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Palm Oil Mill Biogas Producing Process Effluent Treatment: A Short Review

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Abstract: Biogas generation from palm oil mill effluent treatment plant is becoming the future trend for the palm oil millers. Therefore, the efficient treatment of biogas producing process effluent is equally important to minimize the detrimental effect towards human and environment. In addition, stricter regulations in the future, increasing in public awareness and towards water reuse also motivated investigation on this important topic. This study aims to discuss several treatment systems for palm oil mill biogas producing process effluent. Integrated treatment system is vital for treating palm oil mill biogas producing process effluent.

Key words: Palm oil mill, wastewater, biogas, pre-treatment, integrated system

INTRODUCTION

Palm oil industry is among the main agro based industries in Malaysia. The production of Crude Palm Oil (CPO) leads to huge quantities of wastes, particularly Palm Oil Mill Effluent (POME). Biogas generation from anaerobic digestion of POME to generate electricity is becoming the future trend for the palm oil millers (Chow, 2013). It is expected that net profit of RM 3.8 million per year can be obtained in a palm oil mill with processing capacity of 60 t h^{-1} from electricity generation using biogas produced from POME treatment (Chin *et al*., 2013).

The biogas producing process effluent or anaerobically treated effluent (AnPOME) is black-dark brown in colour (Yaser *et al*., 2013) which indicate a water pollution by the public. The AnPOME contains particulates (0.32-0.39% (w/w)) i.e., bioflocs, anaerobic microorganisms, macrofibrils. The soluble fraction consist of carbohydrate, pectin, lignin, tannin, humic and fulvic acid like substance, melanoidin and phenolics compounds (Ho *et al*., 1984; Kongnoo *et al*., 2012; Yaser *et al*., 2013) such as gallic, protocatechuic, 4-hydroxybenzoic, 4-hydroxylphenylacetic, caffeic, syringic acids, p-coumaric and ferulic acids (Jamal *et al*., 2011). The other parameters are shown in Table 1. The conventional POME treatment plant i.e., aerobic ponding system is reported to be insufficient (Yaser *et al*., 2013). The upgrading plan for the current treatment plant is vital since the limit of POME discharge to water body getting stringent from time to time (Fig. 1) and the treated effluent still has detrimental effect to the environment even though fulfilling the current requirement (Aris *et al*., 2008).

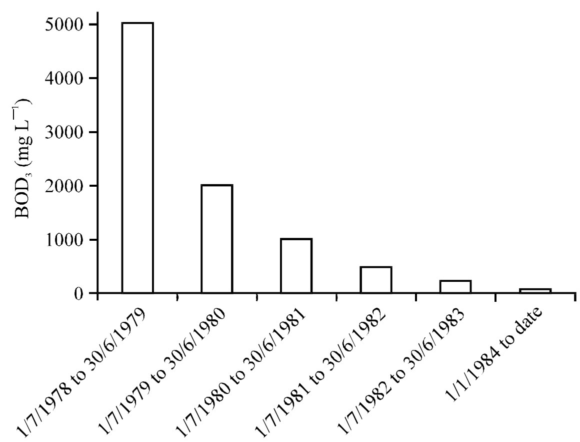

Fig. 1: Evolution of BOD_3 limit for POME discharge (Wu *et al*., 2010)

TREATMENT SYSTEMS FOR BIOGAS PRODUCING PROCESS EFFLUENT

The biogas producing process effluent is able to inhibit the growth of the desirable aquatic biota necessary for self-purification by reduction the penetration of sunlight with a consequent reduction photosynthetic process activity. Besides that, the color compounds from biogas producing process effluent also have cast to chelate metal ion which become toxic to aquatic life. Moreover, the color is able to reduce dissolved oxygen and could be hazard to micro-and macro-aquatic life (Zahrim *et al*., 2009; Bunrung *et al*., 2011). Therefore, over the past years, several studies such as membrane filtration, adsorption, biological oxidation etc., have been dedicated for the treatments of biogas producing process effluent.

