Journal of Oil Palm Research Vol. 36 (3) September 2024 p. 534-546
DOI: https://doi.org/10.21894/jopr.2023.0056

PALM OIL MILL EFFLUENT (POME) AS A SOURCE OF BIOFUELS AND VALUE-ADDED PRODUCTS VIA OIL RECOVERY: A REVIEW

YEE MUN TANG[1]; KOK TAT TAN[2] and LAI PENG WONG[1]*

ABSTRACT

Large scale palm oil production will inevitably generate a vast amount of liquid waste, particularly palm oil mill effluent (POME), that has adverse environmental impacts. While most studies concentrate on the organic removal from POME, the recovery of valuable resources from the effluent is infrequently described. The rising awareness of sustainability has motivated palm oil millers and academics to enhance waste management while also placing cognisance need for the resource's recovery. POME possesses a substantial amount of oil and grease (O&G), which can be valorised into value-added products such as biofuels or phytonutrients via oil recovery. Recovering oil loss through POME not only prevents income loss but also improves downstream treatment effectiveness. In this article, the perspective of oil recovery from POME, focusing on technologies like physical separation, chemical extraction, and ultrasonic irradiation as a pre-treatment will be discussed, along with their effectiveness and limitations. Additionally, future opportunities as well as the economic viewpoint will be looked upon to provide a comprehensive outlook. Overall, this article will provide the readers with an understanding of the significance of recovering oil from POME and its potential as a sustainable resource, contributing to effective waste management and supporting a circular economy.

Keywords: biofuel, oil recovery, palm oil mill effluent, sustainable, valorisation.

Received: 9 February 2023; **Accepted:** 27 August 2023**; Published online:** 26 October 2023.

INTRODUCTION

Malaysia is recognised as the world's second-largest producer and exporter of palm oil after Indonesia, accounting for 25.8% and 34.3% of global palm oil production and exports, respectively, with more than 18 million tonnes of crude palm oil (CPO) produced in 2022 (MPOB, 2022a). While Malaysia benefits economically from its massive palm oil production, it also generates a large quantity of industrial wastewater known as palm oil mill effluent (POME), a high-strength acidic contaminant with substantial solids and organic contents. Despite enhanced extraction efficiency in the palm oil mills, a significant amount of oil and grease (O&G) was unavoidably discovered in the effluent as oil losses. Studies have shown that the average oil loss in POME is around 4000 to 6000 mg/L (Choong *et al.*, 2018; Lee *et al.*, 2019), which has been largely neglected by the industry without realising the effects and potentials that might be generated.

Conventional POME treatment via biological process focuses primarily to avoid penalties from non-conformance with the government regulations by adhering to the stringent discharge limits. However, they have frequently overlooked the resource recovery from POME for higher value-added products. Resource recovery from waste is far more than just being sustainable, as it would concurrently lead to less environmental impacts and promotes economic development in the industry.

---

[1] Department of Environmental Engineering,
Faculty of Engineering and Green Technology,
Universiti Tunku Abdul Rahman,
Jalan Universiti Bandar Barat,
31900 Kampar, Perak, Malaysia.

[2] Department of Petrochemical Engineering,
Faculty of Engineering and Green Technology,
Universiti Tunku Abdul Rahman,
Jalan Universiti Bandar Barat,
31900 Kampar, Perak, Malaysia.

* *Corresponding author e-mail: wonglp@utar.edu.my*

These practices would also act as a cradle for green industry practices such as harnessing renewable energy sources, and reducing dependency on the depletable fossil fuels, while minimising negative impact on the planet all at one go.

The whole objective of this article aims to concisely review and report on the oil management strategies from POME that have not previously been compiled to acquire insight for better effluent management. As the current scenario in palm oil research focuses on resource recovery, this article introduces technologies for oil recovery from POME, along with their mechanisms of action, advantages, and disadvantages, while also presenting a green technology for enhancing oil recovery from POME via ultrasonication. Future opportunities in terms of environmental, social, and governance (ESG) as well as the economic viewpoint were looked upon. This strategy will pave the way for waste recovery and resource valorisation, which will not only effectively reduce pollution degree, but also greatly reduce the usage of non-renewable sources, moving the palm oil industries towards a sustainable development.

PALM OIL MILL EFFLUENT

Over the past 60 years, palm oil production has increased substantially as a result of expanding global population and driving demand from the food and beverage, oleochemical and biodiesel industries. Global palm oil production in 2022 reached a new high of 77 million tonnes, which is 40 times the output from 1970 (Edi, 2022). Nonetheless, the continual expansion of palm oil production will undeniably generate massive volumes of waste. A typical extraction operation of 1 t of CPO would require 5.0-7.5 t of water, with over half of it ending up as liquid waste (Mohammad *et al.*, 2021). POME is the most prominent oily pollutant in palm oil mills derived from the mixture of steriliser condensate, crude oil clarification, and hydro-cyclone effluent. Not to mention that various boiler blowdown, tank and decanter drains, water used for maintenance and cleaning also resulted in POME generation.

Due to the heterogeneity of POME, no fixed values are provided for its attributes, as they fluctuate significantly in response to starting material qualities and processing variations. *Table 1* summarises the general physicochemical properties of raw POME along with the established regulatory limits to the discharge of POME. The raw POME characteristics were found to be non-compliant with the discharge limits.

POME is a solid-liquid effluent composed primarily of fine cellulosic materials as well as water-soluble oil palm components. Commonly, POME is a dense, brownish underutilised agro-industrial wastewater discharged at high temperatures and with a low pH value. Owing to the elevation of solids, O&G, and organic contents, indiscriminate discharge of untreated POME on land and into waterway can be concomitantly sensitive to environmental issues. POME is also eutrophic and emits an unpleasant odour due to its rich mineral content.

Presence of Oil and Grease in POME

Section 304(a) of the Clean Water Act (CWA) classifies O&G as conventional pollutants. In recent years, biological treatment has been the most prevalent approach for the treatment of POME (Cheng *et al.*, 2021; Yashni *et al.*, 2020). Despite POME's biodegradability ability, oil is notoriously difficult to be degraded biologically since not all microorganisms generate lipase enzymes that are capable of decomposing triglycerides. Oil film deposition surrounding the microbes would interfere with the existing biological treatment by hindering the transmission of oxygen and soluble substrate for microbial degradation. This will ultimately result in a decrease in the efficacy of treatment process and an increase in the operational treatment cost.

The oil droplets in POME exist in two phases being either floating in the supernatant or embedded in the solids. Due to the harsh mechanical processing, residual oil in POME is mostly in emulsified and dispersed form (<150 μm). In addition, the presence of natural surfactants in POME, such as glycolipids and phospholipids, increases the oil's stability, making it more resistant to coalescence and more challenging to be separated by natural means. POME is also highly complicated in nature due to the involvement of a diverse structure of cellulose, hemicellulose, and lignin (Hii *et al.*, 2012). The carbohydrate-rich particles in POME encapsulate bulk of the oil droplets due to their amphiphilic properties, with predominating lipophilic capabilities (Wan Sharifudin *et al.*, 2015). In brief, the oil is believed to be primarily trapped in the suspended solids and inseparable mechanically from the multiphase system, contributing to poor recovery and resource wastefulness in the long term.

