# A mini review and bibliometric analysis of palm oil mill effluent in past five years

**F Mohd Pauzi[1], K Muda[1], H F Basri[1], A I Omoregie[1], C Y Hong[1], N S Aftar Ali[1], M Z Mohamed Najib[1], M F Mohd Amin[2], S Ismail[3], M F Mohamad Shahimin[4], and F A Dahalan[5]**

[1] School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[2] Faculty of Earth Science, University of Malaysia Kelantan, Kelantan, Malaysia

[3] Department of Engineering, Faculty of Science and Technology, University Malaysia Terengganu, Terengganu, Malaysia

[4] Department of Chemical Engineering Technology, Faculty of Engineering Technology, University of Malaysia Perlis, Perlis, Malaysia

[5] Water Research Group (WAREG), School of Environmental Engineering, University of Malaysia Perlis, Perlis, Malaysia

Corresponding author: khalida@utm.my

**Abstract**. Indonesia and Malaysia are countries with the highest palm oil production globally. Indonesia is leading the list, followed by Malaysia and Thailand. Palm oil production generates countless benefits to the economy, environment, and society of the contributed countries. This industry provides high income and collection of methane gas for biogas generation and economy of the local community. However, despite the benefits, this industry has some difficulties, including treating the Palm Oil Mill Effluent (POME). POME contains a complex microbial structure and a high amount of oil, grease, and suspended solids. The existing treatment of POME consists of many drawbacks that lead to poor quality of the effluent and failure to meet the minimum requirement from the Department of Environment (DOE). Advance Oxidization Process (AOP), bio granulation, and ponding system are among the research that have been tried to treat POME. The local government still uses old-style treatment types such as Conventional Activated Sludge (CAS), ponding system, and anaerobic digester tank. This review paper presents a mini review of positive and negative consequences the palm oil industry as well as examine a bibliometric study towards the modern research development of the POME. This mini review concludes that the palm oil industry encourages the positive impact in economy, environment and social to the many parties especially country and local community. Besides that, the existing treatment of the POME have to be improved appropriate with the increment of the demand and era.

## 1. Introduction

Malaysia and Indonesia produce 84% of global palm oil. Palm oil has become the most significant industry in Southeast Asia, especially in tropical countries like Malaysia, Thailand, and Indonesia [1]. In the palm oil industry, numerous amounts of water have been consumed and wastewater known as Palm Oil Mill Effluent (POME) is produced [2]. POME has a complex microbial structure, high acidity, Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). Palm oil is essential to the world as it is used daily in biofuels, agrifood, and body care sectors [3]. Besides that, this industry has become quite controversial as the palm oil industry receives a lot of criticism due to less sustainability and greenhouse emissions [4]. Many review papers have undoubtedly emerged since the end of this last year, which discussed specific methods, perspectives, or issues regarding the palm oil industry in Malaysia or Indonesia. As the time goes, the demand of the palm oil rises globally and lead to the increment of the palm oil production. As the result, the existing treatment may not capable to treat the numerous volumes of the liquid waste from the palm oil plantation [5]. The new approach needs to be proposed to reduce the pollutant of the POME released from the plantation. The alternative techniques suggest to increase the quality of the treated POME can be decided by observing the latest research development through bibliometric analysis. Hence, this mini review will focus on the development of the palm oil industry including the opportunities and obstacles of this industry as well as produce the bibliometric analysis to investigate the recent study of the wastewater treatment regarding to the liquid waste release from the palm oil industry.

## 2. Benefits and usage of Palm Oil

The production of palm oil is extremely beneficial to the economy, environment, and daily usage to the community. This paper highlights a few advantages for the modern application of palm oil in the past five years.

### *2.1 Economy*

*2.1.1 Production of palm oil.* For Southeast Asia, the production of palm influences the national economy of their countries, especially on the import and export values that fasten the economic growth and reduce poverty. As the latest provided data, Indonesia produced 40.57 million tons of palm oil, leaving Malaysia with 19.52 million tons in second place, followed by Thailand with 2.78 million tons production of palm oil [6]. Borneo and Sumatra became the leading islands to produce palm oil in Indonesia [7]. The output of these two islands covers two-thirds of Indonesia's total production. In Indonesia, the plantation of palm oil is divided into three administrations: owned by the government, private or personal plantations, and independent estate smallholders. The largest owner of palm oil plantations in Indonesia is Wilmar, consisting of 232,053 hectares (ha), up to 31 December 2020 of planted palm oil covering three countries, Indonesia, Malaysia, and Africa.

For Malaysia, according to the Observatory of Economic Complexity (OEC) [22], in 2019, the estimated export value of palm oil from Malaysia was USD8.91 billion and import value of USD686 million. Malaysia ranked as the second-largest country for exported palm oil and the ninth largest for importing countries. Back to the statistical data in 2018, a total of 41.2 million tons (MT) of biodiesel was produced by Malaysia. The production of palm oil recorded is 35% (14.42 MT), followed by soybean oil, rapeseed oil, and cooking oil with 26% (10.71MT), 16% (6.6 MT), and 11% (4.5 MT), respectively [8]. The most extensive administration of palm oil plantations in Malaysia is conquered by private estates such as Sime Darby and IOI Group. Although Sime Darby led palm oil production in Malaysia, Felda was declared as owning the world's largest land of planted palm oil, with 811,140 hectares of trees in the Malaysian peninsula of Sabah and Sarawak.

The palm oil industry is Malaysia’s primary revenue and the National Key Economic Area (NKEA) [9]. Besides that, the palm oil industry is also the primary biomass source as it produces a massive amount of biomass. Biomass is the animal or plant-based use to generate electricity or heat. The prominent role of biomass is to act as a fuel for combustion. According to MPOB, in 2016 palm oil biomass covers more than 80% of the available biomass in Malaysia. In Malaysia, the biomass sources can be divided into three categories, namely oil palm, forestry or agricultural, and garbage.

*2.1.2 The flow process of palm oil industry.* Fresh fruit bunches (FFB) need to undergo palm oil processes. Along with these processes, a massive amount of water and steam is used, especially in washing and sterilizing the FFB. The effluent from the palm oil mill is known as POME [10]. The raw POME consists typically of 95% to 96% of water, 0.6% to 0.7% of oil, and 4% to 5% of solids, including suspended solids. Besides that, there are also have some solid waste produced from the mill, such as empty fruit bunches (EFB), mesocarp fruit fibers (MFF), palm kernel shells (PKS), oil palm frond (OPF), and palm juice fiber (PJF).

