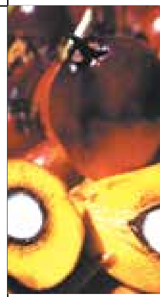

Bio-based Products from Palm Oil Mill Effluent

Stasha Eleanor Rosland Abel*; Soh Kheang Loh and Nasrin Abu Bakar

ABSTRACT

A surplus of palm oil mill effluent (POME) is generated annually. POME - a by-product from the palm oil milling process - is often regarded as a highly polluting wastewater although its high organic load can be economically beneficial. In average, about 0.67-1 t of POME is produced for every t of fresh fruit bunches (FFB) processed. Despite the negative perception on POME, it has great potential to be reutilised as a renewable source for making into various value-added products e.g. citric acid, bioethanol, biohydrogen, bioplastic, among others, through biotechnological approaches. The advantages of bioprocessing of POME include a reduced production cost, environmental impact associated with palm oil processing and energy consumption. This paper reviews some of the recent biotechnological advances in waste (POME)-to-wealth (bioproducts) generation which then promote sustainable palm oil production.

INTRODUCTION

Malaysia is blessed with abundant natural resources with a favorable climate for commercial cultivation of crops such as oil palm. Oil palm, species of the genus *Elaeis guineensis*, is among the most oil yielding crop, with approximately 10-35 t ha^{-1} of fresh fruit bunch (FFB) generated a year in comparison to 0.5-0.7 and 0.3-0.4 t ha^{-1} that of rapeseed and soya bean, respectively (Arhem, 2011). This indeed shows a tremendous contribution of the oil palm industry to Malaysia's economic development from two aspects; oil as a commodity and the oil palm biomass as the main by-product stream. Generally, two main types of by-products namely the solid biomass and liquid wastewater are generated during processing of palm oil (*Figure 1*). For every tone of FFB processed in a palm oil mill, around 5.5% palm kernel shell (PKS), 13.5% mesocarp fibers (MF) and 23.4% empty fruit bunches (EFB) are

* *Malaysian Palm Oil Board,*
6, Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.
E-mail: eleanor@mpob.gov.my

generated as solids waste materials (Liew *et al.*, 2015; Loh, 2017). Besides, ~67% palm oil mill effluent (POME) is also produced as the main liquid waste from milling activities.

Generally, the ever-increasing generation of solid and/or liquid wastes has made their disposal a persistent issue and what's more, the massive production of POME annually with high organic strength. Its high content of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) pose potential threat to the environment if it were discharged in its untreated (raw) form. Thus, a proper treatment and management of POME is crucial in order to ensure sustainable palm oil milling, besides conserving the environment. One of the effective treatment approaches through microbial conversion of POME into high

