Journal of Environmental Management 149 (2015) 222–235

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: A review

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ARTICLE INFO

Article history:
Received 6 February 2013
Received in revised form
23 September 2014
Accepted 14 October 2014
Available online

Keywords:
Palm oil
Palm oil mill effluent
Polishing technologies
Sustainability
Tertiary treatment

ABSTRACT

The Malaysian palm oil industry is a major revenue earner and the country is ranked as one of the largest producers in the world. However, growth of the industry is synonymous with a massive production of agro-industrial wastewater. As an environmental protection and public health concern, the highly polluting palm oil mill effluent (POME) has become a major attention-grabber. Hence, the industry is targeting for POME pollution abatement in order to promote a greener image of palm oil and to achieve sustainability. At present, most palm oil mills have adopted the ponding system for treatment. Due to the successful POME pollution abatement experiences, Malaysia is currently planning to revise the effluent quality standards towards a more stringent discharge limits. Hence, the current trend of POME research focuses on developing tertiary treatment or polishing systems for better effluent management. Biotechnologically-advanced POME tertiary (polishing) technologies as well as other physicochemical methods are gaining much attention as these processes are the key players to push the industry towards the goal of environmental sustainability. There are still ongoing treatment technologies being researched and the outcomes maybe available in a while. However, the research completed so far are compiled herein and reported for the first time to acquire a better perspective and insight on the subject with a view of meeting the new standards. To this end, the most feasible technology could be the combination of advanced biological processes (bioreactor systems) with extended aeration, followed by solids separation prior to discharge. Chemical dosing is favoured only if effluent of higher quality is anticipated.

1. Introduction

The palm oil industry has been an important economic contributor for countries like Malaysia, Thailand, Indonesia, Colombia and other tropical developing regions. While impressive export and production figures are widely reported in almost all palm oil or POME treatment literature, it is not astonishing that a massive production of the effluent has turned out to be a main source of water pollution. In Malaysia, it is estimated that at least 60 million tonnes of POME was generated in the year 2009 alone (Ng et al., 2011). For each tonne of fresh fruit bunch (FFB) processed, large quantities of POME containing 29–33 kg of 30 °C, 3-days Biochemical Oxygen Demand (BOD_3) are discharged into the water bodies (Thanh et al., 1980).

In Malaysia, a lot of efforts on research and development had made the industry dotted with significant successful pollution abatement history. Being the pioneer in targeting sustainable palm oil industry, Malaysia has gained valuable experiences in developing technologies for both upstream and downstream processing. In the year 2011, the palm oil processing mills attained 95.5% compliance to the effluent discharge limits (DOE, 2011). This achievement will continue to soar higher when further aim for the implementation of greater environmental management initiatives such as Cleaner Production (CP), biogas capture for Clean Development Mechanism (CDM) (PEMANDU, 2010; Ng et al., 2011), Roundtable for Sustainable Palm Oil (RSPO) (Basiron, 2007), and possibly towards zero discharge is made.

Previous reviews have been published emphasizing the current conventional POME treatment methods and state-of-the-art laboratory treatability studies. Some papers emphasize reusing the effluent and the industry's solid wastes to attempt resource recovery. As the current scenario in palm oil research focuses on

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http://dx.doi.org/10.1016/j.jenvman.2014.10.016
0301-4797/

tertiary/polishing treatment of POME to progress towards the challenging 20 mg L^{-1} BOD_3 discharge limit, this paper aims to concisely review and report the POME tertiary/polishing technologies which have not been compiled before so as to gain an insight for better effluent management.