OIL MANAGEMENT STRATEGIES FROM POME

Although biological treatment shows a certain level of efficiency in treating POME, it frequently disregards the resource recovery from POME. Resource recovery is one of the most desirable environmental options for handling oily sludge. It not only enables the palm oil industry to reprocess and reformulate the recovered oil for energy recovery, but it also significantly reduces the volume of waste and alleviates the negative impact.

TABLE 1. GENERAL CHARACTERISTICS OF RAW POME AND REGULATORY DISCHARGE LIMITS FOR POME

Parameters	Concentration range	Standard discharge limit
pH	3.3-5.7	5-9
Temperature	80°C-90°C	45°C
Total solids (TS)	11 500-78 000 mg/L	N/A
Suspended solids (SS)	5 000-54 000 mg/L	400 mg/L
Biochemical oxygen demand (BOD)	10 250-43 750 mg/L	100 mg/L
Chemical oxygen demand (COD)	15 000-100 000 mg/L	N/A
Total nitrogen (TN)	180-1 400 mg/L	200 mg/L
Ammoniacal nitrogen (NH_3-N)	4-80 mg/L	150 mg/L
Oil and greases (O&G)	130-18 000 mg/L	50 mg/L

Note: N/A – not applicable.

Source: Department of Environment Malaysia, 1977; Kamyab *et al.*, 2018; Loh *et al.*, 2017; Mahmod *et al.*, 2021.

Oil recovery is identical to oil extraction, with the key distinction being that when a virgin source is employed, it is commonly referred to as 'extraction'. 'Oil recovery', on the other hand, is usually used to define oil extraction from waste or subsequent oil extraction. Mechanisms employed in extracting oil from virgin sources have also been applied in the oil recovery process. Since oil recovery from POME has received less attention from the industry, this section intends to concisely review the oil management techniques that have been explored from POME on a laboratory scale to acquire insight for better effluent management. Various oil recovery methods, including physical, chemical, as well as physicochemical, have been investigated as one of the waste management approaches for POME.

Physical Methods

Oil recovery from POME could be accomplished by using trapping and skimming techniques. This entails the collection of all liquid effluent from the processing stages in a container and allowing it to stand for days until the oil components float to the surface and are skimmed off due to density differences. Commonly, this phenomenon is known as gravity separation. As Stoke's Law states, there are several factors that affect the physical separation, such as the medium viscosity, density, and particle sizes.

To improve the efficiency of oil recovery for gravity separation, researchers had incorporated dissolved air flotation (DAF) into the oil skimming process. When pressurised air is supplied at the bottom of an open container, the resulting air bubbles will adhere to the microscopic oil droplets, causing them to float to the surface and be recovered by the skimming equipment. Faisal *et al.* (2016) studied the optimal DAF parameters and the result shows that 52.6% of the O&G in POME could be removed with an airflow of 11 L/min and a treatment time of 5 days. This represents a 39.9% improvement over conventional separation. By integrating a membrane separation (MS) unit, the oil recovery rate improved to 99.9%. Albeit improved efficiency, the incorporation of DAF and MS units incurred substantial operating and maintenance expenses due to the requirement to generate a continual stream of bubbles and high tendency of membrane clogging.

Mechanical centrifugation is another method of recovering oil by physical means. During centrifugal operation, the force of centrifugation generated by high-speed rotation causes particles in oily sludge to move radially toward the bottom of the centrifugal device. Upon stratification of oily sludge, the top layer of oil-water emulsion liquid can be recovered for value-added products, while the bottom layer of solid particles can be processed for further uses. Laohaprapanon *et al.* (2005) compared gravity separation and mechanical centrifugation to physically separate oil from POME. It was discovered that centrifugation at 7000 rpm for 15 min yielded comparable oil recovery to gravity settling at 55°C for 1 day. Centrifugal efficiency is influenced by a number of factors, including centrifugal speed, power, temperature, and duration (Philemon and Benoît, 2013). Despite its superior performance to gravity separation in terms of space and time, mechanical centrifugation still has a relatively low efficiency.

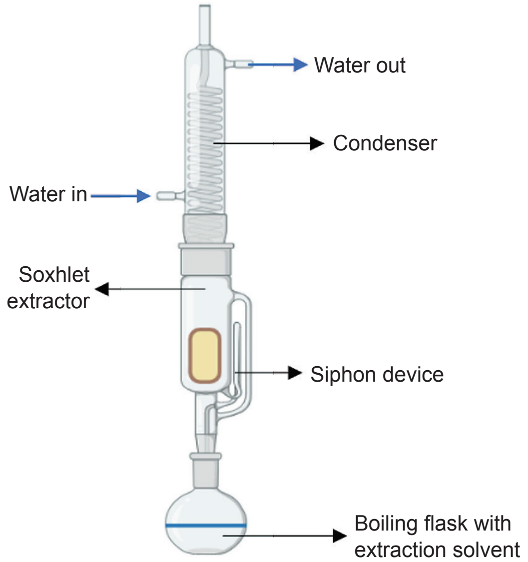
Conventionally, physical separation is the most common and simplest method to adopt. Despite its relatively simple design and low operating expenses, it is inefficient as it necessitates a huge setup area and is only able to recover 35%-55% oil layer on the surface (Loh *et al.*, 2013; Wang *et al.*, 2015). In contrast, the oil encapsulated within the remnant source cannot be freed and will be discharged as sludge. Consequently, the oil from the wastewater is not effectively recovered, necessitating a better recovery method or pre-conditioning of sample.

Chemical Methods

Solid-liquid extraction (SLE), commonly known as Soxhlet extraction, developed by Franz Von Soxhlet in the mid-18th century, has been used to separate various compounds from solid samples. A typical Soxhlet apparatus mainly consists of a boiling flask, a Soxhlet extractor, and a condenser, as illustrated in *Figure 1*.

The process begins with the addition of extraction solvent into the boiling flask. As the flask is steadily heated, the solvent vaporises as it reaches its boiling point. Through the siphon device and condenser, the vaporised solvent condenses and drains into the Soxhlet extractor. The analyte is extracted when the warm solvent contacts the oil source. When the extractor is full, the analyte-containing solvent floods back into the boiling flask. Repetition of cycles will result in complete extraction. Suwanno *et al.* (2017) employed a laboratory-scale Soxhlet technique to recover residual oil from POME. They discovered that 80% of the oil was recovered after 1 hr of reaction at 100°C with a sample-to-solvent ratio of 1:6.

Soxhlet extraction is a less commonly used method for oil recovery from POME on an industrial scale due to several limitations. One of the major drawbacks is that this technique is only applicable to solid samples. With the overwhelming presence of liquid phase in POME, a pre-treatment by drying is required prior to oil recovery. This will undoubtedly result in extended treatment time and higher production costs. Additionally, prolonged high-temperature exposure may also result in lipid peroxidation and deterioration of recovered products (López-Bascón and Luque de Castro, 2020).



Source: López-Bascón and Luque de Castro (2020).

Figure 1. Soxhlet apparatus setup.