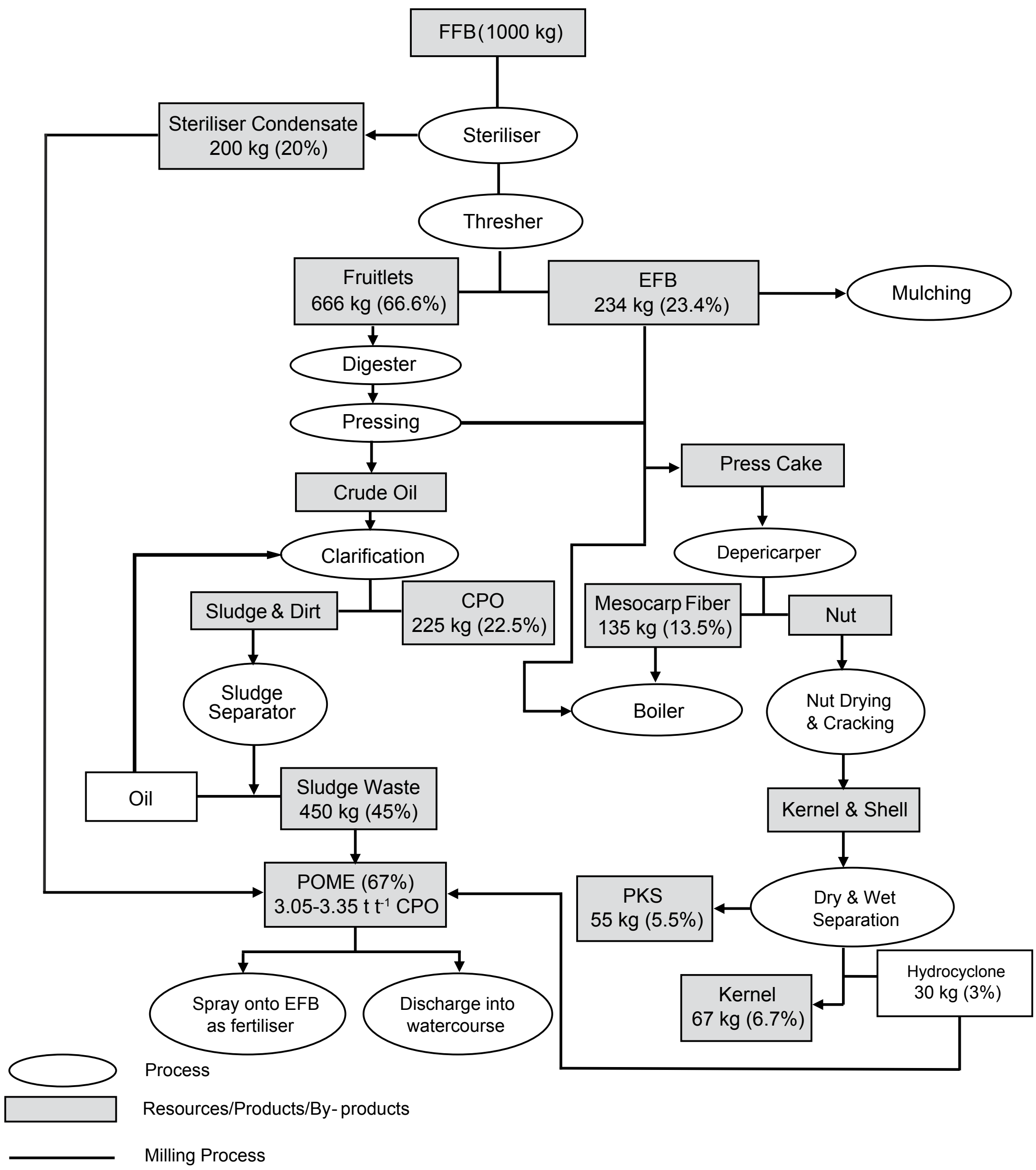

Figure 1. Brief description of palm oil milling process and current practices (Ma, 1999; Vijaya et al., 2008; Liew et al., 2015; Ropandi et al., 2017).

value-added products is applicable and worth pursuing. It seems to be a viable option as POME is rich in nutrients and carbohydrates which can potentially be applied as an inexpensive carbon source to produce a series of economically interesting and valuable products *e.g.* biodegradable plastics - polyhydroxyalkanoates (PHAs) and biochemicals - citric acid, ethanol and lactic acid, *etc*.

POME CHARACTERISTICS AND DISCHARGE LIMIT

The characteristics of POME is dependent on the raw material; FFB quality and milling activities in palm oil mills. Physically, POME is a viscous, thick and brownish liquid containing about 95%-96% water, 0.6%-0.7% oil and 4%-5% total solids. It also has high BOD (>180 00 mg litre^{-1}) and COD (>450 00 mg litre^{-1}), and is discharged at 80°C-90°C at acidic pH (*Table 1*). The high content of organic matters in POME is caused by the presence of several sugars such as arabinose, xylose, glucose, galactose and mannose (Agamuthu and Tan, 1985). Besides, POME also comprises considerable amounts of nutrient including nitrogen, potassium, magnesium, calcium, copper, chromium and iron (Ohimain *et al*., 2012).