Table 1: Characteristics of anaerobically treated palm oil mill effluent (AnPOME)

Source	pH	COD (mg L^{-1})	BOD (mg L^{-1})	Suspended solid (mg L^{-1})	Total nitrogen (mg L^{-1})	Ammoniacal nitrogen (NH_3-N) (mg L^{-1})	Colour (PtCo)	Total phosphate (mg L^{-1})	References
Selangor, Malaysia (closed type anaerobic digester)	7.4	13532	1355a	12750	NS	NS	NS	NS	Chan *et al.* (2011)
Malaysia (Lab scale anaerobic reactor, detention time = 30 days)	7.2	9403	1180	8129	310	NS	NS	50	Ng *et al.* (1985)
Sabah, Malaysia (Anaerobic pond no. 4)	7.7-8.3	1003-1279	NS	290-350	NS	50-100	3816-6994	28-85	Zahrim *et al.* (2009)
Surat Thani, Thailand (raw biogas effluent)	7.5	1832	NS	2370	NS	NS	1633	NS	Bunrung *et al.* (2011)
Yaba Lagos, Nigeria (anaerobic tank digester)	NS	1922	440	NS	NS	NS	NS	NS	Ugoji (1997)
Negri Sembilan, Malaysia (Final discharge pond)	NS	2166	NS	900	26	45	7900	NS	Sulaiman and Ling (2004)
Selangor, Malaysia (Final discharge pond)	7.43	12040	NS	3103	NS	NS	54200	NS	Said *et al.* (2013)

NS: Not stated, COD: Chemical oxygen demand, BOD: Biochemical oxygen demand, $^{a}BOD_3$

Membrane filtration: In membrane filtration, the range of particle sizes is extended to include dissolved constituents (typically 0.0001 and 1.0 μm). The role of membrane is to serve as a selective barrier that will allow the passage of constituents and will retain other constituents (Cheryan, 1998). Wah *et al.* (2002) investigated ultrafiltration (UF) of AnPOME with several pre-treatments i.e., sand filtration, centrifugation and coagulation. Combination of filtration-UF treatment gave the best overall treatment efficiency, with an overall reduction of 93% for total nitrogen, suspended solids, turbidity and colour content. Sulaiman and Liang (2004) showed that the hollow fiber membrane with Molecular Weight Cut Off (MWCO) 100 K gave higher fluxes compared to the MWCO 30 K, however, the latter membrane gave better quality permeate. The quality of permeate achieved from the membrane with MWCO 30 K, gave reductions in COD, SS, TKN and NH_3-N of 98, 98, 54 and 62%, respectively. The final level of colour is still high i.e., 650 PtCo (92% removal). Recently, the effect of pH, ionic strength, pressure and temperature on phenol removal from treated POME using an ultrafiltration (UF) membrane were studied. Maximum phenol removal was achieved at pressure 2 bar and temperature 50°C up to 97.8 and 99.8%, respectively (Said *et al.*, 2013). The major constraint for membrane separation is fouling.

Ozonation: Chemical oxidation involves the use of oxidizing agents such as ozone (O_3), hydrogen peroxide (H_2O_2), permanganate (MnO_4), chloride dioxide (ClO_2) etc., to change the chemical composition of AnPOME (Tchobanoglous *et al.*, 2004). Facta *et al.* (2010) proposed the use of an ozonation proces for colour removal of treated palm oil mill effluent (Fig. 2). Ozone in a certain concentration was injected into the treated POME water through a diffuser for several minutes. The authors found that the colour of treated POME water has successfully changed from 100 PtCo into 40 PtCo or lower (Facta *et al.*, 2010). Ozonation is an interesting process because it works well in alkaline conditions (Al-Kdasi *et al.*, 2004), however it is expensive one (Robinson *et al.*, 2001).

Advanced oxidation process: Advanced Oxidation Processes (AOPs) are processes that degrade organic pollutants by forming hydroxyl radicals ($HO^{\bullet}$) which are highly reactive and non-selective. The important chemical oxidants for AOP are photo-Fenton or Fenton reagent, O_3/H_2O_2, O_3/UV, H_2O_2/UV and TiO_2/UV (Oller *et al.*, 2011). Among the simplest AOP is Fenton oxidation. In Fenton oxidation, $HO^{\bullet}$ is generated through the reaction between ferrous (Fe^{2+}) and hydrogen peroxide (H^2O^2) at acidic condition (Aris *et al.*, 2008):

