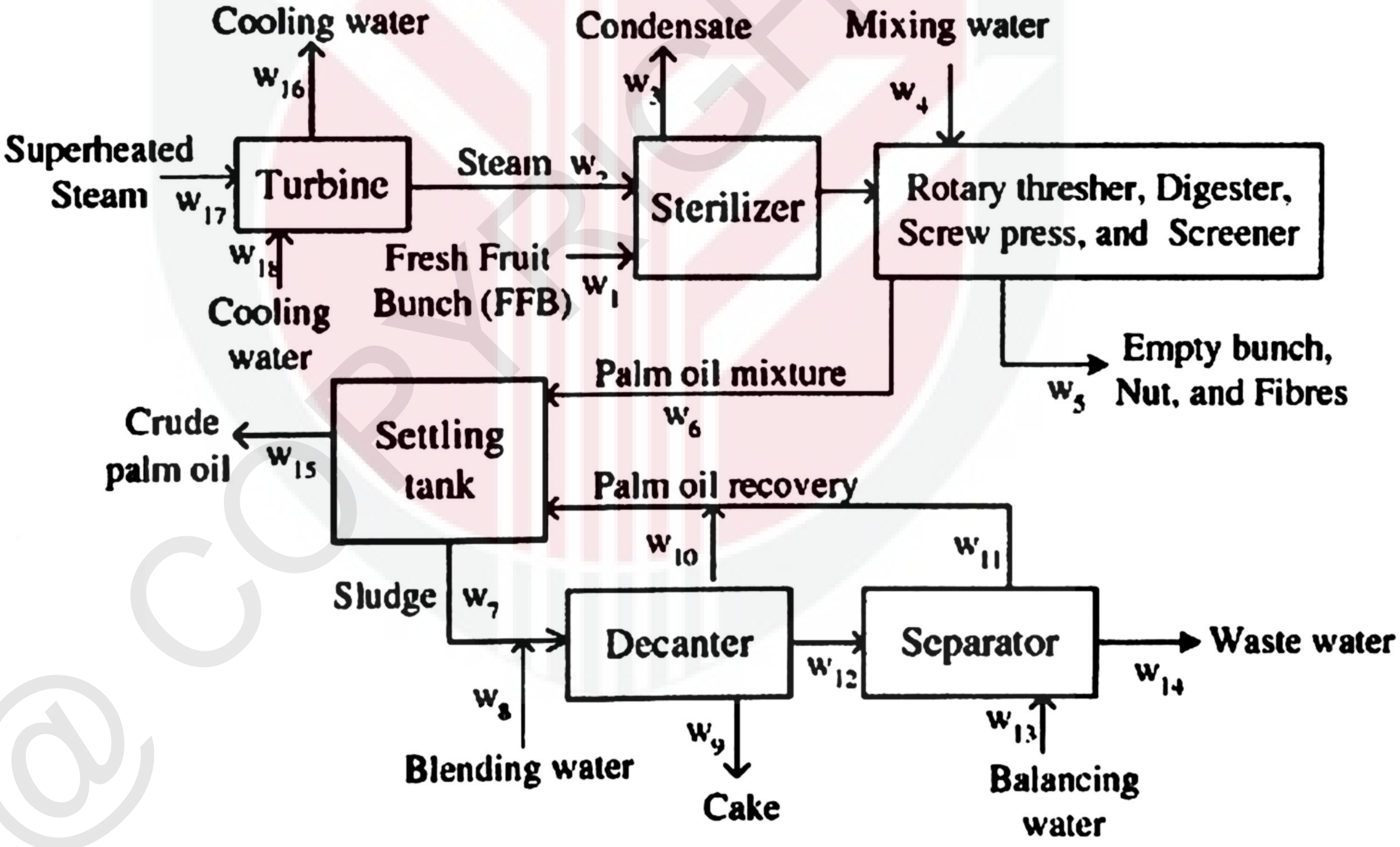


Figure 1.1: Mass flow in palm oil mill

1.2 Problem Statement

POME is a non-toxic liquid waste with unpleasant smell, high COD and BOD value. However, POME contains higher concentrations of various pollutants that can be categorized as a high strength wastewater. Hence, this could lead to serious pollution and environmental problem to the rivers and also to forms of life in the water due to its high COD and BOD values. Recently, the insert treatment was used for oil separation process from oil - water emulsion of palm oil wastewater which requires high cost.

Thus, an effective low cost treatment is required before being discharged into the environment which is mainly for supplying clean water resources. Therefore, microbubble treatment which has unique characteristics such as large gas-liquid interfacial area, longer duration time in liquid phase and fast dissolution rate are used in this work in order to overcome this environmental crisis.

1.3 Objectives

From the problem statements stated, the objectives of this research are:

i. To treat POME for a clean water discharged following the standard from Department of Environment (DoE) by using microbubble treatment.

ii. To investigate the performance of membrane ultrafiltration treatment for water reuse and recycle in palm oil industry.

1.4 Scope of the Study

The scope of this research is within the topic of separation of oil in oil-water emulsion of palm oil waste water by using the microbubble treatment as a pretreatment.

This study investigates combined of the membrane filtration with microbubble technology as a pre-treatment.

This study aims to treat and reuse the palm oil waste water for a clean water discharge comply with the standard from Department of Environment (DoE).

This study covers the treatment of palm oil waste water from Labu palm oil mill located at Labu, Negeri Sembilan.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristic of POME

Oil palm is the world's most important oil plant, with 1 ha of oil palm processing between 10 and 35 tons of fresh fruit bunch (FFB) per year. The POME which is the byproduct of palm oil processing is more polluted than municipal waste water (Kamyab et al., 2018). Pome is about 100 times more polluted because of high COD and BOD value. Hadiyanto et al. (2013) stated that the palm oil waste water contains higher concentration of organic nitrogen, phosphorus and different supplement substance.

Considering the significance of edible oil and fats derived from the palm fruits, the POME contains residual oil that cannot be discarded for the ecosystem. Treatment and disposal of oily wastewater like POME is actually one of the major environmental challenges. Palm oil mill waste has been around for years, but its impacts on the ecosystem are now more prominent. Table 2.1.1 shows the characteristic of POME which is very harmful to environment and ecosystem if it is discharged without a proper treatment method. After the POME has been treated, it can also be reused or recycled back in processing plant such as boiler feed water and general purposes.

Table 2.1 Characteristic of POME and its respective standard discharge limit by the Malaysian Department of Environment (DoE).

Parameter	**Concentration (mg/L)**	**Standard Limit (mg/L)**
pH	4.7	5-9
Oil and grease	4000	50
BOD	25 000	100
COD	50 000	-
Total solid	40 500	-
Total suspended solid	18 000	400

Source: Retrieved from Latif Ahmad et al. (2003) "Water recycling from palm oil mill effluent (POME) using membrane technology".

2.2 Current POME Treatment

POME need to undergo some treatments before it can be discharged into the river due to high value of COD and oil in their composition. POME can be considered as non-toxic waste because no chemical was used during the oil extraction process. However, if the POME directly discharged to the river, it can be the source of aquatic pollution by depleting dissolved oxygen. The current treatments including biological and non-biological treatment method is carried out in oil palm industry to treat the POME before discharged to the river.

Various type of treatment method are carried out by all oil palm industry to meet the Environmental Quality Act (EQA) of 1974. Poh *et al*., (2009) claimed that more than 85% of palm oil mills in Malaysia have adopted the cost effective biological treatment method for treating raw POME in the ponds utilizing microbial activities.

2.2.1 Ponding System

Ponding system can be applied on the available free space near the mills. Ponding system use biological method of treatment to treat the waste water. It is also called sedimentation pond and also for settling of sludge. Ponding system is a low cost and low construction but can achieve some degree of treatment. Ponding is the most common treatment system used in palm oil mills to treat POME with more than 85% of the mills using this method. Ponding system consist of de-oiling tank, acidification ponds, anaerobic ponds and facultative or aerobic ponds (Chan and Chooi, 1984).

Ponding system were used widely in oil refinery, dairy industry and also chemical plant. Wong & Springer (1979) stated that Ponding has been applied to a considerable extent in Malaysia. Palm oil mill effluent, rubber factory effluent and domestic sewage effluent have all been treated in this manner. Figure 2.1 showed the ponding system in Malaysia.

However, ponding system has some disadvantages despite their low cost. Due to the rapid growth of palm oil industry, waste water generated need more space and more depth to accommodate all the waste water from the milling process. Thus, microbubble treatment with high efficiency of separation between oil and water is proposed in this study to solve the palm oil industry issues.

Figure 2.1: Ponding system

2.2.2 Anaerobic Digestion Treatment

Anaerobic digestion is one of POME's most commonly used biotechnologies because it not only digests high organic wastewater content, but also produces renewable energy in the form of biogas. The most widely used designs for POME are traditional ponding system and transparent digestive tanks. Anaerobic digestion is the degradation under the absence of oxygen of complex organic matter. This process takes time because the bacterial consortia responsible for the degradation process takes time to adapt to the new environment before they begin to grow organically.

In the process of degrading POME into methane, carbon dioxide and water, there is a sequence of reactions involved; hydrolysis, acidogenesis (including acetogenesis) and methanogenesis (Gerardi, 2003). Methanogenesis is the rate limiting step in anaerobic digestion of POME (Ibrahim et al., 1984). Conventional anaerobic digesters therefore require large reactors and long retention time to ensure full digestion of the influential treated.

2.2.2.1 Open Digestion Tank

Open digestion tanks with large volumetric capacity are used for anaerobic treatment of POME when there is insufficient land available for ponding (Lam & Lee, 2010). The open digestion tank are differ to ponding system in term of retention time which is shorter about 20 to 25 days. In the meantime, the treated digester POME still needs to pass through the facultative ponds and followed by aerobic ponds to further reduce the organic content in the POME. Despite the advantage of this tank, the disadvantage of this tank is the production of bio methane gas and emit trough the environment.

2.2.2.2 Close Digestion Tank

Close digestion tank has same function as open digestion tank but the tank is closed to capture the bio methane gas that can be used further for fuel consumption and power generation. A study showed that CH_4 generated from a closed digestive tank is 5019 kg per day with a CH_4 composition of 62.5 percent; this figure is much higher than the open pond emission rate of CH_4 (1043.1 kg per day) and the open digestive tank (518.9 kg per day) (Tong & Jaafar, 2004).

2.2.2.3 Facultative Ponding System

In the facultative ponding system, both anaerobic and aerobic take place because of depletion of oxygen. According to Rajaletchumy in 2010, this ponding system typically have a depth of 4-8 feet and can be viewed as having three layers. The top six to eighteen inches is aerobic where symbiotic relationships between aerobic bacteria and algae occur. In the upper oxygenated layer, aerobic stabilisation of BOD occurred by aerobic bacteria.

The aerobic layer is important in maintaining an oxidizing environment in which gases and other compound leaving the lower anaerobic layer are oxidized. The middle two to four feet is partly aerobic and partly anaerobic, where organic material is decomposed by facultative bacteria. The one to two feet below is where anaerobic bacteria decompose to accumulated solids. Methane bacteria in the lower anaerobic layer can convert the BOD to methane.

2.3 Microbubble Treatment

Microbubble has unique characteristics such as large gas-liquid interfacial area, longer duration time in liquid phase and fast dissolution rate. Microbubble can be generated in three various method which are compressing a gas to higher pressure followed with releasing it using specially design nozzle, ultrasonic and through oscillating the fluid either by mechanical vibration or fluidic oscillator. (Rehman, Medley, Bandulasena, & Zimmerman, 2015). Microbubble can eliminate huge amount of TSS, BOD, and COD in tested samples treatment including oily wastewater, treatment of laundry water and treatment of fish water pond.

The characteristics owned by the microbubbles enable it to provide a homogenous mixing and maintain the uniformity. 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. (Lokman, Ithnin, Ramli, Bahar, & Yahya, 2019). Microbubbles is a new element which contributed in wastewater treatment as it can produce small bubbles as smaller than 50 μm with huge interfacial area, long stagnation time, lower bubble rising speed and high interior pressure. (Tan, Bahar, Yahya, & Ithnin, n.d.).