The production process is summarized by Wu *et al.* (2010) [9]. Firstly, the FFB will be sterilized with pressurized steam (3x105 Pa) at the temperature of 140ºC for the moisture to evaporate into the nut. The following process is stripping, where the primary purpose is to separate the sterilized fruit from the bunch stalks using a rotary drum thresher. The solid or fruit that passes through the bar screen in the stripper will be collected then moved into the digester tank to be smashed at the temperature of around 85ºC. The crude palm oil is the squeezed fruit that separates from the nut. The last stage clarifies where to separate the oil form from entrained impurities. The output produced from the press machines is a mixture of palm oil, water, cell debris, fibrous material, and other insoluble solids with high viscosity. Figure 1 shows the flowchart of the process.

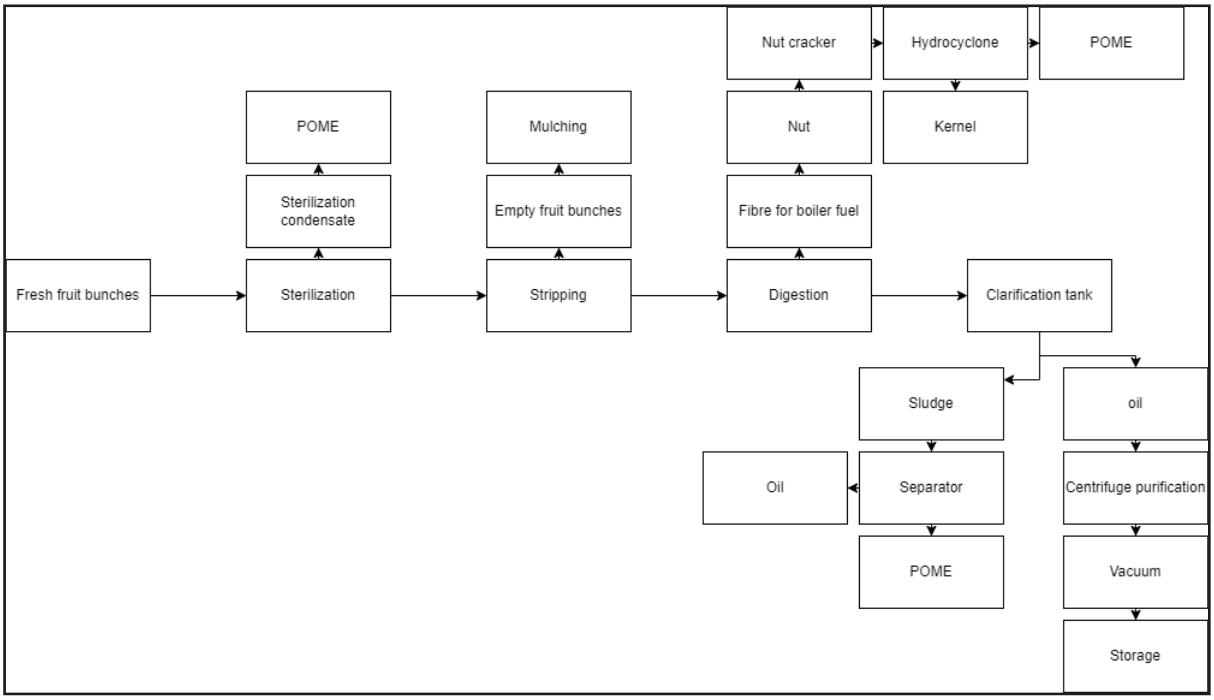


**Figure 1.** The flowchart of the palm oil processes in palm oil mill industry.

*2.2 Environment*

*2.2.1 Biogas generation.* Malaysia and Indonesia still apply the open ponding system to treat the POME [11]. During the treatment process, numerous biogas are released into the atmosphere. Otherwise, the biogas released can be captured and used as renewable energy and improve palm oil processing sustainability. To maintain the POME wastewater treatment that is environmentally friendly, a few methods were designed to process the methane gases released from the POME treatment.

As mentioned, the organic matters in POME are incredibly high. Thus, the addition of anaerobic digestion at the early stage of the treatment process is essential to convert the waste into biomethane. In Malaysia, anaerobic digestion is already applied in POME treatment using a ponding system. However, as there is low demand and lack of awareness, most biomethane are released into the atmosphere and harm the environment. In a study by Subramaniam *et al.* (2008) [12], non-recovered biomethane emission from palm oil mills contributed the highest impact on the environment such as a climate change. It, therefore, made the overall processes not environmentally friendly. The biomethane emission rate from POME is relatively higher than the biomethane emission rate from manure, biomass, and municipal solid waste. Thus, there is a huge potential in utilizing POME to generate high commercial returns and produce renewable energy in a more sustainable way [13].

There are four crucial reactions in anaerobic digestion; i) hydrolysis, ii) acidogenesis, iii) acetogenesis, and iv) methanogenesis [14]. The success of this system depends on the microbial community of the wastewater [15]. In this case, the microbial community inside the POME. pH and temperature also play an essential role in this treatment. The methane will be produced by two groups of bacteria called autotrophic methanogens and hydrogenotrophic methanogens. These bacteria are susceptible to oxygen. The little concentration of oxygen will kill all the methanogens. Figure 2 illustrate the flow process or mechanism of anaerobic digestion.