On the other hand, liquid-liquid extraction (LLE), often termed as chemical extraction or solvent extraction, is currently widely employed in the food, pharmaceutical, and petrochemical sectors for the extraction process. Analytes are isolated based on their relative solubility in two immiscible solutions. LLE differs from Soxhlet extraction in that it does not entail any heating. *Figure 2* depicts the mechanisms of LLE, which consists of three fundamental steps: Interaction, separation, and recovery of solvent.

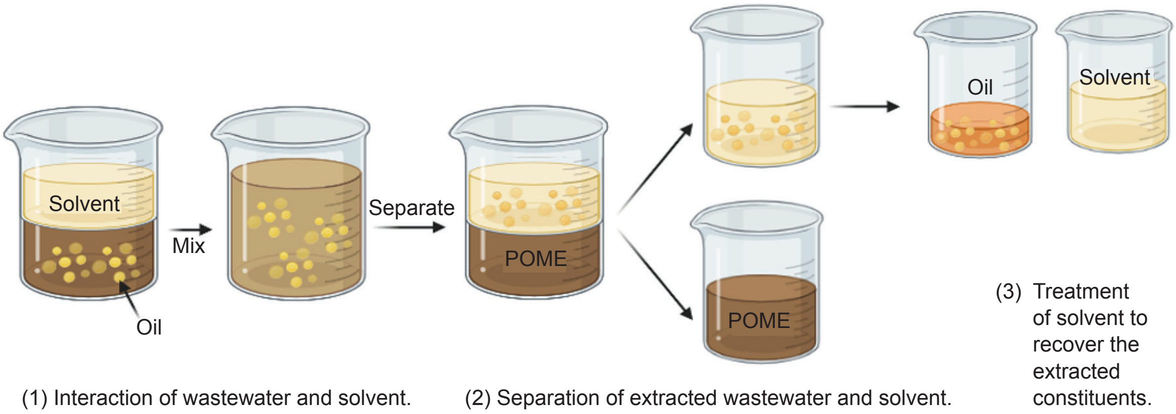
In POME, residual oil can be chemically recovered using non-polar organic solvents like n-hexane, n-heptane, pentane, petroleum ether, and benzene. Among various solvents, n-hexane is the most popular choice due to its superior oil extraction performance. The fundamental properties for the selection of extraction solvent include the solubility, hydrophobicity, molecular weight, vapor pressure, and acid dissociation (Wells, 2003).

Zulqarnain *et al.* (2021) conducted a study on the impact of various solvent extraction parameters on POME oil recovery efficiency. The parameters assessed included the solvent type, sample-to-solvent ratio, mixing time, agitation speed, and pH. The results revealed that the highest oil recovery from POME was 90% under the conditions of a POME-to-hexane ratio of 1:1 for 25 min at an agitation speed of 500 rpm and a pH of 10. Additionally, there are ongoing efforts being undertaken to commercialise solvent extraction as a viable method for POME oil recovery. One notable example is Mecpro Heavy Engineering Limited (2022), a reputable company specialising in process engineering for the palm oil industry, which has recently developed an innovative solvent extraction system known as the Mecpro Multi extraction system. This system is designed to recover both floating and emulsified oil from POME as well as wet mesocarp fibre simultaneously, leading to an oil extraction rate (OER) increase of more than 1%.

As a matter of fact, chemical extraction is considered as one of the most efficient means of separating residual oil from oily sludge. Unlike physical separation, this method requires organic extraction solvents. In addition to sourcing green solvents to reduce environmental pollution, future research may also focus on improving the efficiency of chemical extraction process by reducing the size of substrates, which increases their surface area and facilitates better solvent-substrate contact.

Physicochemical Methods

Progressive freezing concentration (PFC) is a process of concentrating a solution that entails freezing or solidifying one liquid component to form a pure solid, and then separating the solidified fragment from the mother liquor. The PFC process



Source: Suzuki *et al.* (2020).

Figure 2. Mechanisms of LLE.

is affected by several factors, including temperature, duration, freezing rate, oil-water phase, and impurities (Hui *et al.*, 2020). Mohamed Anuar *et al.* (2020) discovered that the PFC technique could recover 67.9% of O&G from POME after 1 hr at a coolant temperature of 6°C. One of the main advantages of PFC is that it is a green technology that operates at low process temperature, which can help maintain thermally sensitive elements of the solution. However, the productivity of PFC is relatively poor, and the energy requirements for the process can be high, making it less economically viable in warm climates. Nevertheless, there is a potential for application of this method in cold winter regions where low temperatures are prevalent.

Adsorption is one of the most popular techniques adopted for oil separation from oily wastewater. Adsorption is a surface-related phenomenon in which the sorbate molecules adhere to the sorbent without penetrating it. Adsorbent materials can be either synthetic or natural. Several sorbents have been reported for the adsorption of oil from POME; including synthetic rubber powder (Ahmad *et al.*, 2005a), chitosan (Ahmad *et al.*, 2005b), palm shell activated carbon magnetic composite (Ngarmkam *et al.*, 2011), modified oil palm leaf (Jahi *et al.*, 2015), esterified sago bark fibre waste (Wahi *et al.*, 2017), as well as polypropylene micro/nanofiber (PP-MNF) (Semilin *et al.*, 2021). The efficiency of oil adsorption ranged from 80% to 99%, with the esterified sago bark fibre waste achieving the lowest efficiency, and chitosan powder achieving the highest. The efficiency of the oil-water adsorption process is determined by the properties of sorbent, the most important of which are the hydrophobic and oleophilic properties. These studies have shown that the adsorption efficiency can be improved by optimising the processing conditions, such as dosage, contact time, pH, and temperature. Physical pressing, chemical extraction, or supercritical carbon dioxide techniques can be used to recover the adsorbed oil from the sorbent. Adsorption is widely utilised for its benefits, such as high efficiency, ease of operation, and environmental friendliness. However, the concern over the reusability of adsorbent and post-adsorption treatment to recover the adsorbed oil is a huge disincentive to this technology as it will certainly increase the expenditure.

Table 2 provides an overview of various oil management strategies for POME, along with their advantages and disadvantages. Among those, chemical extraction would be the preferred option due to its high recoverability efficiency and industrial-scale practicability.

ULTRASONICATION TECHNIQUE – A GREEN TECHNOLOGY TO ENHANCE OIL RECOVERY

The primary drawback of oil recovery from POME is the oil-bearing cell, and most oil recovery systems are geared only toward recovery, with little attempt made to enhance the recovery yields. As approaches outlined above have limitations in extracting the entrapped lipids, research has demonstrated that the incorporation of ultrasound pre-treatment can transcend these barricades.