Microbubbles have various properties that differ from macroscopic bubbles. For example, smaller bubbles have lower buoyancies, so rise more slowly to the liquid surface, providing longer dwell times in the liquid. This can result in very high mass transfer rates during these longer residence times. Microbubbles may have either negative or positive zeta-potentials, which is an important factor in inhibiting agglomeration or coalescence of bubbles and ensuring relatively monodisperse size distributions of microbubbles. Additionally, the smaller the bubble, the larger the specific interfacial area, which enhances the efficient physical adsorption of impurities dissolved in solution, on the bubble surface. Microbubbles have attracted attention for applications in many engineering areas, such as the sewage treatment of wastewater by air flotation. (Kaushik, & Chel, 2014).

It was further found that pollutants, having low solubility in water, accumulate on the bubbles and that the ozone in the microbubbles provides more effective oxidation, and hence, elimination, of certain classes of pollutant. These reactions convert most of the oil droplets floating on the water (in form of sheen) into acids, aldehydes and ketones. These chemical species, in turn, tend to cause the remaining oil droplets to aggregate, allowing them to be removed by conventional sand filtration. It has been found that the method involving microbubbles not only removes oil sheen and the water is clean enough to be discharged after ozonation and sand filtration. In addition, the remaining dissolved organic material pollutants become more prone to biodegradation by microorganisms or other conventional methods of removal. (Cha, Lin, Cheng, & Hong, 2010).

Microbubbles have been used in a variety of ways: in soil fermentation and hydroponic plant growth, in aquaculture, for environmental improvement of water and sewage treatment, and in engineering production. Microbubbles have a number of unique properties (Takahashi et al., 2003). They remain relatively stable in water for a long time (they have a long lifetime) or rise very slowly, gradually shrink, and finally collapse (i.e., shrinking collapse), whereas macro bubbles increase in size, rise rapidly, and burst at the water surface. In addition, they have a much higher inner pressure than the local environment, which accelerates the solubility rate of gas into the liquid (i.e., efficient gas solubility). They also have a negatively charged surface and the ability to produce free radicals such as dOH, and thus, they will not merge to form larger bubbles. (Takahashi et al., 2007).

2.4 Mechanism of microbubble

The microbubble generator circulates the oil-water emulsion in the tank with a constant micro-sized bubble and attracts the oil particle which disperse about 0.1 to 500 µm. The microbubble has ability to separate the oil droplets from the POME without using adsorbent and flocculants. Figure 3.3 shows the comparison between the regular bubbles and microbubbles.

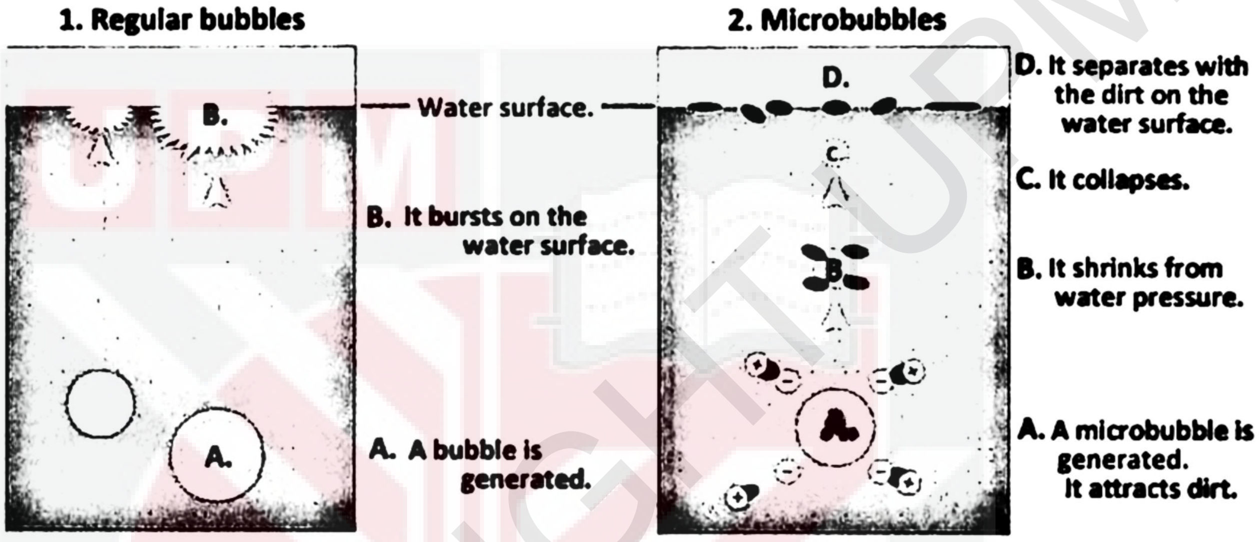


Figure 2.2: Differences between regular bubbles and microbubbles.

Over the past few years, due to their ability to produce highly reactive free radicals, more and more attention has been paid to the potential applications of microbubbles for waste water treatment. The microbubble generated having diameter about 1 to 100 µm will integrate with the oil particle thus forcing the oil droplets float by reducing the total specific gravity more than water. The oil droplets are hydrophobic property characteristic that can be conserved when in contact with the gas. Microbubbles have a number of unique properties (Takahashi et al., 2003). They remain relatively stable in water for a long time or rise very slowly, gradually shrink, and finally collapse whereas regular bubbles increase in size, rise rapidly, and burst at the water surface.

2.5 Membrane Separation Treatment

Membranes are composed of synthetic compounds with a thickness of less than 1.0 mm and can be made from a variety of materials. The ideal material is the one that can produce a less fouling membrane, is inexpensive and stable under various chemical, physical and biological conditions (MWH 2005).

Membrane separation process commonly used in many wastewater treatment to produce high quality water regardless of the water source (Shirazi et al., 2010). Compared with other processes, membrane filtration eliminates a number of contaminants present in feed water, has a small footprint, absorbs fewer chemicals, creates less sludge and is quite easy to operate and maintain (Juang et al., 2007).

2.5.1 Type of Membrane Separation

Membrane separation technique can be divided into two main groups which is low pressure membrane and high pressure membrane (Shirazi et al., 2010). The low pressure membrane are permeable membrane which the separation occur depends on the size of pore. There are two type of filtration which is Microfiltration (MF) and Ultrafiltration (UF). MF pore size ranges from 0.1 to 10 μm which helps in reject micron size particle while UF having pore size around 0.01 μm to avoid small colloid and small solid particles. However, for the high pressure membrane there are also two separation technique which is Nanofiltration (NF) and reverse osmosis (RO) which depends on the difference solubility of the solvent and solute in membrane (Li et al., 2008).

2.5.2 Membrane Fouling

Fouling is the formation of substances that are rejected on the surface and in the membrane pores (Yang et al., 2010). For membrane processes, membrane fouling is very challenging, lowering permeate flux, increasing the driving pressure and reducing membrane life. Cake layers are formed by colloids larger than the membrane pores as a result of the colloid deposition on membrane surfaces (Muthukumaran *et al.* 2011). The mechanism simultaneously blocks several pores hence it is worth noting that once a cake layer is created, it acts as a physical barrier between the membrane pores and the constituents of the feed (Zahrim et al., 2011). Particles smaller than membrane pores can be adsorbed within these pores and constrict the pore diameter, resulting in the minimization of area available for filtration (Juang et al. 2007).

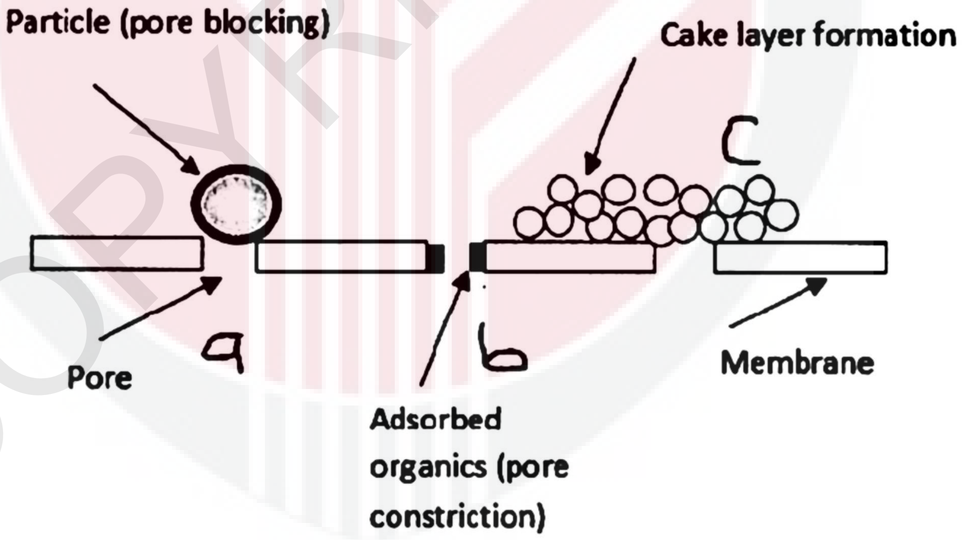


Figure 2.3 Fouling mechanism according to the Hermia model (Hermia 1982)

: a) pore blocking, b) pore constriction, and c) cake layer formation

2.5.3 Recent Study of Membrane Separation in Wastewater Treatment

Advances in membrane technology have revealed many benefits for food industry wastewater treatment. The separated substances and clean water are always recoverable in a chemically unchanged form through the application of membranes and are thus easily reusable. Maximum benefits are obtained when one or both output streams are recycled or reused from the membrane system, thereby reducing the requirement for process materials and minimizing waste disposal costs (Muro et al., 2012).

In POME wastewater treatment, Ng et al. (2018) claimed that a hybrid coagulation ultrafiltration process was utilized to reduce the total suspended solids, turbidity and colour in anaerobically treated POME. Coagulation process was implemented as pre-treatment step before ultrafiltration to reduce total suspended solids, turbidity and colour in the anaerobically treated POME. It allows higher retention of water-soluble substances and contaminants, and thus reducing membrane fouling problem. Other research by Azmi et al. (2014) claimed that the UF method under optimum conditions successfully reduced the pollutant elements up to 90% with high permeate flux rate, 57.23 L/m2 h.

2.6 Potential of Recycle and Reuse of POME

POME which we known as a harmful waste water cannot be directly discharge to water stream of the environment due to their characteristic that against the law and cause severe environmental pollution and destroying aquatic life. Thus, many researcher nowadays are trying to study the potential of recyclable or reusable treated POME back to the processing plant. Sajjad et al. (2018) stated that the treatment of POME by using integrated biofilm and membrane filtration can meet class III and class IV of the National Water Quality standard of Malaysia for water supplied but need an extensive treatment.

Asano et al. (1996) stated that some applications of treated wastewater is more efficient than the disposal of fresh water, and consequently usable fresh water can be retained for drinking. Water researchers are becoming more aware of the potential benefits associated with reuse of wastewater and more attention has been paid to this area over the past decade, instead of recognizing that the production of high-quality treated wastewater is key to public acceptance and protection of the environment.

In palm oil industries, previous research has proven that it is possible to recycle back the treated waste water which can be more cost effective to the mill and also maintaining the good quality of ecosystem towards green environment. Corrosion, scaling, and biological growth are some of the issues associated with reuse of wastewater in industrial systems. Thus, the degree of water quality needed to determine its ability for use for a palm oil industry.