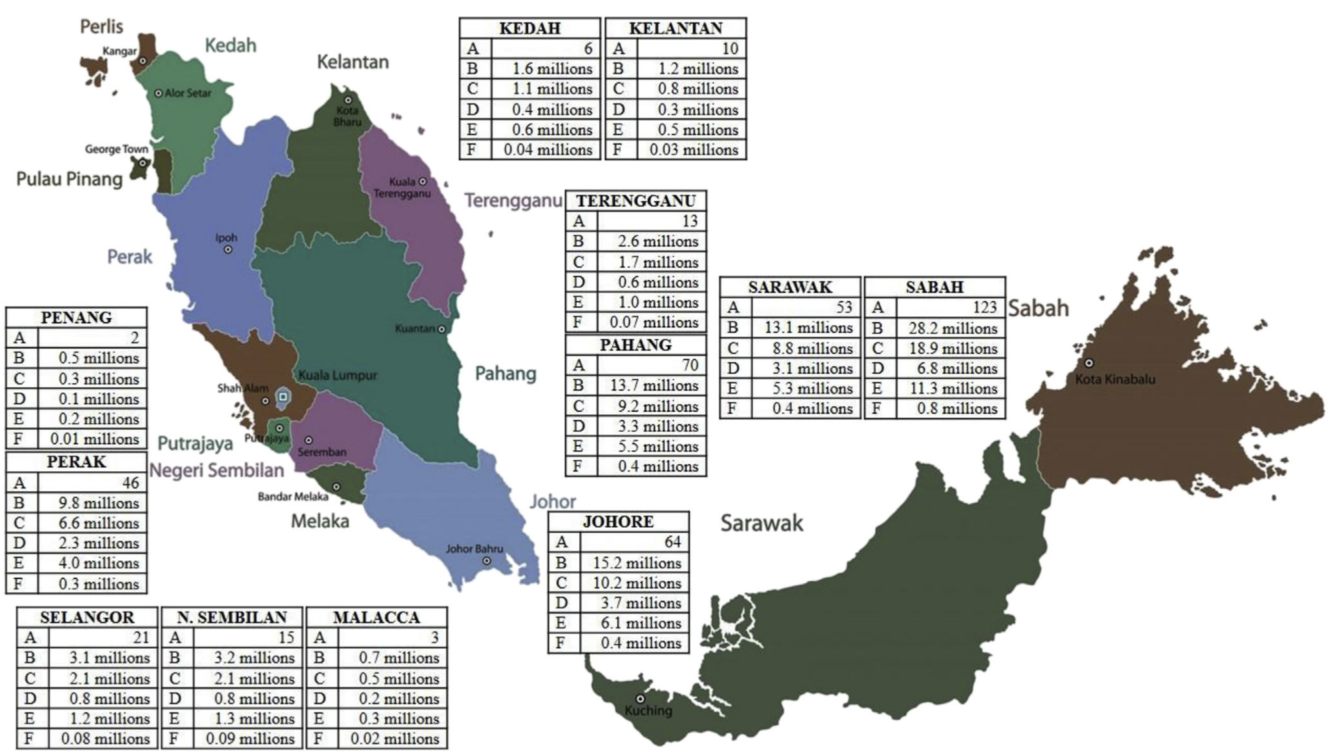
1.1. The palm oil industry at a glance

Development of the oil palm sector is marked as an industrial success story. As the main plantation commodity in Malaysia, the total plantation area has expanded from a mere 400 ha planted area (year 1920) to 54,000 ha (year 1960); subsequently to 2,692,286 ha (year 1996) and the most recent statistic at year 2013 reviewed is 5,229,739 ha of oil palm planted area (DOE, 1999; MPOB, 2014). Travelling across the country, oil palm trees are seen nearly in every bit of unfilled land. According to a stature report by Basiron (2007), forest and oil palm recorded 61.82 and 13.20%, respectively for land coverage in Malaysia. From such a huge area of oil palm plantation, the country is capable of producing more than 94 million tonnes of FFB to be processed by palm oil mills which are spread across the nation (MPOB, 2014). Up to year 2011, Malaysia recorded a total of 426 palm oil mills in operation (DOE, 2011; MPOB, 2012), with 250 mills operated in Peninsular Malaysia and the remaining 176 mills in Sabah and Sarawak.