Huge quantity of POME is generated from three milling activities *i.e.* sterilisation (0.2-0.25 t t^{-1} FFB), clarification (0.4-0.45 t t^{-1} FFB) and hydrocyclone (0.03-0.05 t t^{-1} FFB) in a ratio of 6:15:1 as voluminous quantity of water is used during oil extraction process (Ma, 1999). As no chemical is added, POME is regarded as a non-toxic waste but still can cause environmental issues when discharging in aquatic system with its rich organic and nutrient contents causing large oxygen depleting capability. Currently, the limit of POME BOD final discharge is 100 mg litre^{-1} enforced since 1984 by the Department of Environment (DOE) and most of the palm oil mills comply with the requirement. However, a more stringent 20 mg litre^{-1} BOD discharge limit has to be met sooner or later for environmental conservation although it is difficult now to fully comply associating with inconsistent performance of recent POME treatment technologies.

CONVERSION OF POME TO VARIOUS VALUE-ADDED PRODUCTS

In order to overcome POME disposal issue, many tertiary polishing technologies for POME have been developed including membrane technologies (Amosa, 2017; Ghani *et al.*, 2018), coagulation/flocculation (Poh *et al.*, 2014; Zahrim *et al.*, 2017), advanced oxidation processes (Ng *et al.*, 2016), sequencing batch reactor (SBR) (Chan

TABLE 1. PALM OIL MILL EFFLUENT (POME) CHARACTERISTIC AND DISCHARGE STANDARDS

Parameter	Value	Limit of POME final discharge		
		Since 1-1-1984	Standard A	Standard B
Temperature, °C	80 - 90	45	40	40
pH	3.3 - 5.7	5.0 - 9.0	6.0 - 9.0	5.5 - 9.0
BOD, mg litre^{-1}	18 000 – 25 000	100	20	50
COD, mg litre^{-1}	45 000 – 55 000	-	50	100
Suspended Solid (SS), mg litre^{-1}	25 000 – 31 000	400	50	100
Oil & grease, mg litre^{-1}	5600 - 8800	50	1/ND	10
Ammoniacal N, mg litre^{-1}	77 - 100	150*	10	20
Total N, mg litre^{-1}	670 - 780	200*	-	-

Sources: DOE (2009); Loh *et al*. (2013); Value of filtered sample

TABLE 2. VARIOUS PRODUCTS FROM BIOPROCESSES OF PALM OIL MILL EFFLUENT (POME) AS CARBON SOURCE

Microorganism	Product	Yield (g $litre^{-1}$)	Condition	Reference
Cupriavidus necator	PHB	3.12	POME: 180 ml Sugar: 18 g $litre^{-1}$ Time: 60 hr	Sangkharak *et al.*, 2016
Aspergillus niger (A103)	Citric acid	5.2	POME: 2% (w w^{-1}) Wheat flour: 4% (w w^{-1}) Glucose: 4% (w w^{-1}) Ammonium nitrate: 0% (w v^{-1}) Time: 5 days	Alam *et al.*, 2008
Aspergillus niger ATCC 9642	Citric acid	1.02	POME: 75% Methanol: 3% Time: 7 days	Nwuche *et al.*, 2013
Clostridium acetobutylicum NCIMB 619	ABE	1.12	Temp: 37°C Time: 43 days	Japar *et al.*, 2013
Clostridium acetobutyricum	ABE	3.8	POME: 180 ml Cellulase: 5 U ml^{-1} pH: 7 Time: 6 days	Sangkharak *et al.*, 2016
Mixed culture	Biohydrogen	5.99 ± 0.5 (v v^{-1})	POME: 10% (w v^{-1}) Temp: 37°C pH: 5.5 Time: 14 days	Norfadilah *et al.*, 2016
Mixed cultures (*T. harzianum* and *S. cerevisiae)*	Bioethanol	51.3	Temp: 32°C pH: 6 Time: 5 days	Alam *et al.*, 2009