CHAPTER 3

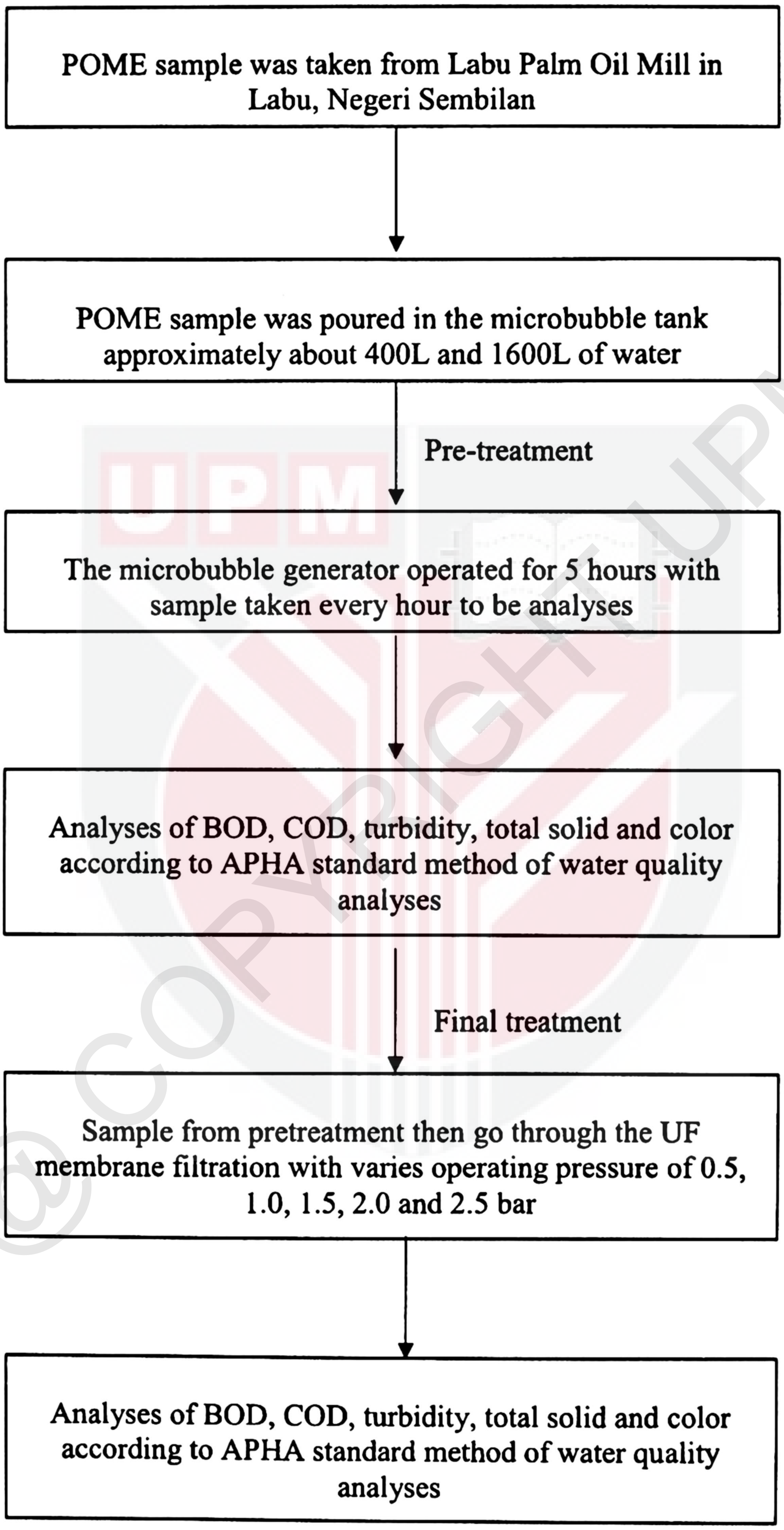
METHODOLOGY

3.1 Source of POME and Sample Collection

The raw POME sample were collected at Labu palm oil mill located in Labu, Negeri Sembilan Coordinates: 2.749955, 101.804352. Labu palm oil mill has large processing rate and produce tons of POME. The raw POME generated were collected from the anaerobic pond about 500 L at temperature about 50 °C to 65 °C and transported to the laboratory. Upon arrival, the POME sample were quickly stored in the chiller at 4 °C to ensure that the result of the experiment will not be affected by microbial action due to biodegradation.

Figure 3.1: Location of Labu Palm Oil Mill, Negeri Sembilan

3.2 Experimental Flowchart



3.3 Microbubble Technology as a Pretreatment

The experimental work starts with the pretreatment of POME by microbubble generator. The POME sample collected from Labu Palm Oil Mill were taken out from the chiller and the experimental work was carried out at ambient temperature. Microbubble tank having a capacity of 2 m^3 were filled with POME about 400 L and 1600 L were filled up with tap water. The sample is having about 1 to 5 ratios of dilution and operated for 5 hours. The sample were taken every one hour to be analyzed in term of BOD, COD, total solid, turbidity and color. Figure 3.2 below shows the microbubble generator component consist of Honda Pump, 2 m^3 tanks, control panel, air injector and hand operated globe valve.

Figure 3.2 Component of microbubble generator

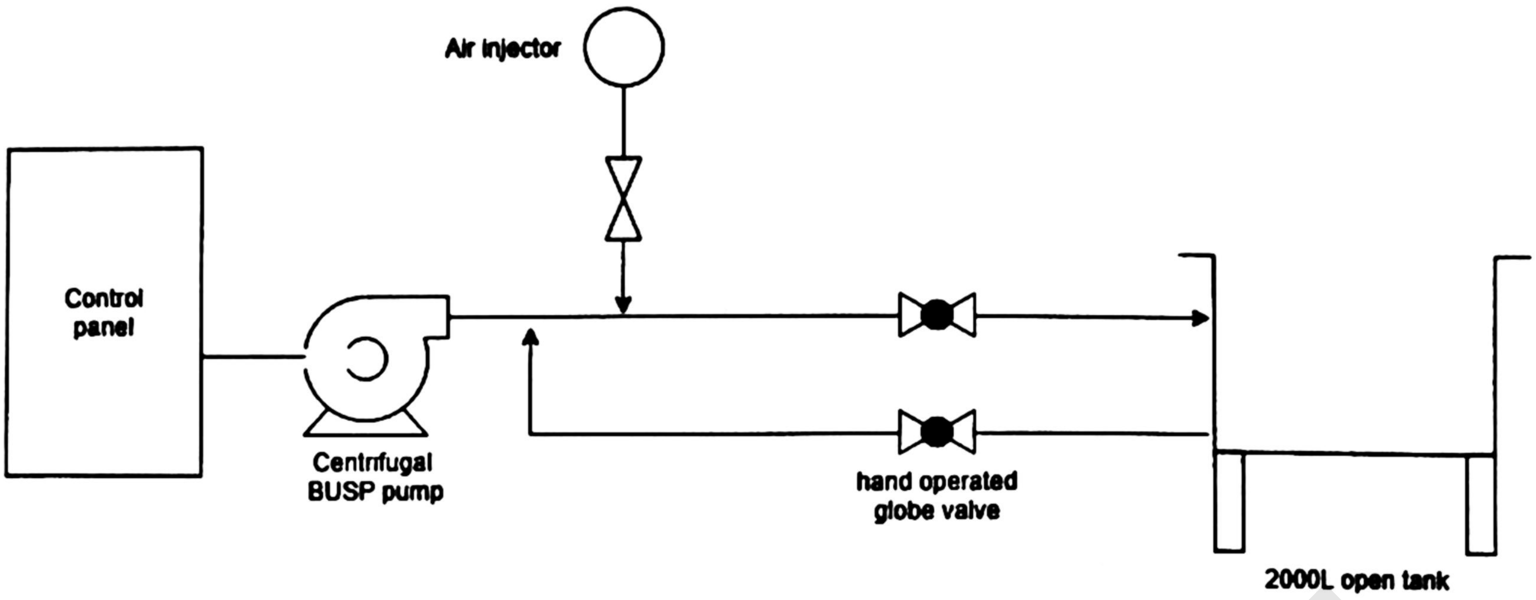


Figure 3.3 Schematic diagram of microbubble generator

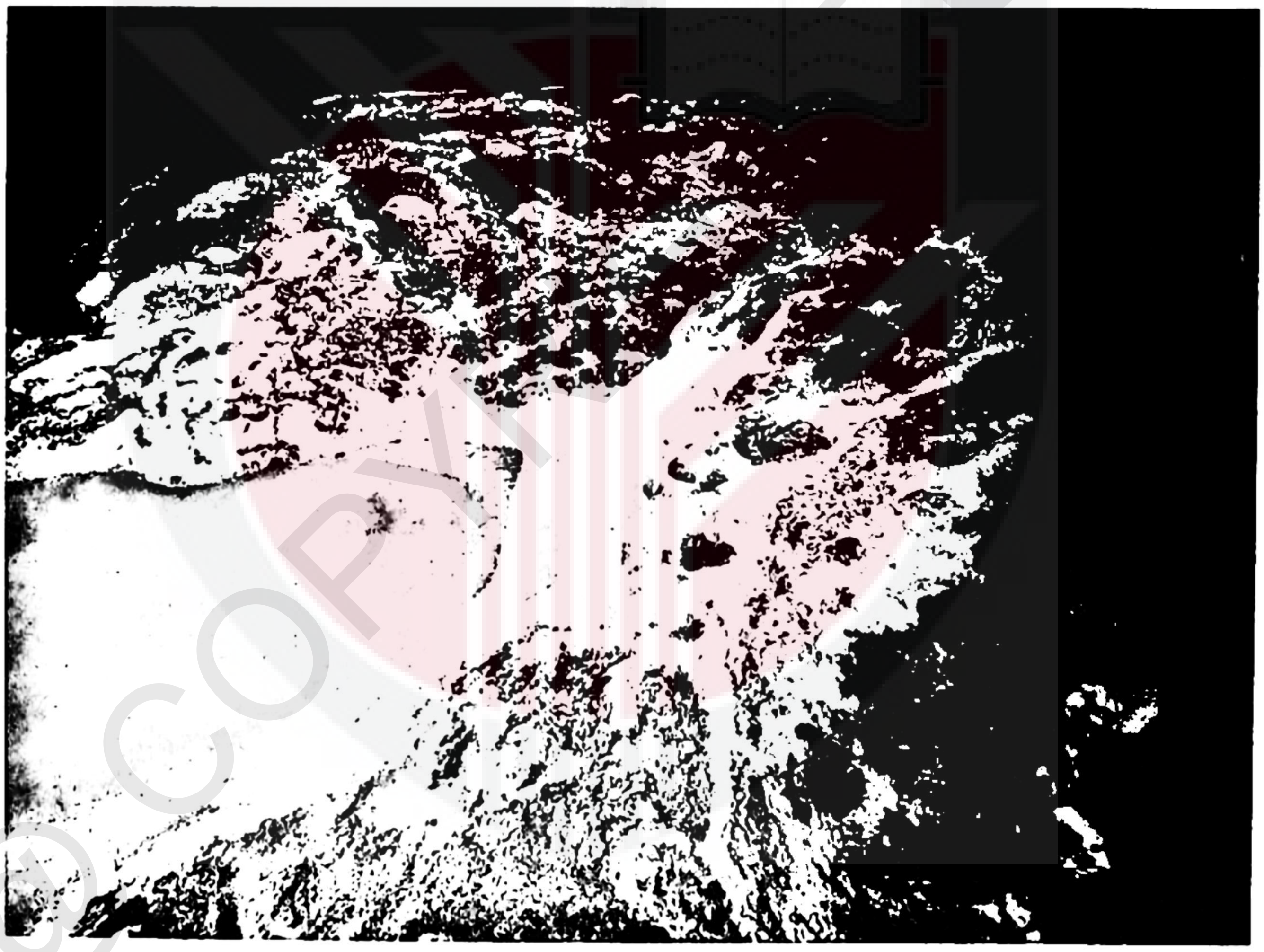


Figure 3.4 Scum produced during microbubble treatment

3.4 Membrane Ultrafiltration (UF) Treatment

The sample from pretreatment will then undergo membrane ultrafiltration treatment in a batch mode by using stirred ultrafiltration cell (Amicon 8200, Milipore USA). 180 mL of pretreated sample were measured and poured into the stirred cell. The membrane used in the stirred cell was a flat sheet regenerated cellulose (RC) membrane (Merck Milipore USA) with 28.7 cm^2 effective membrane area and membrane diameter of 63.5 mm. The molecular weightcut-off (MWCO) of the RC membrane used was 5 kDa and 10 kDa.