Ultrasound is a cyclic sound pressure with a frequency greater than 20 kHz. Ultrasonication technique is often regarded as a 'green technology', as evidenced by its numerous advantages such as high efficiency, low equipment requirement, short operation duration (seconds to minutes), and ability to operate under atmospheric pressure and ambient temperature. Most notably, ultrasonication does not require any chemical enhancers to increase yield, which exhibits the benefit of being non-hazardous to the environment and contributes to waste reduction. In recent years, ultrasound technology has acquired

TABLE 2. OVERVIEW OF OIL MANAGEMENT STRATEGIES FOR POME

Oil recovery method	Advantages	Disadvantages
Trapping and skimming	Simple design Low cost Does not require chemicals	Only able to remove free oil Slow removal process Huge setup area
Dissolved air flotation and membrane separation	Improved efficiency compared to gravity separation Does not require chemicals	High operating costs Tendency of membrane clogging
Mechanical centrifugation	Reduced time and space compared to gravity separation	Emulsified and entrapped oil cannot be recovered High maintenance cost
Soxhlet extraction	Large selectivity High yield	Necessitate pre-treatment of drying and chemicals Adverse thermal effects
Chemical extraction	Industrial practicability High recoverability efficiency	Require chemicals
Progressive freezing concentration	Maintain thermally sensitive element	Low productivity Unsuitable for warm climates
Adsorption	High removal efficiency Ease of operation	Post-adsorption treatment is required Concern over reusability

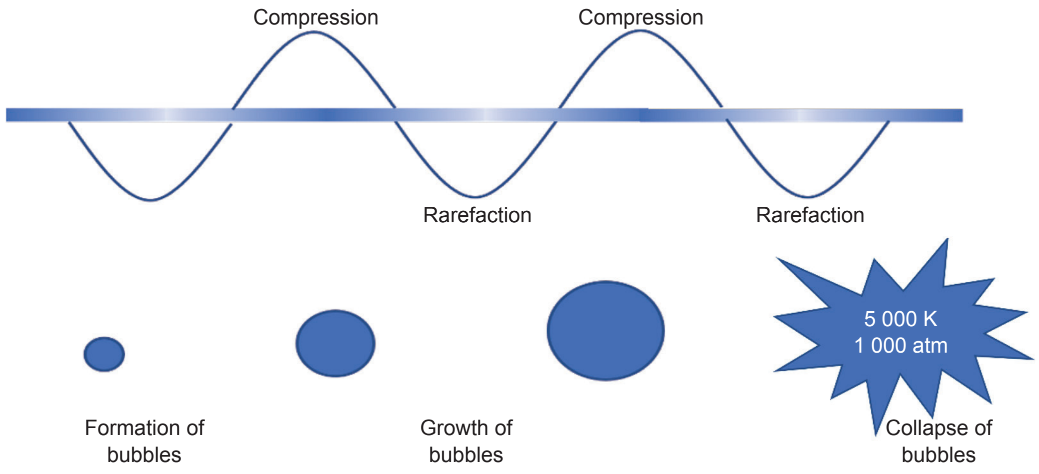
greater application in almost all disciplines, including the fields of medical and therapy, food and beverage, material cleaning, nanotechnology, industrial welding, and environmental applications (Mohammed and Alhajhoj, 2020).

When ultrasound wave propagates in the sample, it generates a series of cycles known as compression and rarefaction, which impose positive pressure by pushing the molecules together and negative pressure by pulling them apart. As a result of instantaneous and enormous pressure difference, microbubbles occur in the rarefaction region. These microbubbles expand in successive cycles by absorbing the ultrasonic energy and collapse violently upon reaching an unstable diameter. This phenomenon is known as acoustic cavitation and is represented in *Figure 3*.

The detonation of cavitation bubbles induces shock waves, which in turn create intense localised heating (5000 K), high pressure (500 atm), and a high heating and cooling rate (10^9 K/s) at the liquid-gas interface turbulence over a few microseconds (Suslick, 1998). Such extreme conditions create other physical and mechanical effect, namely hydromechanical shear forces created by liquid jet stream travelling at a speed of 400 km/hr. These effects can cause breakdown of cell wall and exudation of cellular content, all of which contribute to an increase in yield. In addition, ultrasonication has been associated with sonochemistry reactions. The heat generated by the cavity implosion dissociates the water (H_2O) molecules into highly reactive hydroxide radicals ($OH\cdot$) and hydrogen (H^+) atoms. These radicals recombine during the rapid cooling phase to form hydrogen peroxide (H_2O_2) and molecular hydrogen (H_2). These reactive oxygen species will oxidise and degrade the solutes. Overall, ultrasonic irradiation is an emerging technology with a combination of physical (pyrolysis and shearing) and chemical effects (radical reaction).

Tang *et al.* (2021) studied the use of low-frequency ultrasound to enhance the oil recovery from POME. The oil content after subjecting POME to ultrasound pre-treatment was compared to the oil content from corresponding sample without ultrasound pre-treatment. The results reveal that low-frequency ultrasound pre-treatment improved extractability by 39.17% additional oil content, with the highest extractability achieved under the conditions of 150 W and 15 s. In addition, ultrasonic irradiation on POME could also enhance the organic solids solubilisation, which will be an added advantage for subsequent biological treatment (Isa *et al.*, 2020; Wong *et al.*, 2019).

Essentially, the ultrasound intervention on POME not only allows for potentially higher oil recovery and increases economic returns for palm oil mills, but also appreciably reduces the treatment operation footprint through enhanced organic solubilisation. Although ultrasound pre-treatment exhibited numerous benefits, concerns regarding energy consumption and the possibility of oxidation on recovered products should be considered.



Source: Perera and Alzahrani (2021).

Figure 3. Mechanisms of ultrasonic irradiation.

POTENTIAL PRODUCTS FROM POME-RECOVERED OIL

Table 3 shows the characteristics of residual oil recovered from POME with that of CPO. The attributes of residual oil recovered from POME are comparable to CPO, but with a slightly higher free fatty acids (FFA) and peroxide value (PV). *Figure 4* illustrates the potential products from POME-recovered oil. The recovered oil from POME can be valorised as feedstock for biodiesel production, burner fuel, sustainable aviation fuel, as well as in nutritional platform.

Biodiesel

The imminent depletion of fossil fuel reserves, combined with environmental concerns, has fuelled the desire to achieve greater energy independence by encouraging more research on ecologically friendly and sustainable biofuels. Biodiesel, a renewable liquid fuel, has been advocated as a promising fuel for the future. It outperforms petroleum-based fuels in several aspects, including being biodegradable, non-toxic, and emitting fewer harmful pollutants (Ogunkunle and Ahmed, 2019). Commonly, edible oil is the leading resources for the manufacturing of biodiesel. Nevertheless, the utilisation of edible oil invariably sparks controversy and establishes a conflict between the availability of food and fuel. To alleviate the issue, academics and stakeholders strive to transform the processed-palm-oil waste into biofuel, while reutilising the residual oil recovered from POME for biodiesel production came on top of the plan. Zulqarnain *et al.* (2021) reviewed the biodiesel production process and discussed the research gaps related to valorising POME as a substrate. The authors emphasised that although POME demonstrated a great potential as a feedstock for green fuels, there is a need for more research to improve the efficiency and cost-effectiveness of POME-based biodiesel production.

Burner Fuel

Alternatively, residual oil from POME can be valorised directly as a fuel substitute in a burner without undergoing any refining process. According to Zuber *et al.* (2018), the viscosity of residual oil from POME is 15 times higher than that of conventional diesel, preventing it from flowing or spraying efficiently without any treatment. Through heating, its viscosity can be reduced significantly, while its flowability can be enhanced. Compared with conventional diesel, it has been reported that the use of residual oil from POME in a burner reduces emissions of carbon monoxide (CO) and nitrogen oxides (NOx) by 34% and 90%, respectively, indicating its feasibility as burner fuel.