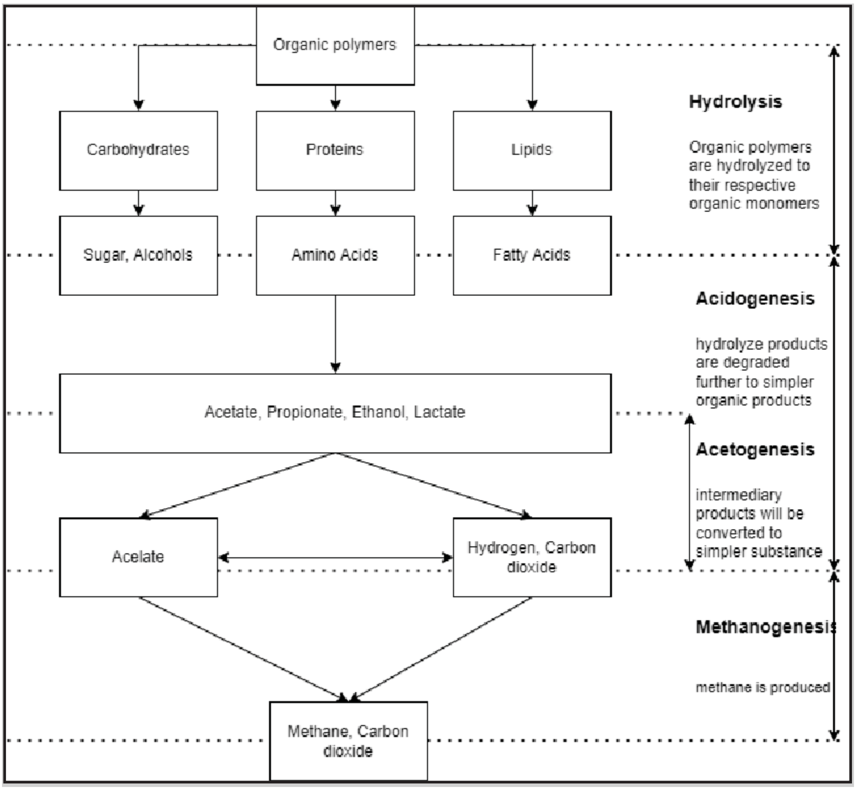


**Figure 2.** Mechanism of anaerobic digestion

*2.2.2 Fertilizer.* The solid waste from the industry, such as EFB, MF, and PKS, can also be used as fuel source to produce steam and energy for the mill. However, the combustion of non-wood structures like EFB will emit white smoke, which is harmful to the environment. The new disposal alternative of EFB needs to be carried out as it covers 25% of waste for every ton of FFB processed [10]. Kerdsuwan and Laohalidanond (2011) [16] found out that the current practice is to process the EFB into the fertilizer for the mushrooms. However, this method is not practical as the amount of EFB increases dramatically every year, and it is not suitable to convert all of this waste into fertilizer.

*2.3 Social*

A study to investigate the positive impact of palm oil mills from the social perspective of the worker. Throughout their research, they found that existing palm oil mills, especially in rural areas Malaysia and Indonesia, contribute to the community's social economy [17]. The existence of mills in their area indirectly offers job opportunities as well as improve housing conditions, landscaping, market infrastructure, migration, religious centers, rural development, and urbanization.

## 3. Challenges in managing POME

Throughout the process of palm oil production in the industry, the waste released from this process covers solid, liquid, and biomass waste. Some waste is converted into other substances by a specific technique and used for other purposes. The main problem is with the liquid waste, known as POME. POME is the wastewater used in palm oil mills for sterilization, hydrocyclone, and separator. The EFB and POME are the most inconvenient waste from palm oil mills [18]. POME is a critical by-product of the palm oil industry since it is very harmful to the environment if it is discharged untreated [19]. More than 50% of the water used in a mill ends up as POME [20]. To produce 1000kg of palm oil, around five to seven tonnes of water are used where 2.5 to 3.75 tonnes of water will become POME. POME will have a significantly negative impact on the environment, especially freshwater sources, if it is washed out from the mill without proper treatment [13].

POME is the liquid waste from palm oil mills [10]. Typically, the color of the POME is thick brown with a high value of BOD and COD [21]. Additionally, POME recorded a pH value of 4.5 to 5 with the temperature reaching 90 $^{o}$C, which supports that it is unsafe to discharge directly in water sources like rivers or seas. Besides that, POME contains around 95% solids, 4% oil, and 1% grease [23]. The DOE imposed a necessity for palm oil mills to fulfill specific characteristics before disposal of waste into the river. According to that regulation, the industrial effluent must achieve a BOD value of below than 20 mg/L for a particular area like Sabah and Sarawak and 100 mg/L for the others area in Malaysia and Indonesia. The standard value of BOD for raw POME is 25,000 to 65,714 mg/L. Due to the high regulation from the DOE, most of the mills in Malaysia and Indonesia do not fulfill this requirement [5;24]

Jawad *et al.* (2018) [25] found that the characteristics of raw POME at a palm oil mill in Seri Ulu Langat, Malaysia, consists of 10,843 mg of oil and grease per 1L of POME. Due to the high value of oil and grease, POME can form an oily layer on the river's water surface and deter light penetration into the water. This situation will lead to poor photosynthesis activities inside the river. Also, dissolved oxygen will be low due to the oily layer that prevents oxygen transfer from air to water. This phenomenon is hazardous to aquatic life which may later affect the food chain [51]. POME also contains a life-threatening quantity of heavy metals such as iron and zinc, with an average value of 119.5 mg per liter of POME [9]. The heavy metals in POME can be transferred to humans through the food chain and lead to acute diseases such as cancer [26]. Besides that, living organisms in a river contaminated with POME contain heavy metals that are non-biodegradable, toxic, and bio-accumulated [52]. Table 1 summarize the characteristics of raw POME and regulation by DOE.

**Table 1**. The characteristics of raw POME and regulations by DOE.

| Parameter | Raw POME | Regulation by DOE (Malaysia) | Regulation by Indonesia |
|---|---|---|---|
| BOD | 25,000 – 65,714 | 100 | 100 |
| COD | 44,300-102,696 | 1000 | 350 |
| TS | 40,500-72,058 | 1500 | 250 |
| SS | 18,000-46,011 | 400 | - |
| Oil and Grease | 4,000-9,341 | 50 | 250 |
| Ammoniacal-Nitrogen | 35-103 | 150 | - |
| Total Nitrogen | 750,103 | 200 | 25 |
| pH | 4-5 | 5-9 | 6-9 |
| Temperature | 80-90 | 45 | - |

## 4. Current treatment of POME

A few factors support that POME is compulsory to be treated before discharged from the mills. POME contains high organic content [27], and recorded a high value of BOD and COD [28]. Besides that, Tan and Lim (2019) [29] discovered that various approaches have already been applied for the treatment of POME in Malaysia, including chemical, physical or biological. The most common treatment in Malaysia is by anaerobic digestion. The famous treatment methods in Malaysia and Indonesia, namely anaerobic ponding treatment, integrated anaerobic-aerobic bioreactor, coagulation and flocculation, thermochemical vermicomposting technology, membrane filtration, photocatalysis, moving-bed biofilm reactor, zero-discharge, phytoremediation, adsorption, and microbial degradation [1]. The summary of every treatment as summarized in Table 2

### *4.1 Anaerobic ponding treatment (APT)*

APT is the most common method to treat wastewater with a high concentration of organic compounds [29]. Overall, this method converts the organic substance into methane and carbon dioxide gasses through an anaerobic process followed by hydrolysis, acidogenesis, and methanogenesis. The biogas released from this approach can be used as an alternative energy to generate electricity [30;31]. However, this method has drawbacks, such as long retention and start-up periods [32]. Conversely, this technique requires less cost and saves energy because it needs the aeration process compared with other approaches. Besides that, APT does not harm the environment because it only involves the natural decomposition process of an organic compound without using a chemical substance. The APT sludge can be converted into fertilizers [33]. However, the significant problem of APT for the mill owner is that this system requires a large area to construct the ponding system. Not only that, but the process to remove sludge at the bottom of the pond also involves higher expenses.