The parameter varied in this experiment is the MWCO which is 5 kDa and 10 kDa. The stirred cell was pressurized using nitrogen gas at 5 different pressure value of 0.5, 1.0, 1.5, 2.0 and 2.5 bar. For each cycle, the time was kept constant which is about 90 minutes where the permeate stable. The volume of permeate collected were recorded and tabulated. The permeate was further analyzed for COD, BOD, turbidity, color and total solid analysis to measure and compare before and after treatment. From the volume of permeate collected, the permeate flux analysis can be calculated. According to (Tchobanoglous et al., 2003) the permeate flux can be calculated as equation below:

$$J = (1/Am)\ dV/dT$$

Where, J is the permeate flux of solution ($L/m^2.h$)

Am = the membrane area, (m^2)

dV = the amount of permeate collected, (L)

dT = the time taken for the permeate flow to be collected. (h)

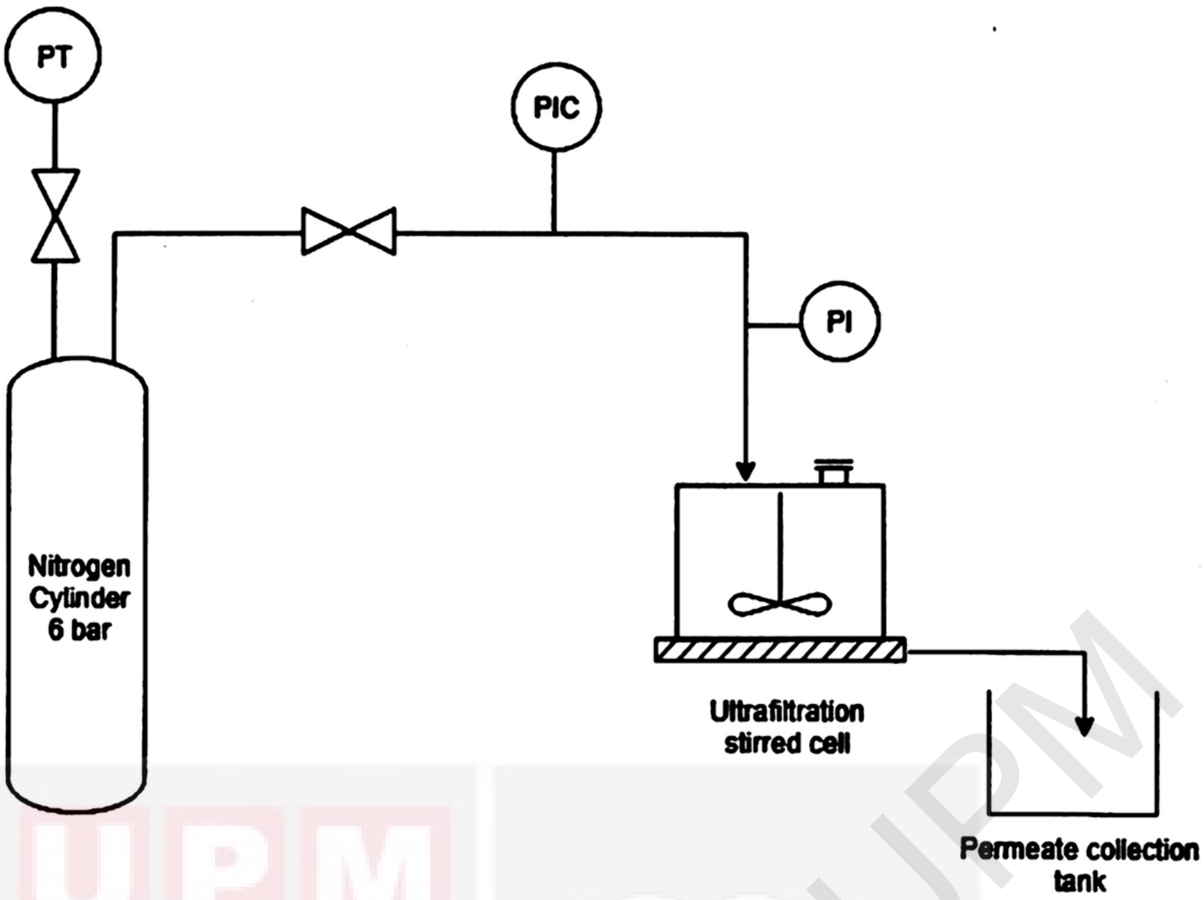


Figure 3.5 Schematic diagram of UF membrane treatment

3.5 POME Analytical Method

The analytical method of water quality were analyzed after pretreatment and after membrane ultrafiltration treatment to compare the reduction with the initial quality of POME. The analysis that were analyzed was BOD, COD, total solid, turbidity and color. The details of all the analytical methods conducted were based on procedures given in the APHA, Standard Method for the Examination of Water and Wastewater (Hammer et al., 2005).

3.5.1 Chemical Oxygen Demand (COD) analysis

The chemical oxygen demand (COD) is used to measure the organic compound in the POME sample. It tests the water's ability to absorb oxygen during organic matter decomposition and the oxidation of inorganic chemicals such as ammonia and nitrate. The COD was measured using a commercial kit (HACH COD High Range) by spectrophotometer (HACH DR/4000U). Before started, the COD digester was preheated to 150 °C. 2 mL of diluted sample was pipetted and 2 mL of distilled water also pipetted into the COD vial as a blank. All the samples were capped tightly to prevent evaporation. The sample will become very hot as it start the chemical reaction.

The vials then inserted in the digester for 2 hours at 150 °C. After 2 hours, the vials were taken out and let it cooled for 10 minutes. The vials then wiped with paper towel and inserted into the spectrophotometer to determine the COD value.

3.5.2 Biological Oxygen Demand (BOD) analysis

The BOD analysis measure the amount of dissolve oxygen demanded by the organic biological organism in the POME sample to break down organic materials. The BOD analysis was carried out by measure 5 mL of sample and 295 mL of distilled water in the 300 mL BOD bottle. To measure the initial dissolve oxygen contain, the dissolve oxygen (DO) meter (YSI Professional plus Multiparameter DO meter) was turned on and immerse in the sample. The DO meter immerse about 5 minutes to get a stable and precision reading.

After the initial reading were recorded, the sample in the BOD bottle were kept in 20 °C dark incubator for 5 days. The purpose of incubated in the dark place is basically to avoid a light for photosynthesis or growing of algae. After 5 days, the sample were taken out and measure the dissolve oxygen contain by using DO meter. The BOD contain can be calculated from the following equation (APHA, 1989):

$$\text{BOD} = \frac{D_i - D_f}{P}$$

Where, D_f = Dissolve oxygen after 5 days, (mg/L)

D_i = Initial dissolve oxygen (mg/L)

P = Fraction of wastewater sample

3.5.3 Total Solid (TS) analysis

The crucible was dried in the oven before it can be used to remove moisture and cooled in desiccator. The crucible then weighted to determine the weight without sample. A 5 mL of POME sample was measured and poured into the crucible and dried in the oven at 105 °C for 24 hours. After 24 hours, the crucible was taken out and cooled in the desiccator until it achieve a constant weight. The crucible contains solid then weighted on the analytical balance and the weight were recorded. The total solid content was calculated from the following equation (APHA, 1989):

$$\text{Total Solid (mg/L)} = \frac{W1-W2}{V}$$

Where, W1 = weight of crucible with solid (mg)

W2 = weight of blank crucible (mg)

V = Volume of sample (L)

3.5.4 Turbidity analysis

Turbidity analysis determine the degree losses of their transparency due to solid and suspended particle. Turbidity is a good water quality analysis to determine the quality of water appearance based on their cloudiness in order to comply with the standard of water reuse. The calibrated turbidity meter (HACH 2100Q Portable Turbidimeter) was turned on and filled the bottle with 10 mL of sample. The sample then inserted in the turbidity meter and press read. The reading will be shown and recorded.

3.5.5 Color analysis

The color analysis was carried out to determine the color of the POME sample after each treatment by using calorimeter (Konica Minolta CR-14 color reader). The calorimeter measure L* a* b* value which L represent for lightness ranging from 0 (black) to 100 (white). The a* value represent the degree of redness ranging from (0 to 60) and b* value measure the degree of yellowness (0 to 60) or blueness (0 to -60). The instrument calibration was carried out using the white colored tile before proceed to the POME sample.

Color analysis of the pretreated and treated POME sample was analysed according to the L* a* b* value and calculate the Chroma (C) and Hue angle (h) by using the following equation:

$$\text{Chroma, C} = \sqrt{a*^2 + b*^2}$$

$$\text{Hue angle, h} = \tan^{-1} \frac{b*}{a*}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of experiment were discussed in this chapter. The data analysis of COD, BOD_5, turbidity, color and total solid analysis were measured at initial condition, after the microbubble pretreatment and after the membrane UF treatment of POME. All analysis carried out were based on the APHA. Standard methods for water and wastewater, 2005.

The two-staged treatment consist of microbubble pretreatment and membrane UF treatment is prior to the objective which is to reuse or recycle POME back to the mill for a general purposes and also can be cost effective due to high usage of water such as boiler feed water.

4.2 Performance of Microbubble Pretreatment

4.2.1 COD

In order to measure the amount of oxygen that can be consumed by reactions in a wastewater solution, COD was analyzed and recorded in figure 4.1. Lower levels of COD mean a larger amount of oxidizable organic content in the sample, which reduces the levels of dissolved oxygen (Parimal Pal, 2017). Reducing dissolved oxygen can contribute to anaerobic conditions that are harmful to decreased aquatic life.

