Journal of Cleaner Production 64 (2014) 619–627

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Anaerobic treatment of palm oil mill effluents: potential contribution to net energy yield and reduction of greenhouse gas emissions from biodiesel production

Soni Sisbudi Harsono [a,b,*], Philipp Grundmann [c], S. Soebronto [d]

[a] Department of Technology Assessment and Substance Cycles, Leibniz-Institute for Agricultural Engineering Bornim (ATB), 14469 Potsdam, Germany
[b] Department of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember (UNEJ), East Java, Indonesia
[c] Department of Technology Assessment and Substance Cycles, Leibniz-Institute for Agricultural Engineering, Potsdam-Bornim (ATB), 14469 Potsdam, Germany
[d] Research Development PT. Asam Jawa, North Sumatra, Indonesia

ARTICLE INFO

Article history:
Received 17 April 2013
Received in revised form
12 July 2013
Accepted 29 July 2013
Available online 6 August 2013

Keywords:
Palm oil mill effluent
Anaerobic digestion
Biodiesel
Net energy yield
Greenhouse gas emissions

ABSTRACT

The effluents from palm oil mills for biodiesel production are generally treated in open ponds, causing large amounts of greenhouse gas (GHG) emissions. This study assesses the use of palm oil mill effluents (POME) as feedstock to produce biogas via anaerobic digestion. Biogas from POME can be converted into electricity and heat to eventually reduce the greenhouse gas (GHG) emissions of biodiesel production from palm oil. This study is using two system boundaries, firstly, system a "gate-to-gate" concerning the POME treatments, and secondly a "cradle-to-gate/total combustion" when we assess the impact of varying POME treatments within the biodiesel chain.

The research draws on field and experimental data from palm oil and biogas production in Sumatra, Indonesia. The findings show that the energy output from the conversion of POME to methane via anaerobic digestion and the subsequent combustion of the methane in a combined heat-power plant exceeds the energy consumption of the palm oil milling process. Treating POME in an anaerobic digester and using the biogas to generate electricity and heat has the potential to significantly reduce the GHG emissions of biodiesel production from palm oil. In the studied case, the energy output from the conversion of POME to electricity and heat is 0.44 MJ kg^{-1} biodiesel and the net energy yield is 0.42 MJ kg^{-1} biodiesel. The ratio of energy output to energy input of the conversion process is about 23.1. The potential reduction of GHG emissions is 658 g $CO_{2\text{-eq}}$ kg^{-1} biodiesel or 15.96 g $CO_{2\text{-eq}}$ MJ^{-1}. This is equivalent to about 33% of the total GHG emissions of biodiesel production from palm oil. Against this background we recommend to further develop and implement the treatment of POME in anaerobic digestion combined with the purposeful use of the methane, electricity and heat produced from the POME. This can make a significant contribution toward meeting international targets of emissions reduction for biodiesel production.

1. Introduction

1.1. Background

Indonesia produced nearly 25 million metric ton of palm in 2011/2012 (USDA, 2012). It is estimated that about 28 m^3 of biogas is generated for every m^3 of palm oil waste of the waste treatment plant of palm oil mills. In the palm oil mills, solid wastes are burned directly in the boiler to generated steam. There are many solid wasted included the fiber, shell and empty fruit bunches (EFB). Palm oil cultivation has become one of the dominant agricultural activities in Indonesia since the late 1990s. Between 1998 and 2007

Abbreviations: CH_4, methane; CHP, combined heat and power; $CO_{2\text{-eq}}$, carbon dioxide equivalents; COD, Chemical Oxygen Demand; CPO, crude palm oil; d, day; EFB, empty fruit bunches; FFB, fresh fruit bunches; g, gram; GHG, greenhouse gases; GWP, Global Warming Potential; ha, hectare; hr, hour; IOPRI, Indonesian Oil Palm Research Institute; LUC, land use change; POME, palm oil mill effluent; yr, year.

* Corresponding author. Tel.: +49 3315699919; fax: +49 3315699849.
E-mail addresses: s_harsono@yahoo.com, sharsono@atb-potsdam.de (S.S. Harsono).

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.07.056

the total area cultivated with palm oil increased from 3.9 million ha to more than 7.9 million ha (Rianto, 2009).

Nevertheless, Laurance et al. (2010) and Yule (2010) stated that sustainability of palm oil production as always been questioned by some countries and the non-governmental organization (NGOs). They claimed that further expansion of palm oil plantation cause more negative impact for environmental such deforestation and increasing greenhouse gas (GHG) emissions due to over utilization of peat land for palm oil plantation.

The criticism not only in the palm oil plantation expansion, but also include in the palm oil mills. Poh and Chong (2009) argued that the most significant pollutant from the palm oil mills is palm oil mill effluent (POME). The increasing production of CPO is accompanied by an increasing output of effluent from palm oil mills. Yacob et al. (2005) and Singh et al. (2010) reported that palm oil mills treat in average 60% of the wastewater in open ponds before it is disposed to the natural waters, while untreated wastewater is mainly used as liquid fraction in the composting process of empty fruit bunches.