Sustainable Aviation Fuel

In conjunction with the global commitment in reducing emissions in the aviation sector, conversion of residual oil from POME into sustainable aviation fuel (SAF) with hydrotreated vegetable oil (HVO) technology could be one of the most effective strategies. Yeoh and Goh (2022) presented a review on current state of HVO production from POME along with its opportunities and challenges. The study also highlights the benefits it could bring to the aviation industry. The conversion of POME into SAF can reduce the carbon footprint of aviation by up to 80% compared to conventional jet fuel. It can also improve energy security by reducing reliance on fossil fuels and diversifying fuel sources.

TABLE 3. CHARACTERISTICS COMPARISON OF POME-RECOVERED OIL AND CPO

Item	Residual oil from POME	Crude palm oil
Free fatty acids, FFA (%)	5-45	Max 5
Iodine value, IV	40-100	50.40-53.70
Peroxide value, PV (meq/kg)	1.36-21.81	Max 3
Fatty acid composition (%)		
Myristic (C14:0)	1.08-1.20	0.90-1.50
Palmitic (C16:0)	45.00-46.20	39.20-45.80
Stearic (C18:0)	3.70-4.45	3.70-5.10
Oleic (C18:1)	37.99-39.80	37.40-44.10
Linoleic (C18:2)	9.80-9.85	8.70-12.50
Linolenic (C18:3)	0.02-0.40	0.00-0.60

Source: Hayyan *et al.*, 2011; Malaysia Department of Standards, 2007; Putri Primandari *et al.*, 2013.

Figure 4. Potential products from POME-recovered oil.

Additionally, the production of SAF from POME can create new economic opportunities by providing an additional source of income for palm oil producers.

Phytonutrients

Phytonutrients are bioactive compounds that have beneficial effects on human health. These extracts have been shown to have antioxidant, anti-inflammatory, and anti-cancer properties, which can be employed as cosmeceuticals additives, colouring agents, as well as nutritional supplements within the pharmaceutical and food industries. Recent studies revealed that POME-recovered oil possesses high nutritional value, prompting the nutraceutical investors to venture in technologies for the valorisation of essential bioactive compounds. In a study conducted by Teh *et al.* (2017), it was reported that POME-recovered oil is rich in various phytonutrients, containing 161 ppm of sterols, 706 ppm of vitamin E (tocotrienol and tocopherols), 569 ppm of pro-vitamin A (carotenoids), as well as 514 ppm of squalene. Sterols are plant-based compounds that have cholesterol-lowering properties, while vitamin E is a group of fat-soluble compounds that act as an antioxidant. Carotenoids are essential for maintaining healthy vision, skin, and immune function, and squalene is a natural antioxidant that can enhance skin health and reduce the risk of chronic diseases. The study also revealed that the phytonutrient contents of POME-recovered oil are comparable to those of CPO, suggesting the possibility for valorisation as a reliable source of nutritional products. Furthermore, Chen *et al.* (2019) provided a comprehensive review of the challenges related to recovering high-value nutrients from POME, including safety, technology, regulations, and cost-effectiveness.

FUTURE OPPORTUNITIES

With the rising generation of POME, there is a need for research to be conducted to intensify the performance of current oil recovery techniques from POME. Given the possibility of industry's reliance on solvent extraction method, an alternative of low-cost green solvent is also one of the highly anticipated opportunities. Methods like supercritical fluid extraction (SFE) or aqueous extraction process (AEP), which involve the use of green solvents such as carbon dioxide or water, could be explored. The massive volume of POME could be a trade-off between the environmental benefits and the cost of the associated technology. Besides, palm oil millers could also look into the incorporation of other green technologies like microwave-assisted or enzymatic hydrolysis as a pre-treatment or polishing step to improve the oil recovery process, as certain treatment methods are insufficient to stand alone. As for the ultrasound pre-treatment in enhancing oil recovery from POME, a thorough study of the system design, ultrasound field patterns, cost-benefit analysis, as well as quality assessment on the recovered products could be undertaken.

A more scientific approach in the entire palm oil industry is necessary for the future growth of the industry, both in terms of efficiency and economics. Biodiesels are one of the potential outcomes for recovered oil from POME. An effective conversion technology with the lowest possible production cost and environmental impact should be designed by conducting economic assessment and life cycle analysis. Besides, a comprehensive strategy for connecting and transporting the effluent from its source to biodiesel manufacturing facility could be devised. Aside from enhancing the conversion and recovery process, researchers can also expand their horizons and explore new possibilities and applications for the recovered oil.

Environmental Aspect of the Residual Oil Recovery Practice

Oil palms were cultivated as a strategy to minimise the country's economic reliance on tins and rubber as early as 1960. The decision to cultivate oil palm is often linked to the negative impacts on the environments which include mass scale deforestation and emission of greenhouse gases (GHG). Another controversial issue of the palm oil industry is the discharge of POME into open water bodies. The water consumption in the palm oil industry is so huge, that POME has become one of the largest contributors to the wastewater in Malaysia.

Both government and private organisations have been encouraged to undertake all development projects with a focus on sustainable development. The implementation of best-developed practices (BDPs) with a 'zero waste' philosophy that emphasises the recycling and utilisation of all waste and by-products from the entire palm oil sector, is promoting the palm oil industry to become more environmental-friendly.

Rather than new forest land exploration that lead disturbance of forest system, loss of animal habitats, and pesticide pollution in maintaining the plantation, researchers can divert their efforts to increase the oil production through adoption of residual oil recovery from processed palm-oil waste as one of its waste management strategies. The adoption of these practices will greatly drive the sector towards cleaner production, with benefits such as reduced waste generation, efficient utilisation of waste, and cost-effective improvements to end-of-pipe solutions when integrated into current production processes.

Along with the country's commitment to the Paris Agreement, the Malaysian government recently declared that carbon tax would be incorporated in the 12th Malaysia Plan (2021-2025). Through introducing the carbon tax, palm oil millers will be obliged to seek into alternative energy source as a method to reduce and offset the carbon footprints from the process. One example is that the residual oil recovered from POME can be used for biodiesel production, which acts as a renewable substitute for petroleum fuel. Advanced feedstocks derived from waste and achieving greater GHG savings are double counted towards transport fuel mandates under the new European Union Renewable Energy Directive (EU RED) II, and POME has been included as one of the sources, which would offer a significant incentive in the field.

Social Aspect of the Residual Oil Recovery Practice

The palm oil industry is currently a hot topic in the society and communities, and the recovery of residual oil from POME is viewed as a potential solution to the sector's social issues. The implementation of residual oil recovery practices could potentially result in the creation of new job opportunities in waste management, oil recovery, and renewable energy production. As the demand for sustainable palm oil grows, there will be a need for more skilled personnel in these areas, which could contribute to the development of local communities. Furthermore, integrating these communities in the process can lead to environmental education and awareness, promoting sustainable practices.

The recovery of residual oil from POME could also result in new partnerships between palm oil producers and other industries, like biofuel industry. This could help strengthen the supply chain and open new avenues for collaboration. The Malaysian government's launch of PEMERKASA stimulus package and Workforce Recalibration Programme could contribute to the social sustainability by encouraging investment in the palm oil industry and providing legal status to foreign workers (Nur Aisha, 2021). These initiatives encourage technology transfer and fair labour practice, resulting in a more socially responsible and sustainable industry.