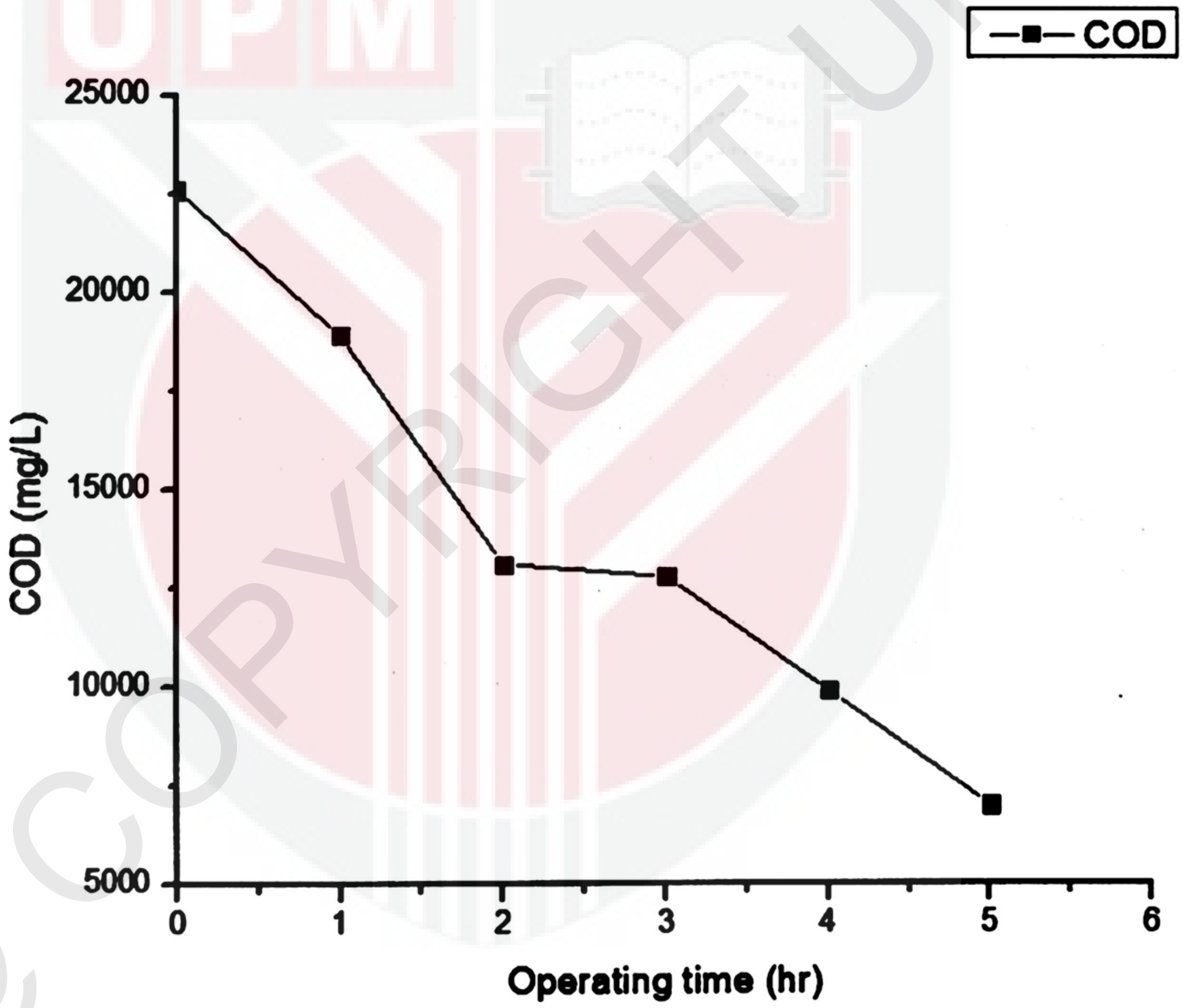


Figure 4.1 COD value at different operating hour

Figure 4.1 showed COD value at different operating hour for separation of oil in oil water emulsion of wastewater by using microbubble technology. The value of COD was observed to decrease throughout the operating time. The reading was found to decrease gradually in every hour the sample were taken. During the 5 hours of operating time, the COD value was initially at 22600 mg/L and drop to 7000 mg/L could be due to high amount of oxidizable organic materials resulting in low oxygen level. However, the amount of COD at 7000 mg/L was considered to be at high level of COD. Reduction of oxygen in the POME sample may create a harmful environment to the aquatic life if it was discharged at high COD value. Therefore, the membrane UF is used as final treatment of this wastewater treatment to achieve a clean water discharged following the standard from Department of Environment (DoE) and prior to reuse and recycle of POME wastewater back to the palm oil mill industry.

4.2.2 BOD

BOD analysis were carried out to measure the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature which is 20 °C. When the BOD is high, there will be more oxygen stripping capacity of the discharged effluent into receiving water where oxygen is used biologically to break down the organic matter and resulting more potential damage to biological life in those wastewaters. Figure 4.2 shows BOD_5 analysis in 5 hours operating time.

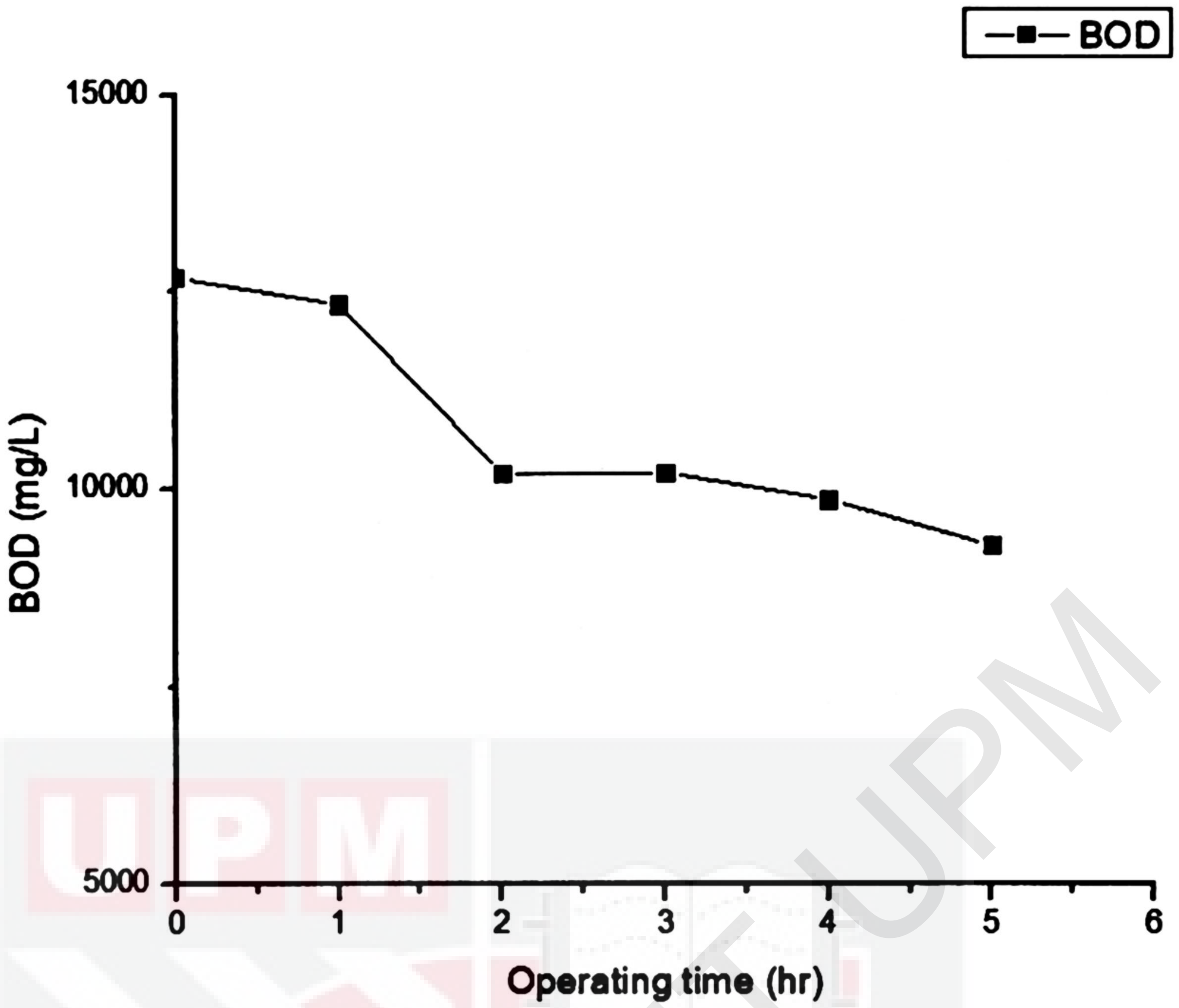


Figure 4.2 BOD_5 analysis in 5 hours

From figure 4.2, a decreasing trend was observed in reduction of BOD against time in the POME sample at 12670 mg/L at initial to 9280 mg/L after 5 hours operating time. Based on Tan et al. (2017), the flowrates that were used will affect the bubble size and give effects to the removal of BOD. A different flowrate produce different size of bubble which will give impact to the floatation process. The smaller the bubble sizes, the more contaminant will be eliminated within a short time, and vice versa (Lokman et al., 2019). From the decreasing trend in figure 4.2, it was proved that the lowest flowrate of microbubbles that were used in experiment performed better in reducing the BOD. Hence, the microbubble pretreatment in this research successfully reduced 27% of BOD in 5 hours by using a low flowrates to produce a fine bubble for floatation process. The reduction of BOD value by using microbubble was prior to reduce the fouling action on the membrane separation treatment.

4.2.3 Turbidity

Turbidity analysis was used to measure the cloudiness of the sample due to amount of suspended solid in the POME sample and measure the physical appearance of the waste water. In this experiment, the turbidity of POME wastewater was analyzed in every hour for 5 hours to achieve a clean water discharged from POME wastewater. Figure 4.3 shows Turbidity analysis in 5 hours operating time by using calibrated turbidity meter.

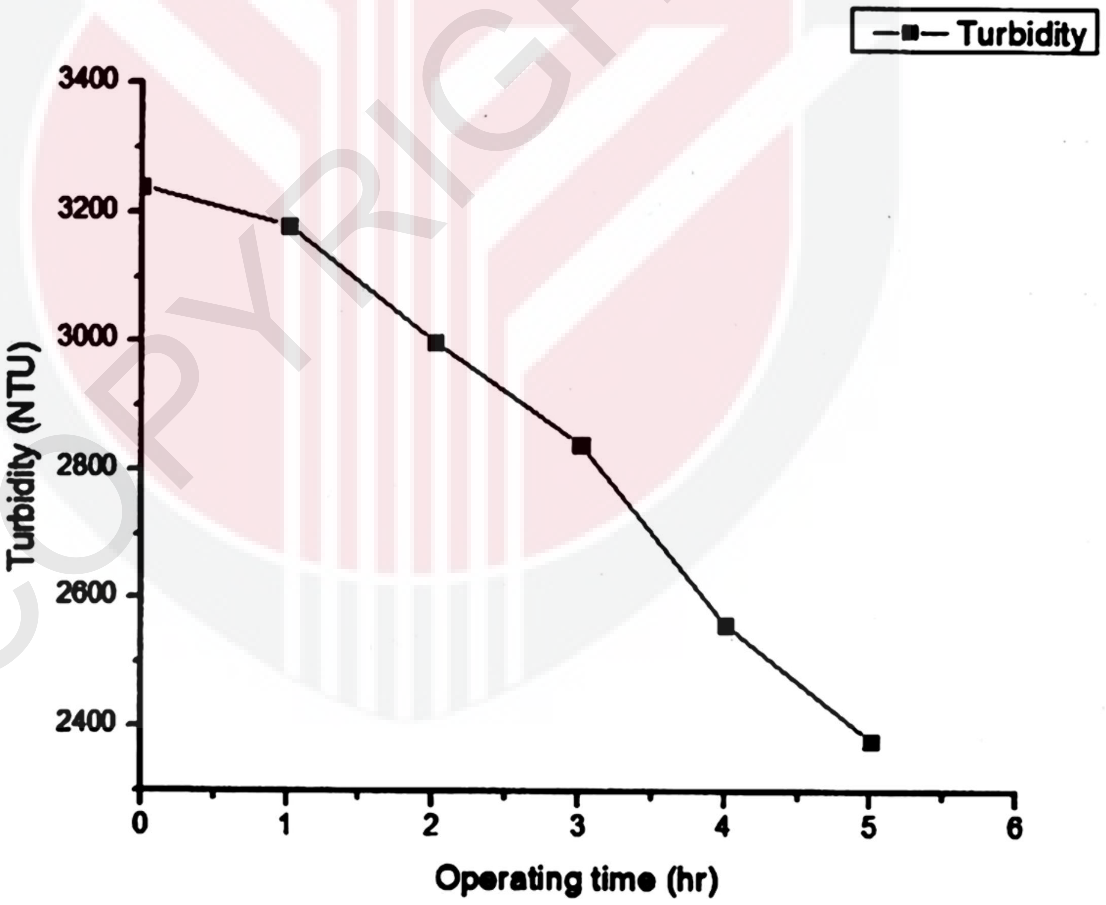


Figure 4.3 Turbidity analysis in 5 hours operating time

From figure 4.3, it can be seen that the initial turbidity of POME was high with 3240 NTU and drop gradually until 2380 NTU after 5 hours. Generally, POME contained suspended solid where the solid is larger than 2 microns which can pass through the filtration process. Most of the suspended solid is made from in organic material including anything that drifting and floating by the microbubble technology such as oil, sediment and algae. From the figure above, we can say that the microbubble pretreatment that were used in this research successfully reduce turbidity with 27% reduction along 5 hours pretreatment time. The cloudiness changes along the 5 hours operating time indicates that the microbubble has high ability to separates the particle in the POME and float on top of water surface as a scum.

4.2.4 Total Solid

Total solid analysis is used to measure the suspended solid and dissolve solid residue left after evaporation process at 105 °C. The dry matter that is left after removal of moisture is commonly referred to as total solids. As an engineer, this analytical value is considered economic significance and there are ethical limitations as to how much solid must stay in a good quality of water in order to recycle back to the mill. Figure 4.4 shows the total solid remained at different operating time.