### *4.2 Integrated anaerobic-aerobic bioreactor (IAAB)*

IAAB is the reactor suitable for treating POME using a combination of aerobic and anaerobic processes. The microorganism degrades the organic waste inside the POME and converts it into biomass and carbon dioxide with the help of dissolved oxygen. For complex organic waste, the microorganisms

**Table 2**. The current treatment of POME.

| | APT | LAAB | CFT |
|---|---|---|---|
| Wastewater | ➔ High concentration of organic compound | ➔ Complex and uncomplex organic wastewater | ➔ POME |
| Mechanism | ➔ Convert organic substance into methane and carbon dioxide | ➔ Microorganism covert the organic materials inside POME into biomass and $CO_2$ | ➔ Using the chemical, biological coagulant<br>➔ Using rick-hush-ash trap<br>➔ Introducing electrical current<br>➔ Destabilize, emulsify and dissolve contaminants |
| Process involved | ➔ Anaerobic process, hydrolysis, acidogenesis, and methanogenesis | ➔ Combination of aerobic and anaerobic | ➔ Filtration<br>➔ Coagulation<br>➔ Flocculation |
| Advantages | ➔ Gases release are reusable to generate electricity<br>➔ Eco-friendly | ➔ High solid retention time<br>➔ Low hydraulic retention time<br>➔ High removal performance (99%)<br>➔ Able to remove large amount of organic compound | ➔ Good filtering performance SS<br>➔ Easy to handle<br>➔ Sludge produced can be convert into fertilizer |
| Disadvantages | ➔ Long retention and start-up period<br>➔ Required large area | ➔ Volume limitation | ➔ Need to combine with other treatment |
| Cost and energy consumption | ➔ Low cost<br>➔ Less energy consumption | ➔ High energy consumption | ➔ Energy saving |

*Cont…*

| | TT | MFT | PT |
|---|---|---|---|
| Wastewater | ➔ POME | ➔ POME | ➔ POME |
| Mechanism | ➔ Transform POME into syngas<br>➔ Carbon monoxide will then mainly be converted into hydrogen gas followed by carbon dioxide as the minor product using a water-gas shift reaction | ➔ separate molecules of different sizes and characteristics<br>➔ uses the different permeability of membranes to filter out the suspended solids in POME<br>➔ membrane separation rejects the organic matter leading to superior seepage quality | ➔ Killing pathogens in wastewater<br>➔ Speeds up photoreaction with the help of catalysts |
| Process involved | - | ➔ Filtration | ➔ Oxidization<br>➔ Photocatalytic |
| Advantages | ➔ High percentage removal (90%), including colour and odor<br>➔ Able to generate electricity and fuel | ➔ Product can be used as fertilizer | ➔ Low toxicity<br>➔ Good in removing heavy metals<br>➔ Ability to withstand biological and chemical corrosion<br>➔ Zero sludge production |
| Disadvantages | - | ➔ Use high flow rate<br>➔ Need full supervision | ➔ Harmful to environment as it release large amount of titanium dioxide |
| Cost and energy consumption | ➔ Low construction and maintenance cost | ➔ Low energy usage | ➔ Low cost |

*Cont..*

| | MBBR | ZLD |
|---|---|---|
| Wastewater | ➔ High concentration of biomass | ➔ POME |
| Mechanism | ➔ stick organic materials to the wet surface to promote bacteria growth<br>➔ microbes will break down the organic materials in the effluent to remove the BOD and COD values | ➔ |
| Process involved | ➔ Activated carbon<br>➔ biofilm | ➔ reverse osmosis<br>➔ crystallization<br>➔ factional electrode-ionization |
| Advantages | ➔ Required small area<br>➔ Able to work under high biomass density<br>➔ Able to convert by-products to fertilizer | ➔ Eliminate water discharge<br>➔ Able to generate electricity |
| Disadvantages | ➔ | ➔ |
| Cost and energy consumption | ➔ High cost<br>➔ High energy consumption | ➔ Low operational cost<br>➔ High capital cost |

degrade with the presence of oxygen to form methane gas, carbon dioxide, and water. The aerobic process is the essential process in wastewater treatment as it obtains a high removal performance [34;35;36]. Meanwhile, the anaerobic process is helpful for resource recovery and pollution control. The best treatment method is using the anaerobic and aerobic processes alternately. The anaerobic process benefits are high solid retention time and low hydraulic retention time. On the other hand, the aerobic process benefits in having a higher removal percentage of soluble organic matter and lower concentration of suspended soil effluent. Practically, IAAB is qualified in removing a large amount of organic compound proficiency. Statistically, IAAB shows excellent achievement by removing TS, BOD, and COD up to 99% and is capable of releasing methane gas to generate electricity [34]. However, this method's significant shortcoming is the volume limitation since it uses a reactor. Besides that, it also requires immense energy, especially to return the sludge to the aerobic department.

### *4.3 Coagulation and flocculation treatment (CFT)*

CFT is the primary alternative for a palm oil mill owner to treat the POME. CFT is a physiochemical treatment beneficial in energy consumption and good performance in filtering suspended solids with a straightforward operation and design process. By nature, CFT uses chemical coagulants to operate. Hence, most research has now started to find an alternative by using natural coagulants and flocculants. The combination of rick-husk-ash is able to trap 95% of turbidity and bacteria in water [37;38]. Rick-husk-ash is the natural coagulant-flocculants in a matrix of cement and filtration bed. Another alternative is introducing electrical current into the wastewater to destabilize, emulsify or dissolve contaminants [39]. Theoretically, hydroxyl ions will be formed as soon as metal ions are present in the water. This method is considered the combination of an advanced oxidation process and biological treatment as it does not involve any chemical substance. This method also promotes energy-saving and is easy to handle. The sludge produced from this technique can be converted into fertilizer to increase palm oil production [38]. Although CTF can reduce the suspended solids and COD of POME, this treatment must be combined with other types of treatment, especially with membrane filtration or anaerobic digestion [28]. Besides that, the sludge produced using CFT with chemical coagulant-flocculants is toxic [37]

*4.4 Thermochemical treatment (TT)*

This process involves the transformation of POME into profitable products such as syngas by using supercritical water gasification with the help of catalysts at high temperatures—the carbon monoxide gases produced at the end of the steam reforming process. Carbon monoxide will then mainly be coverted into hydrogen gas followed by carbon dioxide as the minor product using a water-gas shift reaction. This method would remove 90% of BOD and COD and is capable of odor and color removal of POME [28;40]. TT system is the most common in POME as it is a feedstock that is more favorable than coal before POME is low in sulfur and less reactive [41]. The product from this method can also generate electricity, heat, or liquid fuel. The main reasons why this method is commonly used are due to low construction and operational cost.