Overall, the residual oil recovery practice offers a range of opportunities for employment creation, community development, environmental education, and partnership development. By prioritising these social aspects, the palm oil industry can progress towards a more sustainable future, fulfilling the growing demand for sustainable palm oil while benefiting communities and the environment.

Governance Aspect of the Residual Oil Recovery Practice

Governance factors refer to a country's norms or standards, allowing investors to screen for proper governance practices in the same manner that they do for the environmental and social aspects. The European market is already shifting from voluntary standards to enforcing sustainability by law, and this process is being expedited by the global climate ambitions, which have turned the Paris Climate Agreement into European Green Deal, with the goal of achieving EU climate neutral by 2050. Malaysia has also developed its own mandatory certification scheme known as Malaysia Sustainable Palm Oil (MSPO) for the palm oil industry stakeholders, with the goal of promoting and ensuring the industry's sustainability. However, the EU's failure to recognise the importance of MSPO had ushered for further improvement. Hence, governments over the countries should work together to enable a feasible two-way collaboration.

To achieve a greener future, governments have also introduced renewable fuel policies such as subsidies, incentives, mandates, and taxes to boost the biodiesel sector. One example is the Malaysian and Indonesian governments' announcement of the objective in promoting biodiesel blend B20 and B40 mandates by the end of 2022 (Ajeng Dinar, 2022). Since POME is abundantly generated, cheap, and challenging to dispose of, one of the research areas that can be investigated for sustainability is recovering the residual oil from POME and utilising it for biodiesel production. Without the cooperation by government and industry players, this approach would not be a success.

ECONOMIC VIEWPOINT

Oil recovery from POME could be an appealing alternative as it demonstrated a considerable reduction in organic content in POME, making subsequent treatment more efficient. Research has shown that removing oil from raw sludge reduces COD content by 10%-15% (Liew *et al.*, 2017). Additionally, de-oiling contributes positively to anaerobic digestion rate and biomethane yield, which is advantageous for subsequent biological treatment (Aziz *et al*., 2020). Moreover, the recovered oil from POME can be sold for 40%-60% of the typical CPO price, revealing a new economic opportunity. The market price/t of CPO in 2022 ranges from RM3682 to RM6873 (MPOB, 2022b). With the assumption of recovered oil from POME is sold at 50% of the average market price of CPO (RM5126/t), the selling price of residual oil recovered from POME is approximately RM2563/t.

In 2022, global production of palm oil reached 77 million tonnes, resulting in 231 million tonnes of POME being produced. Not only did the process generate a considerable volume of effluent, but a rough speculation also indicates that the POME discharged contains approximately 1.16 million tonnes of residual oil that can be recovered. This could result in an additional revenue of RM2.9 billion/yr for the industry if the recovery of residual oil from POME is properly implemented. Additionally, this would also support the government's Economic Transformation Program (ETP) and its goal of boosting OER through Entry Point Projects (EPP) 4.

It is crucial to factor in the costs, particularly the equipment cost, to accurately determine the net economic benefit when considering the implementation of oil recovery technology. The cost of adding equipment can vary depending on the specific technology employed and the scale of operation. Some of the other expenses associated with implementing oil recovery technology include the installation cost of equipment, maintenance cost, operation cost, as well as infrastructure improvement cost. While the adoption of oil recovery practice from POME does incur some costs, these expenses can be offset by the value of recovered oil and other benefits. Therefore, a thorough analysis of the associated costs and benefits with the implementation of oil recovery technology is essential for making an informed decision.

CONCLUSION

The huge amounts of waste produced by the palm oil sector have sparked public concern. As a results, efforts are being made to study ways to effectively manage and utilise this waste to mitigate its negative effects on the environment. This review article outlines the valorisation of liquid palm oil waste via oil recovery. Various techniques along with research gaps for oil recovery from POME were looked upon, while also presenting the green technology such as ultrasonic irradiation as a pre-treatment to enhance the efficiency of oil recovery. This review also highlights the use of recovered oil from POME as a renewable and sustainable source of material for producing value-added products, diversifying the utilisation of POME beyond traditional ponding systems. The future opportunities in terms of environmental, social, and governance aspects of residual oil recovery practice were critically evaluated. Overall, the implementation of techniques to recover residual oil from POME is highly recommended as an effective and sustainable waste management solution. It not only helps to conserve the environment, but also creates a new economic opportunity for palm oil millers. Additionally, the utilisation of recovered oil as a sustainable resource can provide industrial symbiosis possibilities and contributes to the circular economy.

ACKNOWLEDGEMENT

This research was financially supported by Universiti Tunku Abdul Rahman Research Fund (UTARRF) (Project Number: IPSR/RMC/UTARRF/2020-C1-W01).

REFERENCES

Ahmad, A L; Bhatia, S; Ibrahim, N and Sumathi, S (2005a). Adsorption of residual oil from palm oil mill effluent using rubber powder. *Brazilian J. Chem. Eng., 22(3)*: 371-379.

Ahmad, A L; Sumathi, S and Hameed, B H (2005b). Adsorption of residue oil from palm oil mill effluent using powder and flake chitosan: Equilibrium and kinetic studies. *Water Res., 39(12)*: 2483-2494.

Ajeng Dinar, U (2022). Indonesia, Malaysia commit to biodiesel mandates despite higher prices. *Reuters*. https://www.reuters.com/business/sustainable-business/indonesia-malaysia-commit-biodiesel-mandates-despite-higher-prices-2022-03-24/, accessed on 20 April 2023.

Aziz, M M A; Kassim, K A; El-Sergany, M; Anuar, S; Jorat, M E; Yaacob, H; Ahsan, A; Imteaz, M A and Arifuzzaman (2020). Recent advances on palm oil mill effluent (POME) pretreatment and anaerobic reactor for sustainable biogas production. *Renew. Sustain. Energy Rev., 119*: 109603. DOI: 10.1016/j.rser.2019.109603.

Cheng, Y W; Chong, C C; Lam, M K; Ayoub, M; Cheng, C K; Lim, J W; Yusup, S; Tang, Y and Bai, J (2021). Holistic process evaluation of non-conventional palm oil mill effluent (POME) treatment technologies: A conceptual and comparative review. *J. Hazard. Mater., 409*. DOI: 10.1016/j.jhazmat.2020.124964.

Chen, H; Zhang, H; Tian, J; Shi, J; Linhardt, R J; Ye, T D X and Chen, S (2019). Recovery of high value added nutrients from fruit and vegetable industrial wastewater. *Compr. Rev. Food Sci. Food Saf., 18(5)*: 1388-1402. DOI: 10.1111/1541-4337.12477.

Choong, Y Y; Chou, K W and Norli, I (2018). Strategies for improving biogas production of palm oil mill effluent (POME) anaerobic digestion: A critical review. *Renew. Sustain. Energy Rev., 82(August)*: 2993-3006. DOI: 10.1016/j.rser.2017.10.036.

Department of Environment Malaysia (1977). Environmental Quality (Prescribed Premises) (Crude Palm Oil) (Amendment) Regulation 1977. *Environ. Qual. Act 1974 (Act 127).*

Edi, S (2022). Varying sustainability standards polarize vegetable oil market. ANN Asia News. https://asianews.network/varying-sustainability-standards-polarize-vegetable-oil-market/, accessed on 11 October 2023.