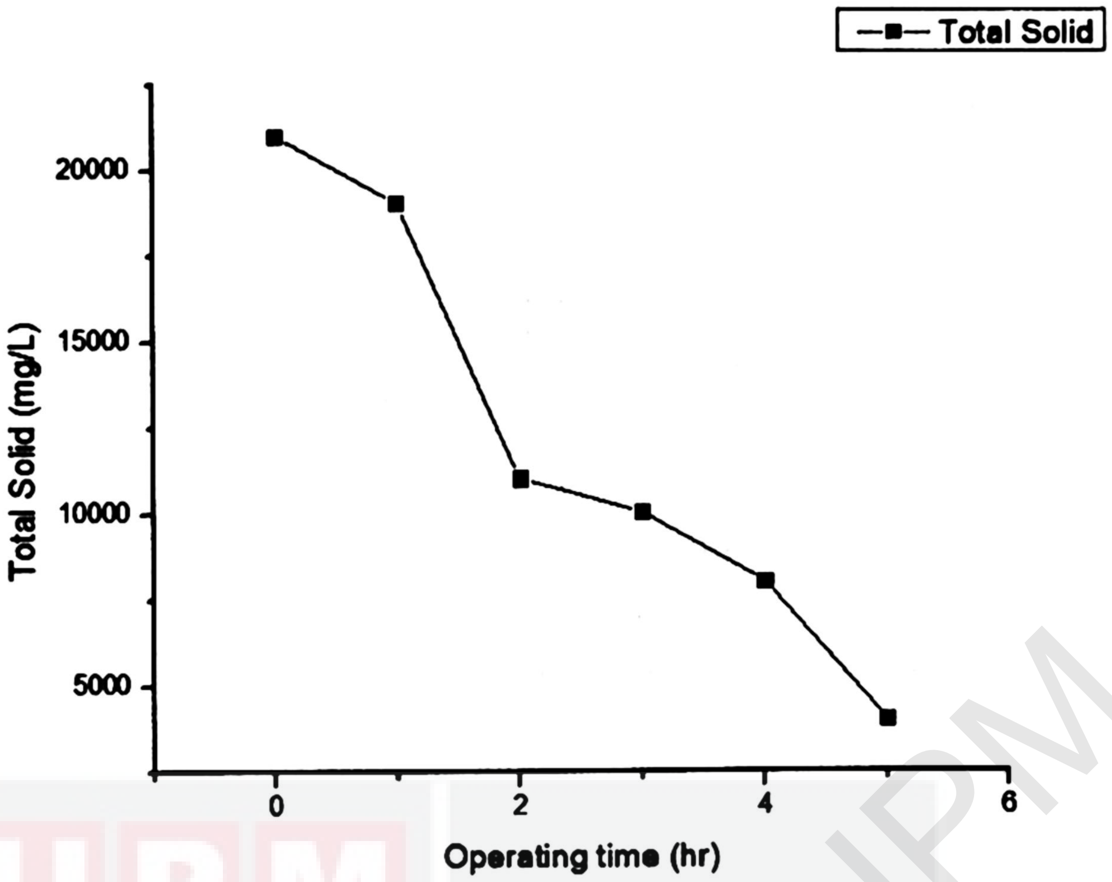


Figure 4.4 Total solid analysis against operating time

From figure 4.4, the trend shows the reduction of total solid in the POME sample in every hour. The longer the operating time, the lower the total solid contained in the sample. The total solid analysis shows 81% of total solid was successful reduce by using this microbubble treatment to avoid major fouling for next UF treatment method. Khuntia (2012) claimed that microbubble produced by the generator was negatively charged which attracted particles and float to the water surface. Normally the pressurized gas within the microbubble is released into the gas phase and bursts as a microbubble rises to the surface of the water. Nonetheless, microbubbles integrated with oil droplets do not burst even though they rise to the water's surface, and will repeat with microbubbles integrated with oil droplets emerging from bubbles larger than microbubbles one after another. Thus, the microbubble has high efficiency to reduce the total solid in the POME sample.

4.2.5 Color

The color analysis was used to determine the color of the pretreated POME sample according to the L* (lightness) a* (redness) b* (yellowness/blueness) by using calorimeter. The chroma (C) and hue (h) was calculated and help in predict the color changing throughout the experiment. The color analysis of pretreated POME sample was analysed to measure the degree of effectiveness in reducing color of the POME sample in microbubble technology. Table 4. 1 shows the pretreated POME wastewater in microbubble technology at different operating time.

Table 4.1 Color analysis of POME wastewater in microbubble technology at different operating time.

Operating Time (Hour)	L*	a*	b*	Chroma (C)	Hue angle (h)
0	13.5	6.5	21.1	22.07	72.88
1	13.6	6.5	20.8	21.79	72.65
2	13.6	6.5	20.6	21.60	72.49
3	13.7	6.5	20.7	21.60	72.56
4	13.8	6.7	20.7	21.76	72.06
5	13.8	6.7	20.7	21.76	72.06

From table 4.1, the trend of L* value increased which indicate the reduction of color lightness of the POME sample. The L* value changes shows that the POME sample turn from slightly dark water to brighter along the 5 hours operating time. More than that, chroma also shows a reduction which result in reducing the color intensity and their sample color saturation while the hue value indicates the sample goes brighter and yellowish. This is due to the enhanced adhesion ability of small microbubbles, the saturation of the added air as well as the reduction ability of particles result in an increased reduction of the suspended solids, a higher solid content in the float sludge separated from the emulsion as the time increases (Hempel, 1994).

4.2.6 Microbubble Pretreatment Outcome

The microbubble technology was capable to separate oil and solid particle as a scum because of their ability to float particle at the surface of the waste water and reduce the organic material in the waste water sample. The microbubble pretreatment was very effective in order to reduce the COD, BOD_5, turbidity, total solid and color up to 69%, 27%, 27% and 81% due to their characteristic in floatation process to bring up particles from the waste water. This pretreatment is prior to the further membrane UF treatment to reduce fouling to the membrane and produce a good permeate quality and also to achieve objective for water reusable and recyclable. As an overall, the microbubble pretreatment can be summarized in such a table 4.2 below.

Table 4.2 Summary of microbubble pretreatment

Parameter	Microbubble pretreatment (hr)						Percentage reduction	WHO guideline for water reuse standard (2004)	Boiler feed water standard
	0	1	2	3	4	5			
COD (mg/L)	22600	18900	13100	12800	9900	7000	69%	500	5
BOD (mg/L)	12670	12330	10200	9850	9850	9280	27%	200	-
Total solid (mg/L)	21000	19000	11000	10000	8000	4000	81%	1650	-
Turbidity (NTU)	3240	3180	3000	2840	2560	2380	27%	-	0-3
Color (Chroma)	22.07	21.79	21.60	21.60	21.76	21.76	1.43%	-	-
Color (Hue)	72.88	72.65	72.49	72.56	72.06	72.06	2.0%	-	-

Even though the parameter was successfully reduced, it was not meet the standard from DoE and WHO. So, the membrane ultrafiltration was proposed to continue the waste water treatment until it can achieve the standard from the DoE and WHO prior to objectives which is to recycle and reuse the treated water back to the mill. Membrane ultrafiltration was used mostly to filter large molecules and allow smaller molecules to pass through the membrane and produce a good quality of permeate.

4.3 Performance of Membrane UF Treatment

4.3.1 Permeate Flux analysis

The membrane permeation flux is defined as the volume flowing through the membrane per unit area per unit time. This membrane separation study was used to filter unnecessary solid particle accumulated thus give a good quality of permeate. The permeate flux analysis was carried by using two type of membrane which is RC membrane 5 kDa and 10 kDa with operating pressure from 0.5 bar to 2.5 bar. Figure 4.5 shows the permeate flux analysis at different operating pressure.

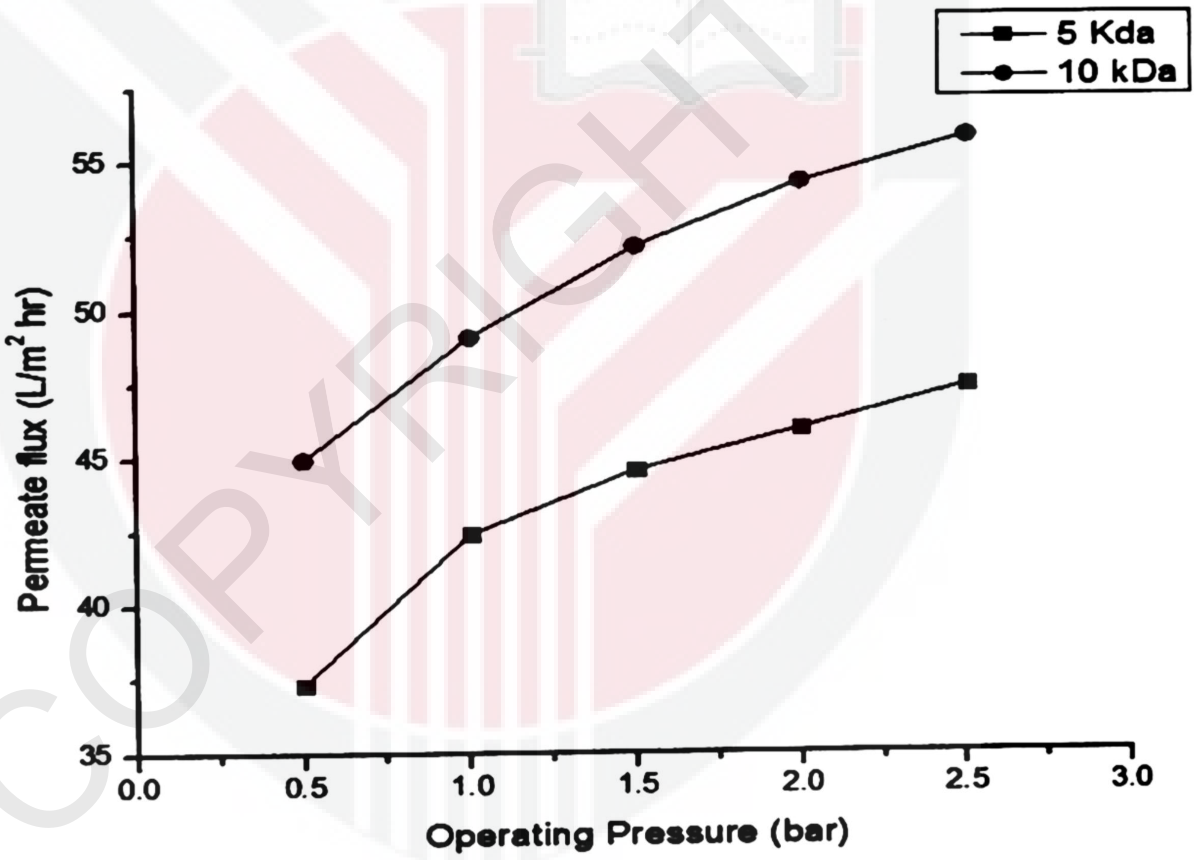


Figure 4.5 Permeate flux analysis at different operating pressure

From figure 4.5, the trends showed both type of membrane used against the operating pressure. The higher the pressure applied to the membrane, the higher the rate of the permeate flux. Nourbakhsh et al. (2014) stated that this is due to increase of pressure that cause a build-up of cake resistance and indirectly increase the membrane fouling.

However, the type of membrane also plays an important role in permeate flux rate. The 5 kDa membrane tend to have a greater fouling than 10 kDa membrane based on their MWCO characteristic.

4.3.2 COD

The COD values after UF membrane treatment was analyzed to determine the capability of UF membrane in order to achieve the objectives of this research. The sample from pretreatment then proceed to UF membrane treatment by using two type of membrane which is RC membrane 5 kDa and 10 kDa MWCO. The COD value of permeate was analyzed using COD spectrophotometric method. Figure 4.6 show the COD value of two type of membrane at different operating pressure.