*4.5 Membrane Filtration Technology (MFT)*

MFT is the standard method used to separate molecules of different sizes and characteristics. It is considered a physical approach because it uses the different permeability of membranes to filter out the suspended solids in POME [42]. In this system, the membrane separation rejects the organic matter leading to superior seepage quality with a high-water recovery ratio. Additionally, MFT does not involve the activated sludge process, which leads to low energy usage. Besides that the by-product of MFT is also rich in nutrients and organic waste that can be reused as fertilizer or renewable energy [43]. MFT is considered the best method for treating POME because it filters suspended solids effectively, produces renewable by-product, and has low energy usage. The MFT can save the environment as it can block the process of eutrophication [44]. However a few disadvantages in using MFT to treat POME. Firstly, the cross-flow feed uses a high flow rate that may lead to the interference of shear-sensitive materials. Next, a possible error may occur during the process that leads to the reduction in permeate flux. Lastly, this system needs full supervision as it may lead to a wide pore size distribution that can reduce the performance of this system [28].

*4.6 Photocatalysis treatment*

Photocatalysis treatment is considered as the physical treatment that speeds up photoreaction with the help of catalysts. Previous results showed that this method is suitable for degrading pollutants and killing pathogens in POME. There are four types of materials used in photocatalysis; i) titanium oxide, ii) sulfides, iii) polymeric carbon nitrite, and iv) bismuth-based photocatalysts [45-46]. The material with advantages in low toxicity, low cost, suitable in various band and valence band positions for degradation band is titanium oxide. The oxidation of the photogenerated holes and reduction of the photogenerated electrons must occur simultaneously in the photocatalytic process. The pre-treatment process in wastewater treatment must be conducted before the main photocatalysts treatment takes place to avoid the fibers from shielding UV penetration [47]. The few advantages of this system, which are good in removing heavy metals, ability to withstand biological and chemical corrosion, and zero sludge production [47]. However, Lee *et al.* (2019) [28] countered the agreement by stating that this method is harmful to the environment as it releases a large amount of titanium dioxide. The titanium dioxide should be removed from the treated effluent.

*4.7 Moving bed biofilm reactor (MBBR)*

MBBR combines the activated carbon process and biofilm to treat wastewater more effectively. The basic concept of MBBR is to start with a high concentration of microbial biomass by improving the suspended and attached growth system. The MBBR consists of a few components: biofilm, flow configuration, aeration system, and media. The highlighted element is biofilm. Biofilm is a slim layer of inorganic and organic materials that stick to the wet surface to promote bacteria growth. Water plays an essential role in determining bacterial life and nutrient availability as it maintains the osmotic pressure [48]. The microbes will break down the organic materials in the effluent to remove the BOD and COD values [49]. Since MBBR uses reactors, it only requires a small area compared with other treatments [48]. Besides that, MBBR does not require backwashing and can work under a high biomass density.

The nitrates' by-products of this method can be generated as fertilizer for palm oil trees. However, the major drawback for MBBR is it requires a high cost for the aeration process to allow fluidization in the reactor [49]

*4.8 Zero Liquid Discharge (ZLD) treatment*
ZLD is the type of treatment that combines several methods of treating POME, such as ultrafiltration, reverse osmosis, crystallization, and factional electrode-ionization. ZLD treatment is a water treatment process in which no water is discharged but instead reused after the treatment. This situation eliminates the risk of water contamination and maximizes water usage. Three types of ZLD are commonly used in wastewater treatment: thermal ZLD system, RO-incorporated thermal ZLD system, and emerging membrane-based ZLD system. The advantage of the ZLD system is that fertilizer and electricity can be directly generated during sludge and biogas recovery [50]. It also considers less operational cost as it causes minor damage to membrane and reactors. This system also reuses 100% of the by-product, making it a zero-wastage system .The main disadvantage of the ZLD system is the high capital cost.

## 5. The recent research trend of POME in Malaysia and Indonesia

*5.1 Method of data collection*
The process of data mining started in early 2022. The selection of documents are from the previous five years, indicating the latest documents produced from 2017 until 2021. Since this paper did not focus on specific experimental or lab work, all the documents were included, including the review papers. The documents that involved Malaysian or Indonesian researchers were retained for the analysis. The final search string for this study are as follow; ( TITLE-ABS-KEY ( "Palm oil mill" ) AND TITLE-ABS-KEY ( waste ) OR TITLE-ABS-KEY ( pome ) ) AND ( LIMIT-TO ( AFFILCOUNTRY , "Malaysia" ) OR LIMIT-TO ( AFFILCOUNTRY , "Indonesia" ) ) AND ( LIMIT-TO ( PUBYEAR , 2022 ) OR LIMIT-TO ( PUBYEAR , 2021 ) OR LIMIT-TO ( PUBYEAR , 2020 ) OR LIMIT-TO ( PUBYEAR , 2019 ) OR LIMIT-TO ( PUBYEAR , 2018 ) OR LIMIT-TO ( PUBYEAR , 2017 ) OR EXCLUDE ( PUBYEAR , 2022 ) ).

The analysis method can be divided into two components: the analysis directly by Scopus, and analysis using the application VOSviewer. Information such as annual and cumulative publications, leading countries, and institution can be observed straight from Scopus. However, to keep the detailed international collaboration, link strength, total link strength, and the connection on the author keywords, further analysis using the VOSviewer had to be done. This study used the VOSviewer version 1.6.17.