Faisal, M; Machdar, I; Gani, A and Daimon, H (2016). The combination of air flotation and a membrane bioreactor for the treatment of palm oil mill effluent. *Int. J. Technol., 7(5)*: 767-777. DOI: 10.14716/ijtech.v7i5.3163.

Hayyan, A; Alam, M Z; Mirghani, M E S; Kabbashi, N A; Hakimi, N I N M; Siran, Y M and Tahiruddin, S (2011). Reduction of high content of free fatty acid in sludge palm oil via acid catalyst for biodiesel production. *Fuel Process. Technol., 92(5)*: 920-924. DOI: 10.1016/j.fuproc.2010.12.011.

Hii, K L; Yeap, S P and Mashitah, M D (2012). Cellulase production from palm oil mill effluent in Malaysia: Economical and technical perspectives. *Eng. Life Sci., 12(1)*: 7-28. DOI: 10.1002/elsc.201000228.

Hui, K; Tang, J; Lu, H; Xi, B; Qu, C and Li, J (2020). Status and prospect of oil recovery from oily sludge: A review. *Arab. J. Chem., 13(8)*: 6523-6543. DOI: 10.1016/j.arabjc.2020.06.009.

Isa, M H; Wong, L P; Bashir, M J K; Shafiq, N; Kutty, S R M; Farooqi, I H and Lee, H C (2020). Improved anaerobic digestion of palm oil mill effluent and biogas production by ultrasonication pretreatment. *Sci. Total Environ., 722:* 137833. DOI: 10.1015/j.scitotenv.2020.137833.

Jahi, N; Ling, E S; Othaman, R and Ramli, S (2015). Modification of oil palm plantation wastes as oil adsorbent for palm oil mill effluent (POME). *Malaysian J. Anal. Sci., 19(1)*: 31-40.

Kamyab, H; Chelliapan, S; Din, M F M; Rezania, S; Khademi, T and Kumar, A (2018). Palm oil mill effluent as an environmental pollutant. *Palm Oil, (2)*: 13-28.

Laohaprapanon, T; Prasertsan, P and Kittikun, A H (2005). Physical and chemical separation of oil and suspended solids from palm oil mill effluent. *Asian J. Energy Environ.*, *6(1)*: 39-55.

Lee, Z S; Chin, S Y; Lim, J W; Witoon, T and Cheng, C K (2019). Treatment technologies of palm oil mill effluent (POME) and olive mill wastewater (OMW): A brief review. *Environ. Technol. Innov., 15*: 100377. DOI: 10.1016/j.eti.2019.100377.

Liew, A S B; Hadi, N A; Halim, R M; Yap, A and Rahman, Z A (2017). Methane avoidance via zero effluent discharge using aquaeco plant. *Proc. of PIPOC.* p. 1-15.

Loh, S K; Lai, M E; Ngatiman, M; Lim, W S; Choo, Y M; Zhang, Z and Salimon, J (2013). Zero discharge treatment technology of palm oil mill effluent. *J. Oil Palm Res.*, *25(3)*: 273-281.

Loh, S K; Nasrin, A B; Mohamad Azri, S; Nurul Adela, B; Muzzammil, N; Daryl Jay, T; Stasha Eleanor, R A; Lim, W S; Choo, Y M and Kaltschmitt, M (2017). First report on Malaysia's experiences and development in biogas capture and utilization from palm oil mill effluent under the Economic Transformation Programme: Current and future perspectives. *Renew. Sustain. Energy Rev., 74*: 1257-1274. DOI: 10.1016/j.rser.2017.02.066.

López-Bascón, M A and Luque de Castro, M D (2020). Soxhlet extraction. *Liquid Phase Extraction: Handbook in Separation Science.* University of Cardoba, Spain. p. 327- 327-354. DOI: 10.1016/B978-0-12-816911-7.00011-6.

Mahmod, S S; Arisht, S N; Jahim, J M; Takriff, M S; Tan, J P; Luthfi, A A I and Abdul, P M (2021). Enhancement of biohydrogen production from palm oil mill effluent (POME): A review. *Int. J. Hydrogen Energy*, *47(96)*: 40637-40655. DOI: 10.1016/j.ijhydene.2021.07.225.

Malaysia Department of Standards (2007). MS 814:2007 Palm oil - Specification (second revision). *Malaysian Stand.*, *814(MS 814:2007)*: 12.

Mecpro Heavy Engineering Limited (2022). Palm oil mill - Oil recovery from effluent water. https://www.mecpro.com/oil-recovery-from-pome.html, accessed on 14 June 2021.

Mohamed Anuar, M A; Amran, N A and Ruslan, M S H (2020). Effect of stirring rate and freezing time on the percentage of recovery of residual oil from palm oil mill effluent via a stirred freeze crystallizer. *IOP Conf. Ser. Mater. Sci. Eng.*, *778(1)*: 012171.

Mohammad, S; Baidurah, S; Kobayashi, T; Ismail, N and Leh, C P (2021). Palm oil mill effluent treatment processes -A review. *Processes*, *9(5)*: 1-22.

Mohammed, M E and Alhajhoj, M R (2020). Importance and applications of ultrasonic technology to improve food quality. *Food Process.*: 1-16. DOI: 10.5772/intechopen.88523.

MPOB (2022a). Production of crude palm oil in 2022. https://bepi.mpob.gov.my/index.php/production/286-production-2022/1092-production-of-crude-oil-palm-2022, accessed on 16 January 2023.

MPOB (2022b). MPOB daily malaysia prices of crude palm oil. https://bepi.mpob.gov.my/admin2/price_local_daily_view_cpo_msia.php?more=Y&jenis=1Y&tahun=2022, accessed on 28 June 2022.

Ngarmkam, W; Sirisathitkul, C and Phalakornkule, C (2011). Magnetic composite prepared from palm shell-based carbon and application for recovery of residual oil from POME. *J. Environ. Manage.*, *92(3)*: 472-479. DOI: 10.1016/j.jenvman.2010.08.031.

Nur Aisha, A W (2021). MPOB: Palm oil industry remains resilient under MCO. *Malay Mail*. https://www.malaymail.com/news/malaysia/2021/08/28/mpob-palm-oil-industry-remains-resilient-under-mco/2001119, accessed on 20 April 2023.

Ogunkunle, O and Ahmed, N A (2019). A review of global current scenario of biodiesel adoption and combustion in vehicular diesel engines. *Energy Reports*, *5*: 1560-1579. DOI: 10.1016/j.egyr.2019.10.028.

Perera, C O and Alzahrani, M A J (2021). Ultrasound as a pre-treatment for extraction of bioactive compounds and food safety: A review. *LWT, 142*: 111114. DOI: 10.1016/j.lwt.2021.111114.

Philemon, Z B 'o and Benoît, N M (2013). Treatment of conditioned oily sludge from Cameroon petroleum refinery by centrifugation. *Int. J. Environ. Sci.*, *3(5)*: 1373-1382.