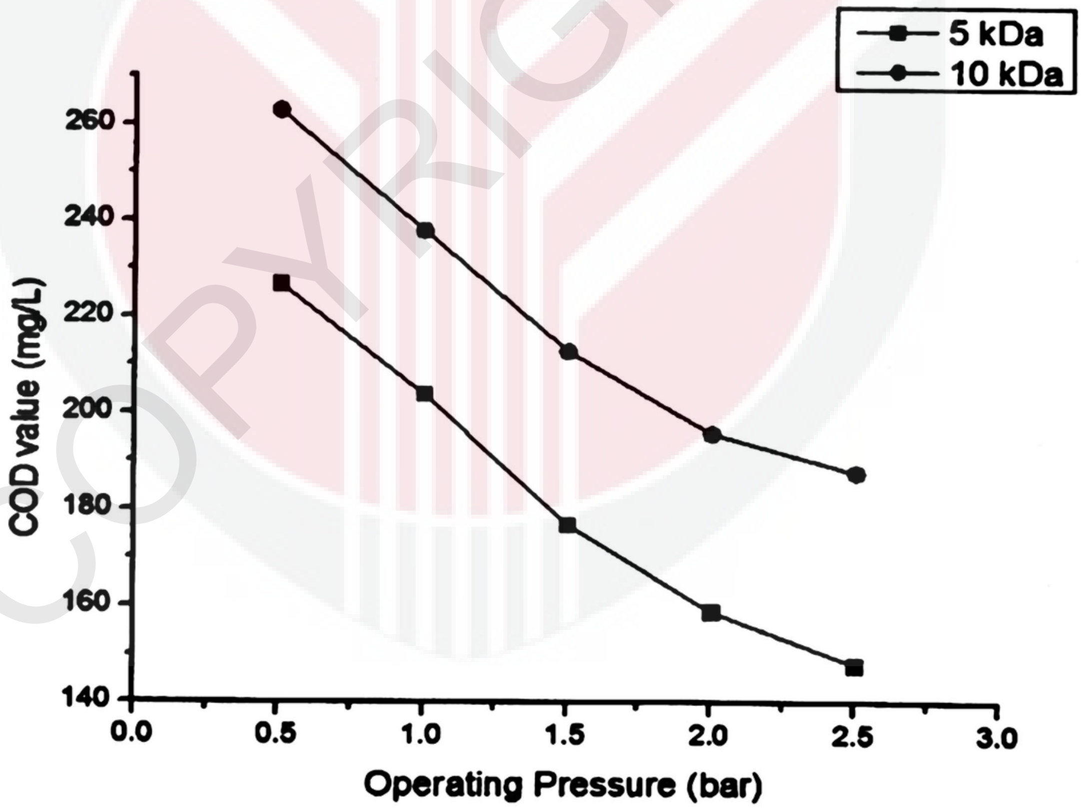


Figure 4.6 COD value of two type of membrane at different operating pressure

Figure 4.6 showed COD value of different type of membrane at different operating pressure. The value of COD was observed to decrease when the pressure increases. The reading drops gradually in this membrane treatment and achieve the standard water limit for COD value. However, the 5 kDa membrane performance much better than 10 kDa membrane due to the fouling on the membrane surface which results in a better quality of treated water. Generally, POME is a thick brownish viscous liquid waste, slurry, high in colloidal suspension and has an unpleasant odor (Ahmad et al., 2009). The UF membrane treatment successfully reduce the COD value in POME until it can achieve the standard limit with a high percentage of removal of the COD.

4.3.3 BOD

In microbubble pretreatment, the BOD initially at 12670 mg/L was reduced to 9280 mg/L with 27% of percentage reduction. Low percentage reduction in pretreatment was due to the flowrate supplied which cannot be measured without flowmeter. Yahya et al. (2017) stated that different flow rate provides different size of bubble. The size of the bubble is therefore one of the main variables with major impacts on floatation. The smaller the size of the bubbles, the more polluting material is extracted and the shorter time it takes. Figure 4.7 shows the BOD value at different operating pressure by using different MWCO RC membrane.

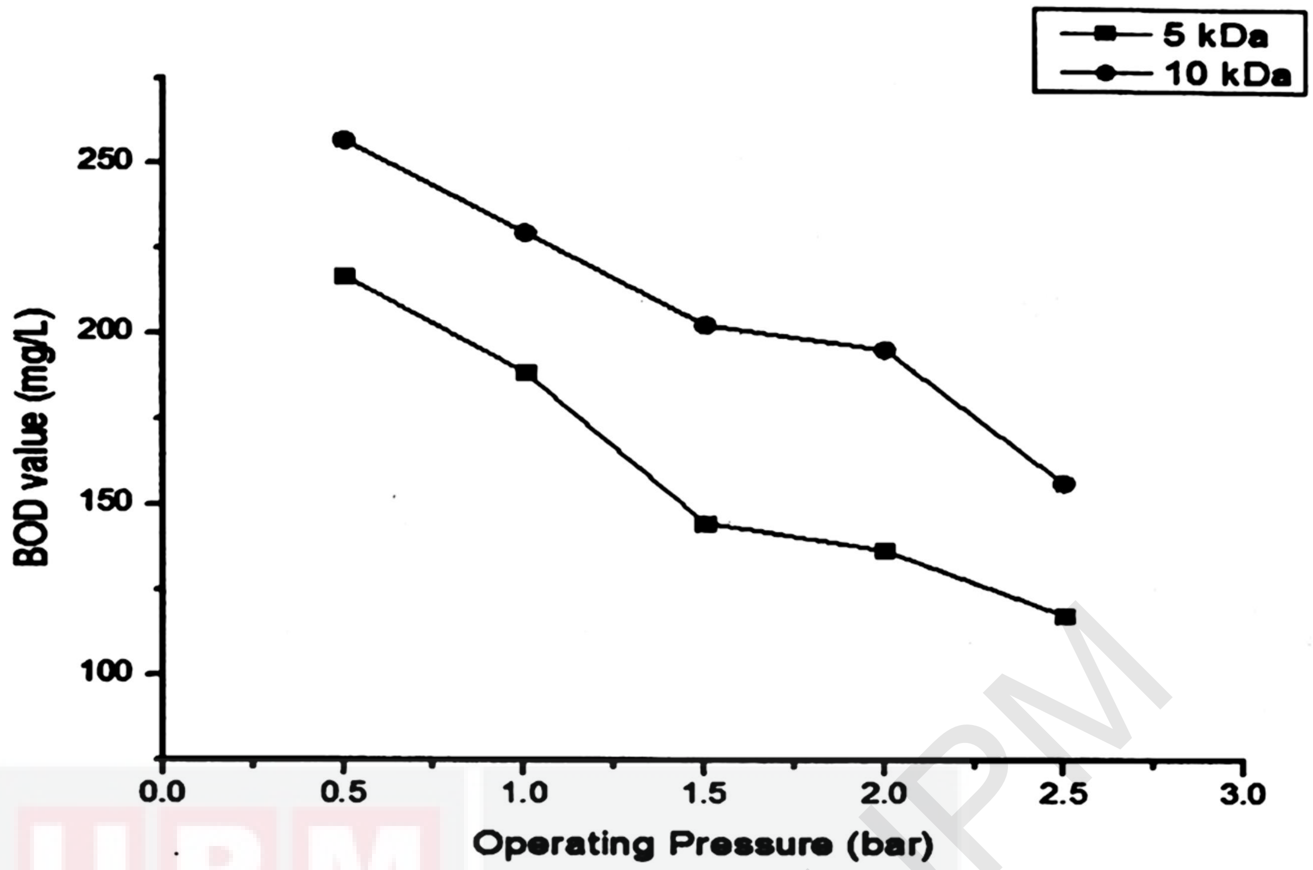


Figure 4.7 BOD value of two type of membrane at different operating pressure

Figure 4.7 showed BOD value of two type of membrane at different operating pressure. The BOD value was significantly decreased with the applied pressure for both type of membrane. The 5 kDa MWCO membrane nearly achieve the standard for discharge water limit of BOD which is at 100 mg/L but the lowest BOD was analysed at 118 mg/L. According to EPA guideline for water reuse standard (2004), the accepted BOD value must be below 30 mg/L which is slightly different from the results. In order to achieve the standard for water reuse, it is suggested to prolong the operating time of microbubble pretreatment and use lower MWCO of RC membrane.

4.3.4 Turbidity

Permeate from the UF membrane treatment then proceed to the turbidity analysis to determine the difference in term of cloudiness of the POME sample. In microbubble pretreatment, the turbidity was reduced from 3240 NTU to 2380 NTU in 5 hours operating time. The turbidity is still considered high and polluted thus a UF membrane treatment is used to separate the unnecessary solid particle which results in cloudiness of the POME sample. Figure 4.8 shows the turbidity value at different operating pressure in UF membrane treatment.

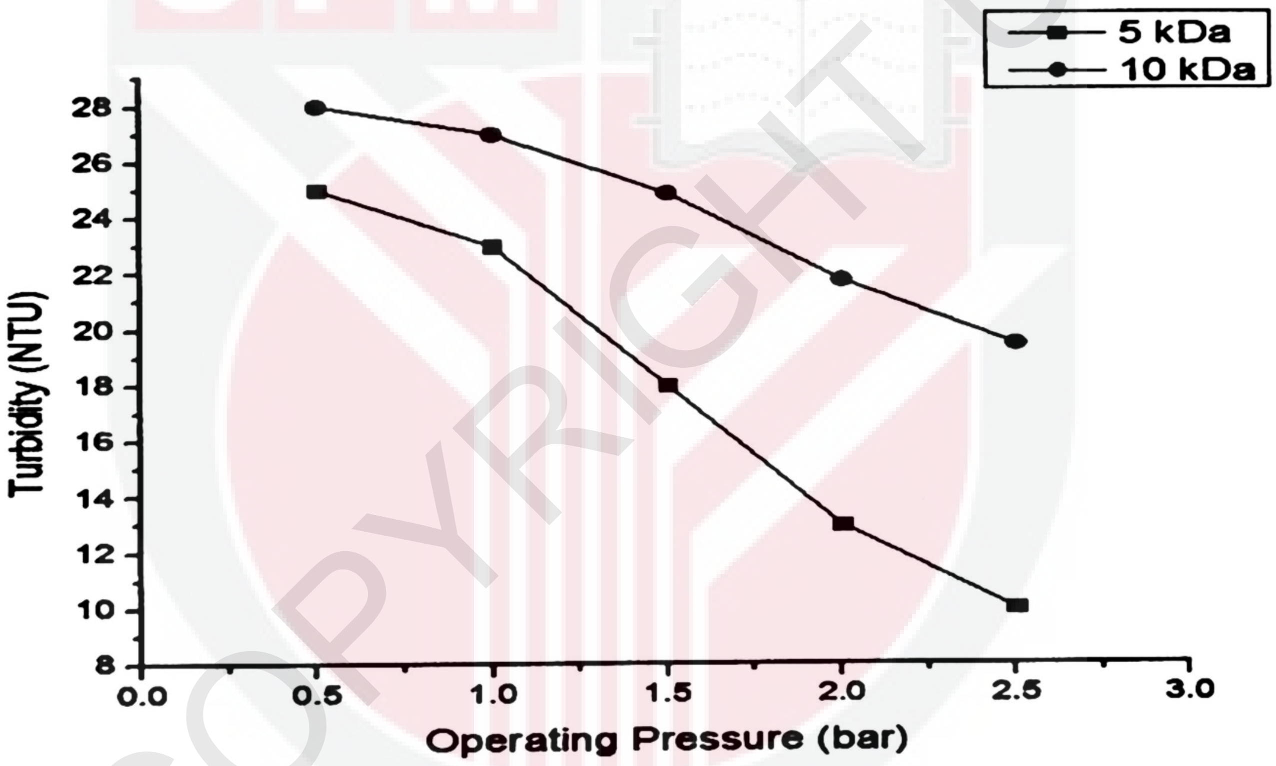


Figure 4.8 Turbidity values using different type of MWCO membrane at different pressure

Figure 4.8 showed that the decreasing trend for both 5 kDa and 10 kDa MWCO membrane as the pressure increase from 0 to 2.5 bar. The 5 kDa MWCO membrane much better to use in order to treat POME in term of turbidity because of the ability of the membrane to block and separate the unnecessary particle which may result in greater fouling on the membrane surfaces. The higher the pressure applied to the membrane, the faster the build-up cake resistance but good permeate produced. However, the lowest value of turbidity was 10 NTU at 2.5 bar operating pressure. The value is still has not yet to achieve the standard for drinking water thus it is still under standard for wastewater discharged limit.