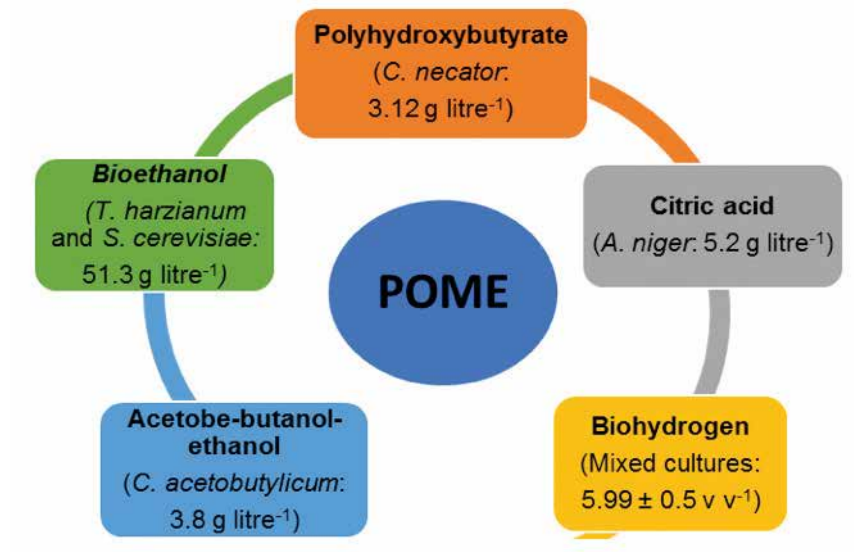

Figure 2. Value-added products derived from palm oil mill effluent (POME) (more detailed information in Table 2*).*

et al., 2010), *etc*. Also emerging are converting POME into value-added products. Among the developed biotechnologies, turning POME into 1) acetone-butanol-ethanol (Kalil *et al.*, 2003), 2) citric acid (Jamal *et al.*, 2007), 3) biohydrogen (Chong *et al.*, 2009), 4) polyhydroxybutyrate (PHB) (Sangkharak *et al.*, 2016) and 5) bioethanol (Wakil *et al.*, 2013) look promising (*Figure* 2). POME serves as a versatile raw material, considering that it can be widely used as a carbon source for microbial growth. The conversion through biological routes with the aid of microorganisms receives tremendous attention nowadays due to the vast possibility microorganisms can offer and readily available resource.

To date, various species of microorganisms including *Clostridium* sp., *Aspergillus* sp. and *Cupriavidus* sp. have been proven capable of employing POME as a carbon source for the production of fine chemicals and bioproducts (*Table* 2). The process viability in terms of utilising localised microorganisms and low-cost POME helps in diminishing pollution problems along with generating additional revenue to the palm oil milling industries.

The products generated from POME have various applications in the industry (*Figure* 2). Citric acid is used as an emulsifying agent in ice creams, cleansing agent, cosmetics and etc. Biohydrogen is currently being seen as a versatile fuel of the future, with potential to replace fossil fuels. It seems particularly suitable for relatively small-scale plant integrated with agricultural and industrial activities or waste processing facilities. For bioethanol, it has a number of advantages over conventional fuels. It is biodegradable and less toxic which helps in reducing the amount of carbon monoxide produced by the vehicle thus improving air quality. PHA is a family of polymers with biodegradability and biocompatibility characteristics. Having the similar properties to thermoplastics, materials made from PHAs are expected to replace the conventional petroleum-based plastics. PHAs and their derivatives have emerged as potential useful materials mainly in agricultural, food and biomedical industries.

CONCLUSION

As the global palm oil demand increases, waste generation *i.e.* POME has also increased. Discharging the POME in untreated form might deteriorate the environment when in contact. Hence, appropriate waste minimisation strategy which is easy to operate and cost-effective is in need. Application of POME as a

potential carbon source for value-added bioconversion could not just reduce pollution issues created, but bring positive impacts to economic and sustainable development.

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