Fig. 1 illustrates the distribution of the palm oil mills throughout the country. In the Peninsular, Pahang state has the highest number of mills while Sabah state tops the country at 123 mills in operation. Despite having the highest number of palm oil processing mills, Sabah state nevertheless is well-known for its biodiversity lushness. Major rivers in Sabah state like the Kinabatangan River, the Segaliud River, the Muanad River, the Segama River, the Pang Burong River, and the Kalumpang River are important to the local communities, tourism activities, and are getting severe exertions on conservation. Hence, most environmental concerns allied with the palm oil industry accentuates in the Sabah state, such as the implementation of the 20 mg L^{-1} BOD_3 discharge limit. Seeing the abundant number of palm oil processing mills in Malaysia, 30 additional mills are indeed under planning and construction throughout the country while 3 existing mills are not in operation (MPOB, 2012). With data on the amount of FFB processed by mills, the quantity of POME production can be projected. In Malaysia, the recorded national production rate for POME is 0.67 cubic meters per tonne of FFB processed by mills (DOE, 1999; Ma, 1999; Ng et al., 2011). POME can be further divided into the sterilizer condensate, clarification wastewater, and hydrocyclone wastewater in a ratio of 9:15:1 (Wu et al., 2010). The information in Fig. 1 shows the booming Malaysian palm oil industry (year 2011), but in contrast, a large amount of liquid wastes are produced requiring appropriate treatment before discharge.

1.2. Palm oil factory processes as sources of pollution

In Malaysia, the wet palm oil milling process is typically applied. The method uses hot water to leach out the oil, which also explains the large consumption of water resources for milling processes and the concomitant large production of wastewater. A less popular dry milling method uses mechanical presses on the digested mash to squeeze out the crude oil. In short, the crude palm oil extraction process starts with collection of the FFB from the oil palm plantations. In the palm oil processing mills, fresh bunches are delivered into horizontal sterilizers (commonly used in modern factories compared to the vertical sterilizers) or pressure vessels where a live steam is applied against the fruits at approximately 100–140 °C for 25–30 min (small bunches, 3–6 kg) or 50–75 min (larger bunches, 17 kg) to cook the palm fruits. The reported pressure used in sterilizers was 35–45 psi. The primary objective of sterilizing the fresh bunches is to deactivate and henceforth inhibit the enzyme activity (lipolytic enzymes) of palm fruits. The fat-splitting or lypolitic



KEDAH	
A	6
B	1.6 millions
C	1.1 millions
D	0.4 millions
E	0.6 millions
F	0.04 millions

KELANTAN	
A	10
B	1.2 millions
C	0.8 millions
D	0.3 millions
E	0.5 millions
F	0.03 millions

TERENGGANU	
A	13
B	2.6 millions
C	1.7 millions
D	0.6 millions
E	1.0 millions
F	0.07 millions

PAHANG	
A	70
B	13.7 millions
C	9.2 millions
D	3.3 millions
E	5.5 millions
F	0.4 millions

SARAWAK	
A	53
B	13.1 millions
C	8.8 millions
D	3.1 millions
E	5.3 millions
F	0.4 millions

SABAH	
A	123
B	28.2 millions
C	18.9 millions
D	6.8 millions
E	11.3 millions
F	0.8 millions

PENANG	
A	2
B	0.5 millions
C	0.3 millions
D	0.1 millions
E	0.2 millions
F	0.01 millions

PERAK	
A	46
B	9.8 millions
C	6.6 millions
D	2.3 millions
E	4.0 millions
F	0.3 millions

JOHORE	
A	64
B	15.2 millions
C	10.2 millions
D	3.7 millions
E	6.1 millions
F	0.4 millions

SELANGOR	
A	21
B	3.1 millions
C	2.1 millions
D	0.8 millions
E	1.2 millions
F	0.08 millions

N. SEMBILAN	
A	15
B	3.2 millions
C	2.1 millions
D	0.8 millions
E	1.3 millions
F	0.09 millions

MALACCA	
A	3
B	0.7 millions
C	0.5 millions
D	0.2 millions
E	0.3 millions
F	0.02 millions

Fig. 1. An overview of the Malaysian palm oil industry in year 2011. A – The number of palm oil processing mills in operation; B – The fresh fruit bunches processed by mills (tonnes); C – The estimated POME production (tonnes); D – Sterilizer condensate (tonnes); E – Clarification wastewater (tonnes); F – Hydrocyclone wastewater (tonnes).