4.3.5 Total Solid

Permeate from UF treatment was analysed for total solid (TS) content. In the pretreatment stage, the TS analysis shows a reduction of 81% from the value of 4200 mg/L to 800 mg/L. By using UF membrane separation, it is believed to filter the suspended solid which can be retained on a water filter and are capable of settling out of the water. By using oven drying method, the moisture content evaporated and left solid residue. The results of TS analysis as shown in figure 4.9.

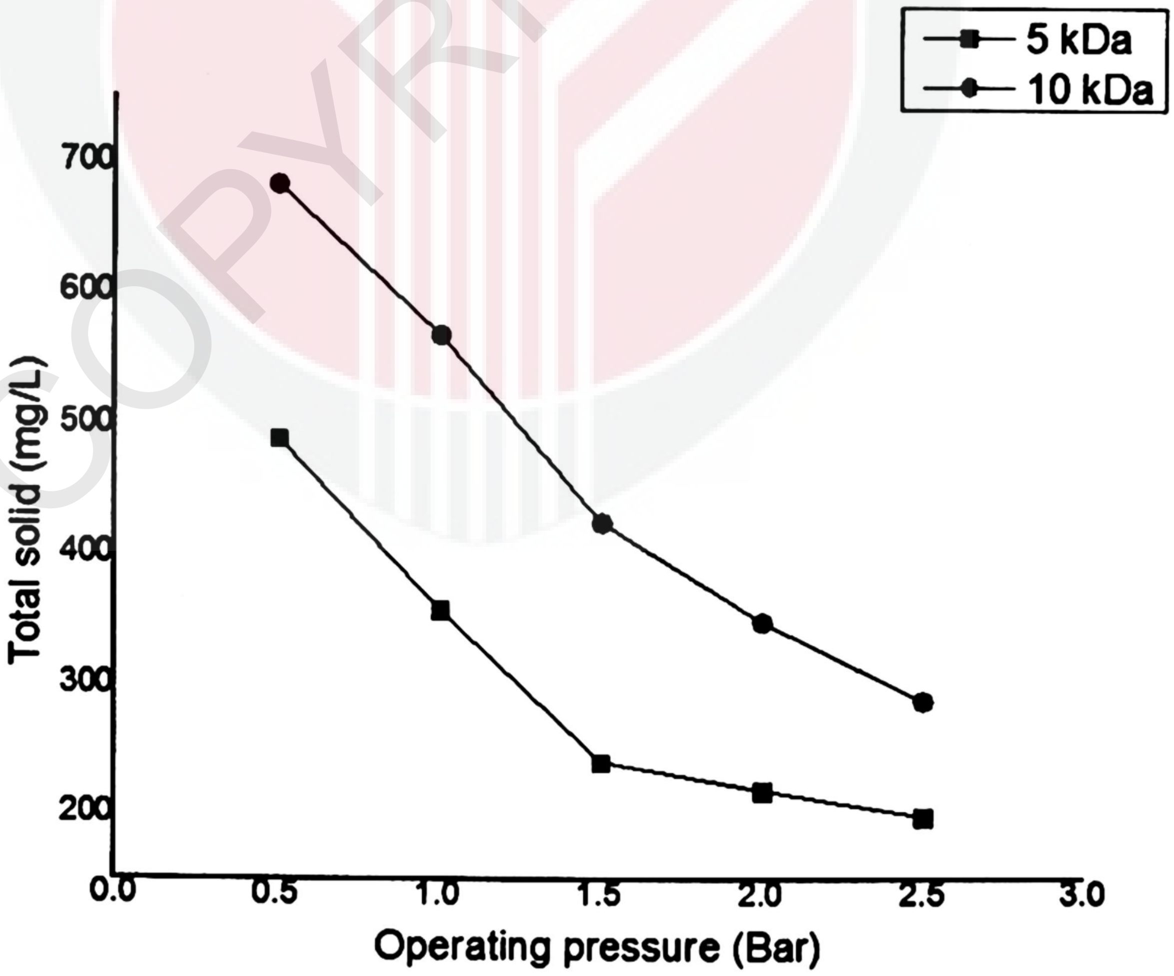


Figure 4.9: Total solid values using different type of MWCO membrane at different operating pressure

Figure 4.9 showed the trend reduction of TS analysis at different operating pressure using different MWCO membrane filtration. The trend of TS value gradually decrease as the operating pressure increase was due to the fouling factor and the permeate quality. As the pressure increase, the fouling factor will be greater hence produce a low flux rate but with a good permeate quality. The solid suspended on the membrane surface will cause a clogged between the pores and allow a good quality of permeate to pass through the membrane filtration. From the results, it can be deduced that the 5 kDa MWCO membrane produce much good quality of permeate than 10 kDa due to the size of pores that allow the unnecessary solid particles pass through the membrane filtration.

4.3.6 Color

Color analysis was carried out after membrane separation treatment to measure color changes throughout the process. The L* a* b* value indicates the characteristic of the color according to the color brightness, blueness or redness and yellowish properties. In the microbubble pretreatment, the color was reduced from slightly dark color to a brighter color due to the floatation process. The membrane separation has the ability to separate the unnecessary particle and produce a good quality of permeate due to the low MWCO characteristic. Table 4.3 and 4.4 shows the color analysis of permeate by using different type of membrane.

Table 4.3 Color of treated POME at different operating pressure by using 5 kDa MWCO RC membrane

Operating Pressure(bar)	L*	a*	b*	Chroma (C)	Hue angle (h)
0.5	20.3	6.7	17.6	18.83	69.16
1	20.4	6.5	17.6	18.76	69.73
1.5	20.3	6.5	17.5	18.66	69.62
2	20.8	6.6	17.5	18.70	69.33
2.5	20.8	6.7	17.4	18.65	68.94

Table 4.4 Color of treated POME at different operating pressure by using 10 kDa MWCO RC membrane

Operating Pressure(bar)	L*	a*	b*	Chroma (C)	Hue angle (h)
0.5	19.8	6.6	17.6	18.80	69.44
1	20.0	6.5	17.5	18.67	69.62
1.5	20.1	6.7	17.7	18.93	69.27
2	20.4	6.6	17.7	18.89	69.55
2.5	20.4	6.6	17.6	18.80	69.44

Table 4.3 and 4.4 showed the color analysis of permeate by using different type of membranes. The L* value which indicates the lightness are brighter after the treatment compared to before the pretreatment. The chroma and hue value also slightly decrease after the membrane separation treatment because of the characteristic of membrane filtration which allow only certain size of particle and discard the unwanted particle through fouling action on the surface of the membrane.

4.3.7 UF Membrane Treatment Outcome

Table 4.5 Summary of 5 kDa MWCO UF membrane treatment

Parameter	Operating pressure of UF membrane separation (bar)					Percentage reduction	WHO guideline for water reuse standard (2004)	Boiler feed water standard
	0.5	1.0	1.5	2.0	2.5			
Permeate Flux (L/m^2 hr)	37.35	42.41	44.59	46.00	47.46	-	-	-
COD (mg/L)	227	204	177	159	148	99%	500	5
BOD (mg/L)	217	189	145	137	118	99%	200	-
Total solid (mg/L)	488.7	356.9	240.3	218.2	198.3	99%	1650	-
Turbidity (NTU)	25	23	18	13	10	99%	-	0-3
Color (Chroma)	18.83	18.76	18.66	18.70	18.65	15%	-	-
Color (Hue)	69.16	69.73	69.62	69.33	68.94	5%	-	-

Table 4.6 Summary of 10 kDa MWCO UF membrane treatment

Parameter	Operating pressure of UF membrane separation (bar)					Percentage reduction	WHO guideline for water reuse standard (2004)	Boiler feed water standard
	0.5	1.0	1.5	2.0	2.5			
Permeate Flux (L/m^2 hr)	44.95	49.08	52.17	54.35	55.88	-	-	-
COD (mg/L)	263	238	213	196	188	99%	500	5
BOD (mg/L)	257	230	203	196	157	98%	200	-
Total solid (mg/L)	682	566.4	422.6	346.4	286.2	98%	1650	-
Turbidity (NTU)	28.0	27.0	24.9	21.8	19.5	99%	-	0-3
Color (Chroma)	18.80	18.67	18.93	18.89	18.80	15%	-	-
Color (Hue)	69.44	69.62	69.27	69.55	68.44	6%	-	-

The results of membrane ultrafiltration treatment showed both membrane can meet the standard for water reused and recycled by WHO which 5 kDa membrane performed better. The 5 kDa membrane can achieve the standard by using 1.0 bar of pressure meanwhile for 10 kDa membrane, 2.0 bar of pressure is needed to achieve the standard. The combination of microbubble treatment and membrane ultrafiltration was very effective in waste water treatment and can be applied to the industrial scale.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This project proposed a work on a treatment of POME waste water prior to meet the standard from DoE and WHO. The objective of this research which is to reuse water or water reclamation back to the mill and to indirectly achieve the standard discharge limit by DoE. This research was conducted by using two stages of treatments, microbubble technology as a pretreatment and UF membrane separation as a final treatment.

The microbubble pretreatment successfully reduce the parameter of the POME up to 69% of COD, 27% of BOD, 81% of total solid, 27% of turbidity and 2% of color. The microbubble has a unique characteristic that can produce high efficiency of floatation due to the negatively charged microbubble that bind together oils and solid particles and float on the surface of water as a scum. This research finding showed that the parameter was reduced as the time increase and indirectly reduce the major fouling factor before the following UF membrane separation treatment.

The UF membrane separation was carried out by using two type of RC membrane which is 5 kDa MWCO and 10 kDa MWCO at different operating pressure. The UF membrane separation conducted using stirred ultrafiltration cell (Amicon 8200, Milipore USA) in a batch mode. From the finding, it is believed that the 5 kDa performed better than the 10 kDa due to their characteristic of lower MWCO values which allow good quality of permeate and discard any particulate thus produce high efficiency of waste water treatment. The combined treatment successfully reduce up to 99% of all parameter except the color. The finding shows that this new type of wastewater treatment is promising to achieve both standard discharged limit and also the standard limit for water reuse and recycle.

According to the results obtained, it can be concluded that membrane ultrafiltration coupled with microbubble pretreatment has high efficiency to treat POME waste water and offer easier operating condition.

5.2 Future Recommendation

Based on this project work, the application of this new wastewater treatment should be studied further. It is recommended to install the flowmeter at the microbubble generator to measure the flowrates which affects the size of the microbubble produced. Even though the results meet the standard from DoE and WHO, the treated POME still have the unpleasant smell and high pH value. So it is recommended to investigate another treatment to reduce the smell and pH value.

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APPENDICES

A. Microbubble pretreatment raw data

Chemical oxygen demand

Operating time (hr)	1st	2nd	COD (mg/L)
0	220	232	22600
1	180	189	18900
2	140	122	13100
3	146	110	12800
4	105	93	9900
5	78	62	7000

$$\text{COD} = \frac{(220 + 232)}{2} = 226 \text{ (x5 dilution factor) (x20 dilution factor)}$$

COD = 22600

Biochemical oxygen demand

Operating time (hr)	D_i	D_f	BOD (mg/L)
0	4.88	0.65	12670
1	4.70	0.58	12330
2	3.69	0.53	10200
3	3.63	0.22	9850
4	3.51	0.28	9850
5	4.70	0.20	9280

$$\text{BOD} = \frac{4.88-0.65}{(\frac{5}{300})} = 253.8 \text{ (x5 df) (x10 df)}$$

BOD = 12670

Turbidity

Operating time (hr)	Turbidity (NTU)	Turbidity (NTU)
0	648	3240
1	636	3180
2	600	3000
3	568	2840
4	512	2560
5	476	2380

Turbidity = 648 (x5 df)

Turbidity = 3240 NTU

Total Solid

Operating time (hr)	Total solid (mg/mL)	Total solid (mg/L)
0	4.2	21000
1	3.8	19000
2	2.2	11000
3	2.0	10000
4	1.6	8000
5	0.8	4000

Total solid = 4.2 mg/mL (x1000) (x5 df)

Total solid = 21000 mg/L