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Review

# Trend and current practices of palm oil mill effluent polishing: Application of advanced oxidation processes and their future perspectives

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A B S T R A C T

Palm oil processing is a multi-stage operation which generates large amount of effluent. On average, palm oil mill effluent (POME) may contain up to 51, 000 mg/L COD, 25,000 mg/L BOD, 40,000 TS and 6000 mg/L oil and grease. Due to its potential to cause environmental pollution, palm oil mills are required to treat the effluent prior to discharge. Biological treatments using open ponding system are widely used for POME treatment. Although these processes are capable of reducing the pollutant concentrations, they require long hydraulic retention time and large space, with the effluent frequently failing to satisfy the discharge regulation. Due to more stringent environmental regulations, research interest has recently shifted to the development of polishing technologies for the biologically-treated POME. Various technologies such as advanced oxidation processes, membrane technology, adsorption and coagulation have been investigated. Among these, advanced oxidation processes have shown potentials as polishing technologies for POME. This paper offers an overview on the POME polishing technologies, with particularly emphasis on advanced oxidation processes and their prospects for large scale applications. Although there are some challenges in large scale applications of these technologies, this review offers some perspectives that could help in overcoming these challenges.



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## 1. Introduction

Palm oil has become a significant commodity in the world, with Malaysia and Indonesia leading in both production and exports of palm oil products. Malaysia accounts for about 39% of world palm oil production and 44% of world exports (May et al., 2013; Mohammed and Fong, 2014). Palm oil is therefore an important agro-based industry in Malaysia, contributing significantly to its growth domestic product (GDP). Because of its importance, more land is being converted to oil palm plantation and more factories are being opened to process the palm oil. Although this is economically positive, there is an intrinsic environmental problem associated with the processing of crude palm oil into finished products. Large volume of highly polluting wastewater is generated from palm oil processing. This problem occupies a central position among the environmental problems confronting Malaysia (Chan et al., 2010).

Palm oil processing consumes a lot of water and produces a correspondingly large volume of wastewater. It is estimated 5 to 7.5 tons of water would be required to process one ton of crude palm oil (Wu et al., 2009) and unfortunately, more than 50% of this water would end up as wastewater (Ahmad et al., 2010, 2008a). This wastewater is termed palm oil mill effluent (POME), a thick-brownish effluent containing large amounts of solids and other organic pollutants with potentials to pollute the environment. Open ponding is commonly employed by the Malaysian palm oil mills to treat POME through aerobic/anaerobic processes. Besides drawbacks such as long hydraulic retention time (HRT) and large space requirement, effluent from the ponds frequently fails to meet the discharge limits set by the Malaysian Department of Environment (DOE) (Bello et al., 2014; Ng et al., 2016).

Over the years, researchers have investigated alternative treatment technologies such as adsorption (Said et al., 2016), coagulation/flocculation (Bhatia et al., 2007a), microbial fuel cell (Cheng et al., 2010), up-flow anaerobic sludge blanket (UASB), expanded granular sludge bed (EGSB) reactors (Fang et al., 2011), membrane filtration (Ahmad et al., 2005; Mohammad et al., 2009) and advanced oxidation processes (AOPs) (Parthasarathy et al., 2016a; Saeed et al., 2016). Although mostly under laboratory-scale studies, these technologies have shown potentials to address some of the drawbacks of the ponding system. However, the current research interest is on the development of polishing technologies that can produce effluent conforming with the regulatory discharge standards. Of particular concern, are the residual COD, nutrients and the offensive dark color of the conventionally treated POME. This color is due to the decomposition of lignocellulosic materials (Tan et al., 2014), resulting in the production of lignin, tannin, humic acids, carotene and other organic matter which are recalcitrant to the conventional treatments. Beside aesthetic problem, color affect sunlight penetration and limit potential wastewater reuse. Residual oil is another source of concern, as many industries discharge treated POME with oil above the discharge limit (Shavandi et al., 2012a).