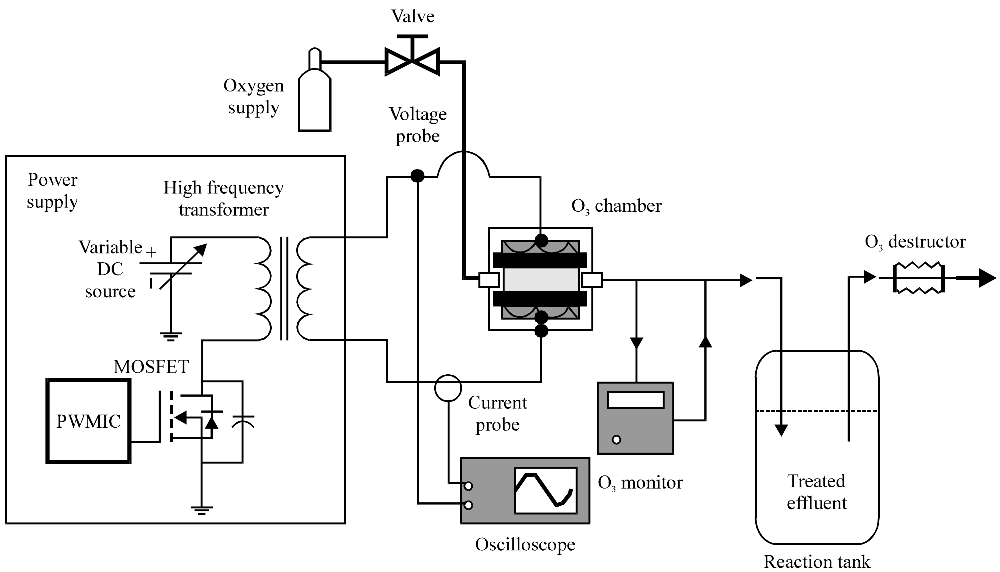

Fig. 2: Ozonation setup (Facta *et al*., 2010)

$$H_2O_2+Fe^{2+}\rightarrow Fe^{3+}+HO^{\bullet}+OH^- \quad (1)$$

Fenton oxidation in conventional way (ambient) and solar-Fenton for AnPOME treatment was investigated by Aris *et al*. (2008). The highest removals of COD and color for ambient-Fenton were 75.2 and 92.4%, respectively. The COD and color removal of 82.4 and 95.1%, respectively, were achieved by solar-Fenton. The solar-Fenton removal was mainly through oxidation process. Precipitation and coagulation of iron also contributed to the removal of COD and color but at a lesser extent. Enhancement of color removal by the coagulation process is mainly through elimination of the remaining iron rather than removal of the organics (Aris *et al*., 2008). The major problem with Fenton process is that they only effective at acidic pH. Normally the biogas producing process effluent is in alkaline condition. Furthermore treated water will end-up in acidic condition which is not suitable to be discharged in surface water. Thus to discharge the AOP treated water, neutralization process is required.

Sonication: Sonochemical decomposition of organic pollutants in aqueous solution is driven by the formation and collapse of high-energy cavitation bubbles. Application of ultrasonic irradiation or sonication to digested palm oil mill effluent has been studied by Rosli *et al*. (2010). In this study, ultrasonic irradiation alone (Fig. 3) only reduce 55% COD in 45 min reaction time. Similarly, the addition of activated carbon alone can only reduce 38% COD. However, combination of ultrasonic irradiation could reduce up to 96% COD (Rosli *et al*., 2010).

Adsorption: Adsorption is an essential process for obtaining high quality water and the treatment of biological treated POME via adsorption process has been studied either by commercial activated carbon or waste materials. Treatment of biogas reactor effluent using palm fiber ash as an adsorbent was conducted by Bunrung *et al*. (2011) in laboratory scale. At the optimum parameters i.e., 15% (w/v) palm ash and 8 h treatment, they found that the colour removal efficiency was up to 82%.

Kutty *et al*. (2011) investigated the application of Microwave Incinerated Rice Husk Ash (MIRHA) as an adsorbent in removing pollutants from treated POME wastewater. Optimum removal of COD (41%) and colour (88%) was achieved at 40000 and 50000 mg L^{-1} dosage of MIRHA at 6 h contact time, respectively. The MIRHA proved to be effective in removing Zn(II), Cu(II), COD and colour from POME. In another study, it was reported that the removal of organics was studied using commercial Powdered Activated Carbon (PAC) as adsorbent. It shows that the COD and TSS removal increases as the PAC dosage increases before both reach equilibrium at dosage 2 g (Tamrin *et al*., 2013).