*5.2 Result and discussion*
As shown in Figure 3 and Figure 4, for the past five years, a total of 861 documents regarding POME were recorded in the Scopus database. The highest publication was recorded in 2020 (199 papers), followed by 2021 (173), and 2019 (171). The trend of the publications can be said to increase every year until 2020 before it started to decline in 2021. A few factors may have led to the decrease, such as the CoVID-19 pandemic that complicated the research process. Based on the affiliation that actively produced papers on POME, the top leading academic institution is UKM with 103 documents, followed by UTM (101), and UMP (84). Nine out of the top institutions that researched POME are from Malaysia. On the other hand, only Universitas Sumatera Utara (USU), the academic institution from Indonesia, was listed on the seventh rank with 37 publications.

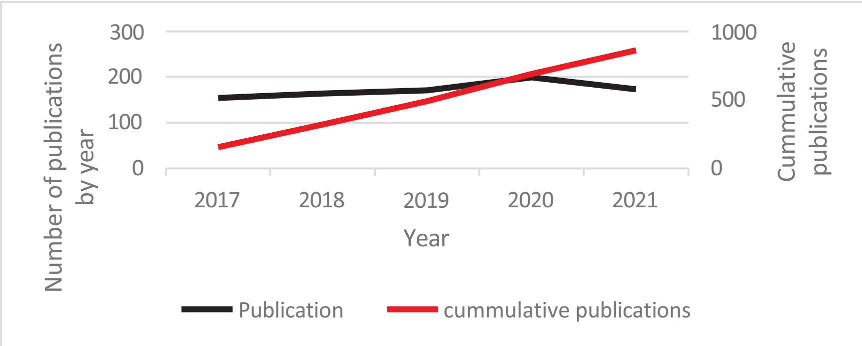


**Figure 3**. Number of publications from 2017 to 2021.

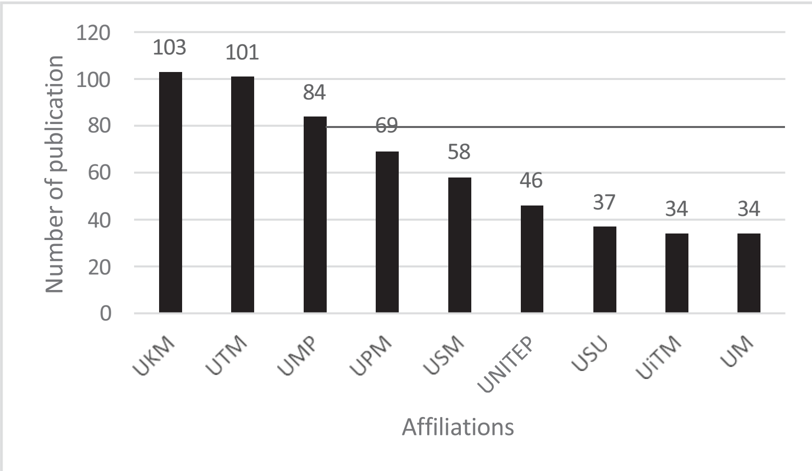


**Figure 4.** Active affiliations.

Out of 861 papers in 2017 until 2021, 656 papers involved Malaysian researchers, while only 231 papers were contributed by Indonesian researchers. Other countries with initial collaborations with Malaysia or Indonesia are Japan, Nigeria, the United Kingdom, China, India, the United States of America, Thailand, Bangladesh, and Saudi Arabia. With regard to international collaborations, Malaysia is linked with 45 countries compared to Indonesia with only 16 countries. Malaysia and Japan have 31 publications, making them the countries with the highest link strength. Malaysia and Indonesia recorded 26 papers that linked together. Surprisingly, Malaysia and Nigeria also have a high international collaboration rate as they published 25 documents that involved researchers from both countries. For Indonesia, according to the analysis by VOSviewer, the connection of Indonesia-Malaysia share the same strength as the collaboration between Indonesia-Japan. Overall, 46 countries own at least one document linked to Malaysia or Indonesia in producing a research paper on POME. The screenshot from VOSviewer application as displayed in Figure 5.