Due to the pollution potential of POME and the failure of many industries to comply with the discharge standard, the Malaysian DOE is proposing more stringent regulations. For example, the BOD discharge limit has recently been reviewed from 100 mg/L to 20 mg/L (Tabassum et al., 2015). Thus, stringent regulations may continue to evolve as Government and the public intensify efforts towards environmental protection and sustainability. Currently, the industries are already facing a lot of challenges in meeting the existing regulations (Najafpour et al., 2006). Therefore, the next few years will see more efforts towards developing effective polishing technologies for POME. Accordingly, the current trend on POME research has already shifted towards developing polishing technologies. For example, over 90% of the publications on POME in the last two years have been on the polishing technologies.

Therefore, a review of POME polishing technologies and their prospects seems timely. Although Liew et al. (2014) had presented a review on the conventional and emerging technologies for POME polishing, the paper discussed more on the palm oil processing, legislation and conventional treatment technologies, leaving other important studies out. On the other hand, the review by Rupani et al. (2010) focused largely on sludge treatment using vermicomposting. Thus, a critical review on the polishing technologies of POME covering the recent advances is yet to be presented. In view of that, this review aims at presenting the state of the art of the POME polishing technologies, with emphasis on AOPs as potential technologies. The objective is to place the on-going effort in context, highlight the challenges in adopting AOPs and proffer some possible solutions. First, an overview on POME and conventional treatment technologies are given. The recent advances on the polishing technologies are then presented, with emphasis on the application of AOPs. The last part of the paper discussed prospects and challenges of using AOPs in POME polishing. Although it is pertinent to discuss the palm oil processing stages that generate the effluent, previous studies have covered that (Hosseini and Abdul Wahid, 2015; Wu et al., 2009) and are therefore excluded from this review.

### 1.1. *Quantity and characteristics of POME*

Palm oil processing involves various stages, each producing large quantity of POME. The quantity of POME generated is directly related to the amount of crude palm oil processed. Malaysia produces huge amount of palm oil annually which results in generating large volume of POME. For example, in 2008 alone, about 44 million tons of POME was produced in Malaysia (Wu et al., 2010) and the figure keeps raising. Consequently, in 2013 and 2014, approximately 48–72 million tons and 49–74 million tons of POME were respectively produced (Ding et al., 2016).

POME is a thick brownish colloidal mixture of water, oil and fine suspended particles, which is normally hot when discharged. Table 1 shows the characteristics of raw POME which contains high concentrations of pollutants. The discharge of wastewater with such concentration of pollutants would be detrimental to the environment. The industries commonly use open ponding systems to treat the POME. In most cases, however, these processes could not produce satisfactory effluents. Table 1 also shows typical characteristics of treated POME obtained from a discharge point of a local palm oil mill in Malaysia. It can be seen that the BOD is much higher than the discharge limit set by the Malaysian DOE. The color,

**Table 1**
Characteristic of raw and treated POME modified from Bello et al. (2013) and Saeed et al. (2016).

| Parameters | Raw POME | Treated POME | DOE Discharge Limit |
|---|---|---|---|
| Temperature (°C) | 85 | 25–30 | 45 |
| pH | 4.2 | 8.4 | 5.0–9.0 |
| Oil & grease (mg/L) | 6000 | – | 50 |
| BOD (mg/L) | 25, 000 | 580 | 100 |
| COD (mg/L) | 51,000 | 4500 | – |
| TS (mg/L) | 40,000 | – | 1500 |
| TSS (mg/L) | 18,000 | 130 | 400 |
| TVS (mg/L) | 34,000 | – | – |
| TN (mg/L) | 750 | 127 | 200 |
| Color (ADMI) | Above 500 | Above 500 | 200 |

BOD: Biological oxygen demand; COD: Chemical oxygen demand; TS: Total solids; TSS: Total suspended solids; TVS: Total volatile solids; TN: Total nitrogen; ADMI: American dye manufacturers institute.