Ion exchange: Ion-exchange is a reversible chemical reaction between an complex solid and a solution. An attempt was made to remove residual contaminants such as color after biologically treated POME using anion base resin was carried out by Bello *et al*. (2013). It was found that the highest uptake capacity was obtained at pH 3. The exhaustion time appeared to increase with increase in bed length and decrease in flow rate (Bello *et al*., 2013).

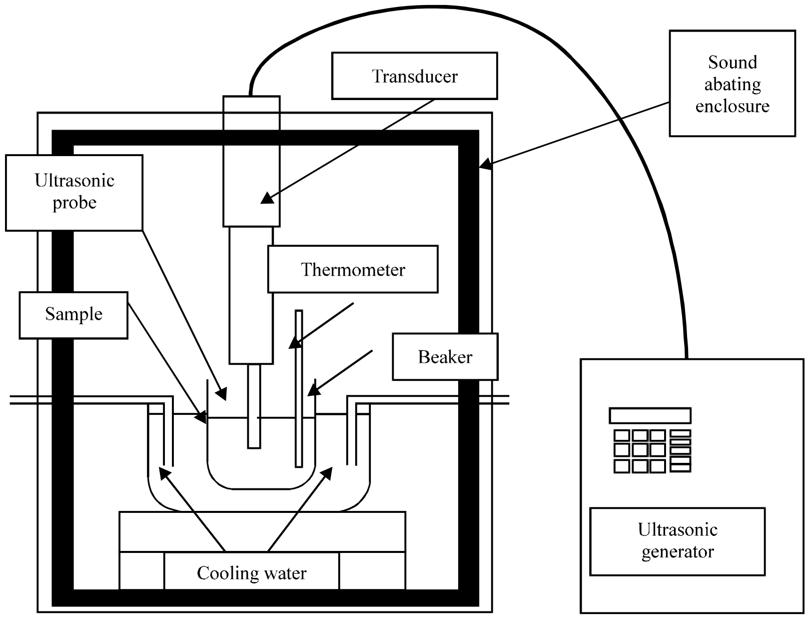

Fig. 3: Sonication setup (Rosli *et al*., 2010)

Coagulation/flocculation: Coagulation of coloured effluents has been used for many years, either as main or pre-treatment, due to its low capital cost. Ho and Tan (1989) studied AnPOME treatment using coagulation aluminium sulphate/flocculation cationic polyacrylamide CF, Dissolved Air Flotation (DAF) and CF-DAF. Addition of polymer with is shown to increase the settling rate. Although, the methods were able to achieve a 97% removal of the suspended solids of the digested liquor (1200 mg L^{-1} alum and 3 mg L^{-1} polymer), the removal of soluble solid is very difficult. The authors stated that the total solid removal for CF, DAF and CF-DAF are 56, 59 and 63%, respectively (Ho and Tan, 1989). Malakahmad and Chuan (2013) also reported that the coagulation of AnPOME using alum only able to reduce 59% COD. The condition for optimum conditions are pH = 6.4, alum dosage = 2124 mg L^{-1} and slow mixing = 20 min.

Advancement in polymer synthesis and purification resulted in the development of vast types of polymers. The best polymer should be selected to ensure the highest performance of coagulation as well as to reduce the chemical cost (Zahrim *et al*., 2011). Jami *et al*. (2012) applied polymer as coagulant aids and compares the use of coagulants ferric chloride and aluminium sulphate to reduce turbidity. The result of the coagulation process showed that ferric chloride gave a better reduction of turbidity at dosage of 100 mg L^{-1}, pH of 8 and with polymer dose of 100 mg L^{-1} than alum (Jami *et al*., 2012). Recently, Zahrim *et al*. (2014) utilized calcium lactate for the treatment of AnPOME. The maximum lignin, Low Molecular Mass Coloured Compounds (LMMCC), COD and ammonia nitrogen removal is >90, 70, >90 and 90%, respectively (Zahrim *et al*., 2014).