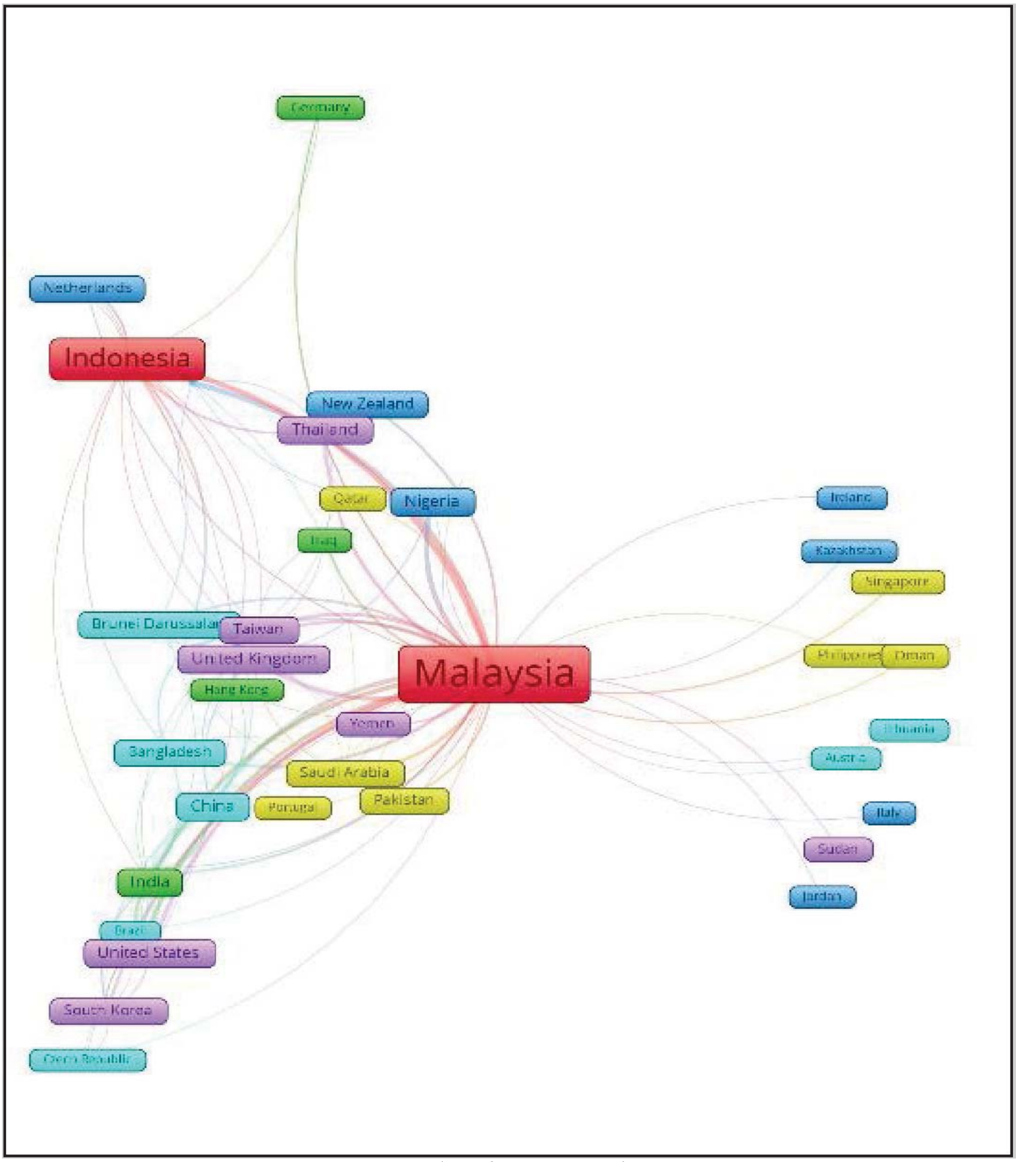


**Figure 5.** A screenshot from VOSviewer

## 6. Conclusion

Overall, this study concludes that the world supply for palm oil depends on Southeast Asia countries, especially Indonesia, Malaysia, and Thailand. The palm oil industry in these countries has both positive and negative impacts on the economy, environment, and society. Indonesia recorded the highest palm oil production worldwide; however, Malaysia leads the research by producing research articles, including review papers, experimental papers, and others. The biggest challenge in managing the palm oil industry is in treating the wastewater from the mills or known as POME. POME has a complex microbial community as recorded by the high concentration of suspended solids, acidity, oil and grease, COD, and BOD. This review paper also discussed the current treatment applied in Indonesia and Malaysia. The study found that the ponding system is the favorite method of palm oil mill owners. Each type of treatment has its advantages and disadvantages. Malaysia and Indonesia have produced a total of 861 documents regarding POME in the past five years. Malaysia shows its excellence in research trends by leading the research activity and moving ahead of Indonesia.

**Acknowledgment**: The authors would like to express their appreciation for the financial support from Universiti Teknologi Malaysia with the Research University Grant Vot. No. 09G78.

**References**

[1] Kristanti R, Hadibarata T, Yuniarto A and Muslim A 2021 Palm Oil Industries in Malaysia and Possible Treatment Technologies for Palm Oil Mill Effluent: A Review. *Journal of Enviromental* 50-65.

[2] Hariz H, Yasin M, Ba-Abbad M and Hakimi N 2019 Potential of the microalgae-based integrated wastewater treatment and CO2 fixation system to treat Palm Oil Mill Effluent (POME) by indigenous microalgae; Scenedesmus sp. and Chlorella sp. . *Wat Processs Engineering*, 32.

[3] Mutsaers H 2019 The challenge of the oil palm: using degrated land for its cultivation. *Outlook Agric.* 190-197.

[4] Jamaludin N M 2019 Evaluating the palm oil demand in Indonesia: production trends, yields, and emerging issues. *Clean. Prod* 496-509.

[5] Tamrin K Z A 2017 Determination of optimum polymeric coagulant in the palm oil mill effleunt coagulation using multiple-objectives optimisation on the basis of ratio analysis (MOORA). *Environmental Science and Pollution Research*.

[6] Rithie H and Roser M (6, 2021). *Our world data*. Retrieved from Our world data: https://ourworldindata.org/palm-oil

[7] Shahbandeh M (20 1, 2022). *Statista*. Retrieved from Statista: https://www.statista.com/topics/6079/global-palm-oil-industry/#dossierKeyfigures

[8] Von Schenck W 2020 *Union Zur Forderung Von Oel-Und Proteinpflanzen E.V (UFOP) (2020)*. Retrieved from UFOP report on global market supply 2019/2020. Agricultural Market Information Company (AMII): https://www.ufop.de/files/7215/7953/0161/WEB_UFOP_Global_Supply_Report_A5_EN_19_20.pdf

[9] Wu T M 2010 Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. *Environ. Manage* 1467-1490.

[10] Chew C L et al. 2021 Improving sustainability of palm oil production by increasing oil extraction rate: a review. *Food Bioprocess Technol*.

[11] Chan Y J T W 2015 Fuzzy optimisation approach on the treatment of palm oil mill effluent (POME) via up-flow anaerobic sludge blanket–hollow centered packed bed (UASB–HCPB) reactor. *J. Water process engineering* **5** 112-117.

[12] Subramaniam V M A 2008 Environmental performance of the milling process of Malaysian palm oil using the life cycle assessment approach. *J. Environ Sci* 310-315.

[13] Lam M K, Lee K T 2011 Renewable and sustainable bioenergies production from palm oil mill effluent (POME): Win–win strategies toward better environmental protection. *Biotechnology*