However, there are large quantities of water based wastes that are not able to burn by themselves. These wastes have to be processed or digested in the waste treatment plant on order to comply with Department of Environment the Republic of Indonesia regulation before they can be allowed to be discharged into the water course. During the fermentation process, biogas is the unavoidable but valuable gaseous product of such a process.

North Sumatra province of Indonesia has a significant number of large agricultural operations. These agricultural operations produce a considerable amount of organic waste in the form of palm oil mill effluent (POME). Handling such large amounts of organic wastes, especially POME, in a environmentally friendly manner a highly challenging.

Given this huge amount of palm oil production, therefore the quantity of waste produced is expected to be large. These wastes, if not disposed properly, will have great negative impacts on the surrounding environment, i.e.: water pollution and greenhouse gas emissions.

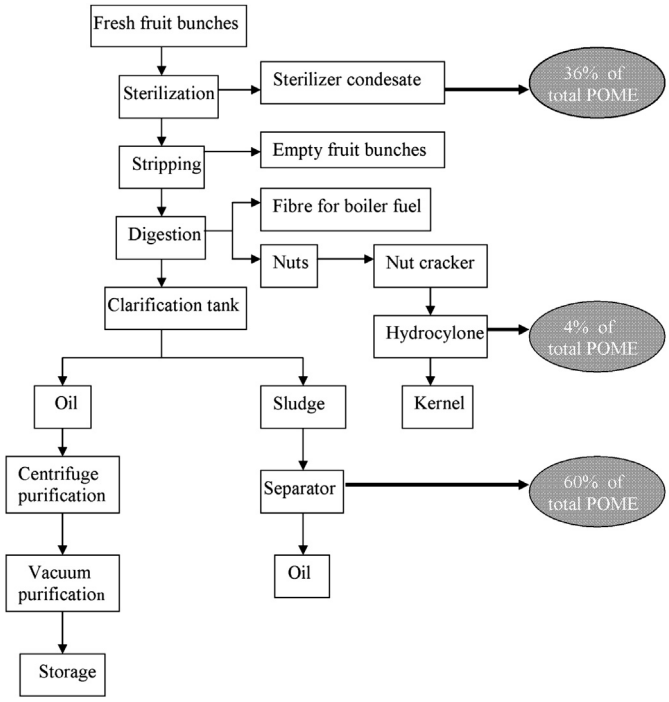

Fig. 1. Simplified process flow diagram of the production of crude palm oil including palm oil mill effluents (POME) (Lam and Lee, 2010).

Compared to gas emissions and solid wasted production, wastewater management in crude palm oil mill has long been a topic of research and discussion.

Several researchers highlight that storing POME without adequate treatment in open ponds causes environmental degradation and high emissions of GHG (Yacob et al., 2005; Basri et al., 2010). The environmental degradation including much more water resources is polluted and makes irrigated areas.

Hence, immediate remedies should be taken to overcome this problem and further strengthen for utilization of POME as energy resources for biodiesel production as content of this study and more environmental friendly solutions for treating POME are desired.

1.2. Nature of POME and treatment process

1.2.1. Nature of POME

POME is the liquid effluent discharged from the palm oil mills as a thick brownish liquid at a temperature between 80 and 90 °C with a pH typically between 4 and 5 (Singh et al., 2010). It is a combination of wastewaters generated and discharged from sterilizer condensate (36% of total POME), clarification wastewater (60% of total POME) and hydrocyclone wastewater (nearly 4% of total POME) (Wu et al., 2009).

Fig. 1 shows flow diagram where the POME is produced from palm oil mill.

Sources of POME in the palm oil mill processing as shown in Fig. 1 are follow.

a. Sterilization of Fruit Fresh Bunch (FFB)

At the process of sterilization, pressured steam (3×10^5 Pa) at high temperature 140 °C is used to infuse moisture into the nuts which can cause it to expand (Wu et al., 2009). Beside that, sterilization has purpose to eliminated the oil-splitting enzymes and slow down the formation of free fatty acids in the oil. The last, sterilization is applied to ensure that air is expelled from sterilizer in order to avoid oxidation by air (Poku, 2002). The waste that is expelled from sterilizer is one of the major sources of POME.

b. Stripping, digestion and pressing the fruits

The stripping is to separate the sterilize fruits from the bunch stalks by using rotary drum thresher. The detached fruits are passed through a bar screen in the stripper, collected by a bucket conveyor and the send in to digester. In the digester, the fruit is softened by steam-heated cylindrical vessel fitted with central rotating at high temperature, between 80 and 90 °C, then the fruits mesocarp will be loosened from the nuts and delivered to mechanical press machine to squeeze out the crude palm oil (Wu et al., 2009).

c. Clarification

The purpose of clarification is to separate the oil from its entrained impurities. The fluid flowing out from the press machine is a mixture of palm oil, water, cell debris, and other insoluble solids that content high viscosity. Then, the hot water is added into the clarifier to break the oil emulsion and acts as barrier to cause the insoluble solids to settle to the bottom of the clarifier while the lighter oil droplets flow through the watery mixture on the top. Consequently, the bottom phase from the clarifier is drained off as sludge of POME for further purification before being discharged.

d. Kernel oil recovery

Press cake form the press machine consists of a mixture of fiber and nuts. After the separation of fiber from the nuts by strong air