Biological treatment: Since, aerobic ponding system is required large treatment area due to high Hydraulic Residence Time (HRT), several studies especially on sequencing batch reactor have been conducted to increase the efficiency. A Sequencing Batch Reactor (SBR) is a variation of the activated sludge biological treatment process that achieves equalization, aeration and clarification in a timed sequence, in a single-reactor basin. Fun *et al*. (2007) investigated the treatment of AnPOME using SBR system. The biological treatment was conducted in three days aeration and one day idle time. The highest removal achieved was 62% for TSS, 82% for total COD and 88% for soluble COD (Fun *et al*., 2007). For the first time, decolourisation of AnPOME by means of suspended growth activated sludge (SAS) and attached growth Activated Sludge Granular Activated Carbon (ASGAC) sequencing batch operation was reported by Zahrim *et al*. (2009). During the period of treatment, colour removal for the SAS and ASGAC was about 7 and 35%, respectively. The COD for the SAS and ASGAC was about 33 and 65%, respectively. This study proved that the ASGAC was superior to SAS for treatment of AnPOME (Zahrim *et al*., 2009). In another study, Chan *et al*. (2011) studied thermophilic aerobic treatment (50°C) system of AnPOME. They found that the maximum COD, BOD and TSS removals were up to 86, 87 and 89%, respectively.

Besides that, biogas producing process effluent was also reuse as nutrient supplement for other biological processes. An attempt to treat AnPOME-aerobic palm oil mill effluent using water hyacinth (*Eichhornia crassipes*) was reported by Yeoh (1993). With a Hydraulic Retention Time (HRT) of 5 days, the water hyacinth (*Eichhornia crassipes*) was able to further reduce the BOD and ammoniacal nitrogen of the treated effluent by 40 and 54%, respectively. However, the decolourisation in this system is around 4% (Yeoh, 1993). Recently, Zahrim and Rajin (2014) studied the potential of Diluted Treated Palm Oil Mill Effluent (DTPOME) as a source of nutrient for growing water hyacinth (*Eichornia crassipes*). It was found that the specific growth rate for the water hyacinth is 0.01834 g g^{-1} day^{-1} with removal of around 85% ammonia nitrogen (NH_3-N) (Zahrim and Rajin, 2014). Zainal *et al.* (2012) reported that the removal of Chemical Oxygen Demand (COD), ammoniacal-nitrogen and total phosphorus using green algae, *Spirulina platensis* is 90, 87 and 80%, respectively. Composting is regarded as a sustainable technology for processing solid and liquid waste from the palm oil mill into fertiliser. Anaerobic composting was carried out by mixing sawdust (SD) with Palm Oil Mill Effluents (POMEs) (raw POME and POME from anaerobic pond 2) and the phytotoxicity of the composts was evaluated on spinach (*Ipomoea* sp.) and Chinese cabbage (*Brassica* sp.) using simple seed germination and root elongation techniques. The results suggested that 70% SD+30% POME was the most desirable composition for both composting processes since the germination index values of both plant species examined were >100% at day 60 which indicate the disappearance of phytotoxins (Zahrim *et al*., 2014).

Integrated system: Since standalone treatment has its own disadvantages, the integration of different treatment process is required to devise a technically and economically feasible option for biogas producing process effluent treatment. Earlier, Ho and Tan (1988) carried out combination of dissolved air flotation (DAF)-pressurized activated sludge. They reported that the BOD, COD, total solids, suspended solids and oil and grease removal were 98, 98, 88, 99 and 93%, respectively. (Idrisa *et al*., 2010) stated coagulation (using ferric chloride+polyacrylamide) adsorption-ultrafiltration was able to reduce colour = 100 PtCo (96% removal). Ratpukdi (2012) has investigated integrated coagulation and advanced oxidation processes. At the end of experiment (180 min), the integrated system could remove 95.5% of color in ADMI unit (Ratpukdi, 2012).

CONCLUSION

Palm oil mill biogas producing process effluent should be treated before it can be discharged. The biogas effluent contains bioflocs, anaerobic microorganisms, macrofibrils, while the soluble fraction consist of carbohydrate, pectin, lignin, tannin, humic and fulvic acid like substance, melanoidin and phenolic compounds. Several types of treatment have been reviewed including membrane separation, ozonation, sonication, adsorption, ion exchange, coagulation/flocculation and biological treatment. Although biological is the cheapest treatment for palm oil mill biogas producing process effluent, the recalcitrant compounds are the major hindrance for successful biological treatment. Therefore, pre-treatment should be investigated deeply and will be a major challenge in the future. Minimizing palm oil mill biogas producing process effluent load to the effluent treatment plant by using it as nutrient source for composting process is also interesting topic to be explored.

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