Putri Primandari, S R; Yaakob, Z; Mohammad, M and Mohamad, A B (2013). Characteristics of residual oil extracted from palm oil mill effluent (POME). *World Appl. Sci. J.*, *27(11)*: 1482-1484.

Semilin, V; Janaun, J; Chung, C H; Touhami, D; Haywood, S K; Chong, K P; Yaser, A Z and Zein, S H (2021). Recovery of oil from palm oil mill effluent using polypropylene micro/nanofiber. *J. Hazard. Mater.*, *404*: 124144. DOI: 10.1016/j.jhazmat.2020.124144.

Suslick, K S (1998). Sonochemistry. *Jirk-Othmer Encyclodpedia of Chemical Technology.* 4th edition. New York: John Wiley & Sons, Inc. p. 516-541.

Suwanno, S; Rakkan, T; Yunu, T; Paichid, N; Kimtun, P; Prasertsan, P and Sangkharak, K (2017). The production of biodiesel using residual oil from palm oil mill effluent and crude lipase from oil palm fruit as an alternative substrate and catalyst. *Fuel*, *195*: 82-87. DOI: 10.1016/j.fuel.2017.01.049.

Suzuki, D; Sato, Y; Kamasaka, H; Kuriki, T and Tamura, H (2020). Oiling-out effect improves the efficiency of extracting aroma compounds from edible oil. *NPJ Sci. Food*, *4(18)*: 1-11. DOI: 10.1038/s41538-020-00079-8.

Tang, Y M; Wong, W Y; Tan, K T and Wong, L P (2021). Enhanced oil recovery from palm oil mill effluent using ultrasonication technique. *IOP Conf. Ser. Earth Environ. Sci.*, *945(1)*: 012042.

Teh, S S; Ong, A S H and Mah, S H (2017). Recovery and utilization of palm oil mill effluent source as value-added food products. *J. Oleo Sci.*, *66(11)*: 1183-1191. DOI: 10.5650/jos.ess17078.

Wahi, R; Chuah Abdullah, L; Nourouzi Mobarekeh, M; Ngaini, Z and Choong Shean Yaw, T (2017). Utilization of esterified sago bark fibre waste for removal of oil from palm oil mill effluent. *J. Environ. Chem. Eng.*, *5(1)*: 170-177.

Wan Sharifudin, W S S A; Sulaiman, A; Mokhtar, N; Baharuddin, A S; Tabatabaei, M; Busu, Z and Subbian, K (2015). Presence of residual oil in relation to solid particle distribution in palm oil mill effluent. *BioResources*, *10(4)*: 7591-7603.

Wang, J; Mahmood, Q; Qiu, J P; Li, Y S; Chang, Y S; Chi, L N and Li, X D (2015). Zero discharge performance of an industrial pilot-scale plant treating palm oil mill effluent. *Biomed Res. Int.*, *2015*: 1-9. DOI: 10.1155/2015/617861.

Wells, M J M (2003). Principles of extraction and the extraction of semivolatile organics from liquids. *Sample Preparation Techniques in Analytical Chemistry*, *(2)*: 37-225.

Wong, L P; Isa, M H; Bashir, M J K and Guo, X X (2019). Optimization of ultrasound irradiation for palm oil mill effluent. *IOP Conf. Ser. Earth Environ. Sci.*, *344(1)*: 012008.

Yashni, G; Al-Gheethi, A; Radin Mohamed, R M S; Arifin, S N H and Mohd Salleh, S N A (2020). Conventional and advanced treatment technologies for palm oil mill effluents: A systematic literature review. *J. Dispers. Sci. Technol.*, *42(12)*: 1766-1784. DOI: 10.1080/01932691.2020.1788950.

Yeoh, M L and Goh, C S (2022). Hydrotreated vegetable oil production from palm oil mill effluents: Status, opportunities and challenges. *Biofuels, Bioprod. Biorefining*, *16(5)*: 1153-1158.

Zuber, M A; Ithnin, A M; Yahya, W J; Wahab, A D A and Ahmad, M A (2018). Performance of sludge palm oil combustion using waste oil burner. *J. Adv. Res. Fluid Mech. Therm. Sci.*, *49(1)*: 55-61.

Zulqarnain; Yusoff, M H M; Ayoub, M; Nazir, M H; Zahid, I; Ameen, M; Abbas, W; Shoparwe, N F and Abbas, N (2021). Comprehensive review on biodiesel production from palm oil mill effluent. *ChemBioEng Rev.*, *8(5)*: 439-462.

JOURNAL OF OIL PALM RESEARCH

GUIDE FOR AUTHORS

(for more details, kindly surf http://jopr.mpob.gov.my)

Type of Articles

1. **Regular Article**
   Full-length original empirical investigations, consisting of introduction, materials and methods, results and discussion, conclusions. Original work must provide references and an explanation on research findings that contain new and significant findings. Conclusion should be brief and focus on the research output, should not be in point form. These papers should not exceed 6000 words of text (including tables, figures and references) and generally not more than a total of 10 figures and tables. After peer-review, the article word count limit can be extended to a maximum of 8000 words to better address the reviewers' and editors' comments. Any additional figures or tables can be included in the supplementary data. Please note that papers submitted to JOPR will be sent back to authors because of poor figure resolution or exceeding the number of figures permitted.

2. **Short Communication**
   Significant new information to readers of the Journal in a short but complete form. Preferably not exceeding 3000 words (including tables, figures and references), and is intended for rapid publication. They are not intended for publishing preliminary results or to be a reduced version of regular article.

3. **Review Article**
   Critical evaluation of materials about current research that have already been published by organising, integrating, and evaluating previously published materials. Re-analyses as meta-analysis and systemic reviews are encouraged. Review articles provide systemic overview, evaluation and interpretation of research in a given field. They should not exceed 12 000 words (excluding references only) and should contain no more than a total of 20 figures and tables. Any additional figures or tables can be included in the supplementary data. Please note that papers submitted to JOPR will be sent back to authors because of poor figure resolution or exceeding the number of figures permitted. The same information should not be repeated in a figure and a table.

Language

Please write your text in good English (only British English is accepted). We do not accept American English or a mixture of these.

JOPR's Template

JOPR's template, which is a standard format that facilitates the manuscript writing and copyediting process. This template is created to provide a detail and clear house style of JOPR. The template is drafted according to JOPR's house style, but in standard word version format. When writing a paper, authors need to format their papers to fit into the journal's house style. To make this easier, Word templates are available for many of other established journals, ready for them to download and apply to their research paper format. It is crucial for author to write a research paper while considering formatting. Each journal has its own guidelines for formatting; hence, the template defines how an article will look when it is published online or in print.

JOPR's Aims & Scope

This is established to provide a detail and clear aims and scope for author reference. Authors should declare in the cover letter how the research fits the aims and scope of JOPR.

JOPR's House Style

A detail listing of JOPR's house style for authors and a checklist to facilitate the copyediting process and standardise the copyediting process. The JOPR's house style remains the same and is drafted into a detail version for author's reference.

Manuscript Submission

- Manuscripts should be submitted via: https://www2.cloud.editorialmanager.com/jopres/
- JOPR does not permit dual submission, publication and/or any archive platform (preprint) in violation of journal ethical practices.

For more details and to download the JOPR's House Style and Template, kindly surf http://jopr.mpob.gov.my