*Advances* 124-141.
[14] Demirel B S P 2008 The roles of acetotrophic and hydrogenotrophic methanogens during anaerobic conversion of biomass to methane: a review. *Rev Environ Sci Biotechnol* **7** 173–90.
[15] P W 2010 Biogas production: current state and perspectives. *Appl Microbiol Biotechnol* **85** 849–60.
[16] Kerdsuwan S and Laohalidanond K 2011 Renewable Energy from Palm Oil Empty Fruit Bunch. *Renewable Energy*.
[17] Ayompe L, Schaafsma M and Egoh B 2021 Towards sustainable palm oil production: The positive and negative impacts on ecosystem services and human wellbeing. *Journal of Cleaner Production*.
[18] Khalid N, Rajandas H, Parimannan S J, Croft L, Loke S, Chong C, Yahya A 2019 Insights into microbial community structure and diversity in oil palm waste compost. *J. Biotech*.
[19] Poh P M C 2009 Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. *Bioresour. Technol*, 1-9.
[20] Fitrah R A A 2019 Enhanced biogas production by mesophilic and thermophilic anaerobic co-digestion of palm oil mill effluent with empy fruit bunches in expanded granular sludge bed reactor. *IOP COnf Ser. Mater. Sci. Eng*, 012029.
[21] Poh P E Y W 2010 Palm oil mill effluent (POME) characteristic in high crop season and the applicability of high-rate anaerobic bioreactor for the treatment of POME. 11732-11740.
[22] OEC 2019 OEC. Retrieved from OEC: https://oec.world/en/profile/hs92/palm-oil
[23] Azmi N S Y K 2014 Wastewater treatment of palm oil mill effluent (POME) by ultrafiltration membrane separation technique coupled with adsorption treatment as pretreatment. *Agriculture and Agricultural Science Procedia* **2** 257-264.
[24] Saputera W H, Amri A F, Daiyan R, Sasongko D 2021 Photocatalytic Technology for Palm Oil Mill Effluent (POME) Wastewater Treatment: Current Progress and Future Perspective. *Materials*. **14(11)** 2846. https://doi.org/10.3390/ma14112846
[25] Jawad R, Ismail M and Izhar S 2018 Adsorption Of Heavy Metals And Residual Oil From Palm Oil Mill Effluent Using Novel Adsorbent Of Alginate And Mangrove Composite Beads Coated By Chitosan In A Packed. IIUM Engineering Journal.
[26] Ghaedi M M N 2013 Removal of heavy metal ions from polluted waters by using of low cost adsorbents: Review. *Journal of Chemical Health Risks* **3(1)** 7-22.
[27] Hashiguchi Y Z 2020 Toxicity identification and evaluation of palm oil mill effluent and its effects on the planktonic crustacean Daphnia magna. *Sci. Tot. Env*. **710** 136277.
[28] Lee Z C 2019 Treatment technologies of palm oil mill effluent (POME) and olive mill wastewater (OMW): A brief review. *Environ. Technol* **15** 100377.
[29] Tan Y a 2019 Feasibility of palm oil mill effluent elimination towards sustainable Malaysian palm oil industry. *Renew. Sust. Energy Rev* **111** 507-522.
[30] Yap C C 2020 Comparison of different industrial scale palm oil mill effluent anaerobic systemsin degradation of organic contaminants and kinetic performance. *J Cleaner Prod* **262** 121361.
[31] Monir M A 2018 Gasification of lignocellulosic biomass to produce syngas in a 50-kW downdraft reactor. *Biomass and Bioenergy* **119** 335-345.
[32] Khadaroo S P 2019 Applicability of various pretreatment techniques to enhance the anaerobic digestion of Palm oil Mill effluent (POME):hance the anaerobic digestion of Palm oil Mill effluent (POME):hance the anaerobic digestion of Palm oil Mill effluent (POME): A review. *Journal of Environmental Chemical Engineering* **7(5)** 103310.
[33] Chin Y J 2020 Comparison of different industrial scale palm oil mill effluent anaerobic systems in degradation of organic contaminants and kinetic performance. J. Cleaner Prod, 262, 121361.
[34] Chan Y C 2012 An integrated anaerobic-aerobic bioreactor (IAAB) for the treatment of palm oil mill effluent (POME): Start-up and steady state performance. Process Biochemistry **47(3)** 485-495.
[35] Ohimain E a 2017 A review of biogas production from palm oil mill effluents using different

configurations of bioreactors. *Renew. Sust. Energy Rev* **70** 242-253.
[36] Hadibarata T K 2017 Biodegradation of pyrene by Candida sp. S1 under high salinity conditions *Biopro Biosys. Eng*. **40(9)** 1411-1418.
[37] Huzir N A 2019 Optimization of coagulation-flocculation process for the palm oil mill effluent treatment by using rice husk ash. *Ind. Crops Prod*. **139** 111482.
[38] Lek B P 2018 Treatment of palm oil mill effluent (POME) using chickpea (Cicer arietinum) as a natural coagulant and flocculant: Evaluation, process optimization and characterization of chickpea powder. *J. Environ. Chem. Eng* **6(5)** 6243-6255.
[39] Nasrullah M S 2020 Electrocoagulation treatment of raw palm oil mill effluent: Effect of operating parameters on floc growth and structure. *Journal of Water Process Engineering* **33** 101114.
[40] Ng K Y 2019 TiO2 and ZnO photocatalytic treatment of palm oil mill effluent (POME) and feasibility of renewable energy generation: ent (POME) and feasibility of renewable energy generation. *J. Cleaner Prod* **233(8)** 209-225.
[41] Cheng Y N 2019 Syngas from catalytic steam reforming of palm oil mill effluent: An optimization study. *Int. J. Hydrogen Energy* **44(18)** 9220-9236.
[42] Goswami L K 2018 Membrane bioreactor and integrated membrane bioreactor systems for micropollutant removal from wastewater: A review. *J. Wat. Process Eng* **26** 314-328.
[43] Abdurahman N A 2017 An integrated ultrasonic membrane an aerobic system (IUMAS) for palm oil mill effluent (POME) treatment. *Energy Procedia* **138** 1017-1022.
[44] Aziz M K 2020 Recent advances on palm oil mill effluent (POME) pretreatment and anaerobic reactor for sustainable biogas production. *Renew. Sust. Energy Rev* **119** 109603.
[45] Alhaji M S 2016 Photocataytic treatment technology for palm oil mill effluent (POME) - A review. *Process Saf. Environ. Prot* **02** 673-686.
[46] Alhaji M S 2018 Photooxidation of pre-treated palm oil mill Effluent using cylindrical column immobilized photoreactor. *Process Saf. Environ. Prot* **50** 180-189.
[47] Tang K H 2021 Interactions of Microplastics with Persistent Organic Pollutants and the Ecotoxicological Effects: A Review. *Tropical Aquatic Soil Pollut* **1(1)** 24-34.
[48] Bakar S N H A H H 2018 A review of moving-bed biofilm reactor technology for palm oil mill effluent treatment. *J Cleaner Prod* **171** 1532-1545.
[49] Leyva-Díaz J M G P M 2020 Moving bed biofilm reactor as an alternative wastewater treatment process for nutrient removal and recovery in the circular economy model. *Bioresource Technol* **299** 122631.
[50] Tabassum S Z 2015 An integrated method for palm oil mill effluent (POME) treatment for achievng zero liquid discharge - A pilot study. *J. Cleaner Prod* **95** 148-155.
[51] Jameel A T, M S 2011 Removal of oil and grease as emerging pollutants of concern (EPC) in wastewater stream. *IIUM Engineering Journal* **12(4)** 161-169.
[52] Bernard E J A 2013 Adsorption of Pb, Fe, Cu and Zn from industrial electroplating wastewater by orange peel activated carbon. *International Journal of Engineering and Applied Sciences,*, **4(2)** 95-103.