UNIVERSITI PUTRA MALAYSIA

METHANE PRODUCTION FROM ANAEROBIC CO-DIGESTION OF SEWAGE SLUDGE AND DECANTER CAKE

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By

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Increased production of sewage sludge from wastewater treatment and decanter cake from palm oil mill industry results in the generation of large quantities of solid waste. These wastes can cause environmental pollution and can give bad impact on human lifestyle. Sewage sludge can produce methane gas at a very minimum rate of production. Co-digestion with decanter cake which content high of carbon can increase methane gas production. In this research, an anaerobic co-digestion has been considered to convert these organic pollutants into methane gas. The preliminary study was set up to optimized the ratio of sewage sludge (as inoculum) and decanter cake (as substrate) in batch biochemical methane potential (BMP) in serum bottle of 125 mL volume for 30 days. The effect of different inoculum to substrate ratios (I/S) on biogas production was investigated at mesophilic condition (38 ± 1 °C) and constant initial pH 7. The batch study was conducted at the ratio I/S of 2:1, ratio 1:1 and ratio 1:2 and sewage sludge only as control experiment. The preliminary study resulted in daily biogas collection for the ratio of 1:2 showed the highest cumulative biogas production of 247 mL. Total solid content and ammonia removal had been compared at initial and final fermentation in the biochemical methane potential (BMP) batch fermentation. The highest methane yield was obtained at the mixing ratio of 2:1 with 165.6 mL CH4/g VS and this ratio had been choose to be the best I/S ratio from BMP test. Then the ratio of 2:1 is upscale into a lab-scale anaerobic digester to determine the maximum production of methane gas. 6.4L of anaerobic digester has been used with 5.6L of the working volume and was fermented for 30 days. Cumulative biogas production resulted in 5848 mL and cumulative methane gas production resulted in 10451 mL CH4/g VS. Theoretically, biogas is mainly composed of methane (60 %) and carbon dioxide (40 %) as of end product of anaerobic digestion. These were compared for all ratios and resulted significantly as theoretical. The experimental value of methane yield from lab-scale anaerobic digester then compared with the theoretical value of methane yield by using the Gompertz equation solve in Excel Solver. As a comparison, all co-digestion ratios produced more biogas than the

sewage sludge alone. This proved that anaerobic co-digestion of sewage sludge and decanter cake can improve the production of biogas.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGELUARAN METANA DARI PENCERNAAN ANAEROBIK BERSAMA ENAPCEMAR KUMBAHAN DAN KEK PENYIRING

Oleh

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Peningkatan pengeluaran enapcemar kumbahan dari rawatan air sisa dan kek penyiring dari industri kilang kelapa sawit menghasilkan penjanaan sisa pepejal dalam jumlah yang besar. Bahan buangan ini boleh menyebabkan pencemaran alam sekitar dan boleh memberi kesan buruk kepada gaya hidup manusia. Enapcemar kumbahan menghasilkan gas metana pada kadar pengeluaran yang sangat minimum. Pencernaan bersama kek penyiring yang kandungan karbonnya tinggi dapat meningkatkan pengeluaran gas metana. Dalam penyelidikan ini, pencernaan anaerobik bersama telah dipertimbangkan untuk mengubah bahan pencemar organik ini menjadi gas metana. Kajian awal dibuat untuk mengoptimumkan nisbah menggunakan enapcemar kumbahan (sebagai inokulum) dan kek penyiring (sebagai substrat) dalam potensi metana biokimia (PMB) dalam botol serum dengan isipadu 125mL selama 30 hari. Kesan nisbah inokulum ke substrat (I/S) yang berbeza terhadap pengeluaran biogas disiasat pada keadaan mesofilik (38 ± 1 °C) dan pH awal yang tetap 7. Kajian kumpulan dilakukan pada nisbah I/S 2:1, nisbah 1:1 dan nisbah 1:2 dan enapcemar kumbahan hanya sebagai kawalan eksperimen. Kajian awal menghasilkan pengumpulan biogas harian dengan nisbah 1:2 menunjukkan pengeluaran biogas kumulatif tertinggi sebanyak 247mL. Jumlah kandungan pepejal dan penyingkiran ammonia telah dibandingkan di awal dan di akhir penapaian potensi metana biokimia (PMB). Hasil metana tertinggi diperoleh pada nisbah pencampuran 2:1 dengan 165.6 mL CH_4/g VS dan kemudian telah dipilih untuk menjadi nisbah yang paling terbaik dari eksperimen potensi metana biokimia (PMB) untuk penapaian kumpulan. Nisbah 2:1 ditingkatkan kepada pencerna anerobik skala makmal untuk menentukan pengeluaran maksimum gas metana. 6.4L pencerna anaerobik telah digunakan dengan isi padu 5.6L dan ditapai selama 30 hari. Pengeluaran biogas kumulatif menghasilkan 5848mL dan pengeluaran gas metana kumulatif menghasilkan 10451 mL CH_4/g VS. Secara teorinya, biogas terdiri terutamanya dari metana (60%) dan karbon dioksida (40%) sebagai hasil akhir pencernaan anaerobik. Hal ini dibandingkan untuk semua nisbah dan hasilnya adalah signifikan seperti teorinya. Nilai eksperimen

hasil metana dari pencerna anaerobik skala makmal kemudian dibandingkan dengan nilai teoritik hasil metana dengan menggunakan penyelesaian persamaan Gompertz dalam Excel Solver. Sebagai perbandingan, semua nisbah pencernaan bersama menghasilkan lebih banyak biogas daripada enapcemar kumbahan sahaja. Ini membuktikan bahawa pencernaan anaerobik bersama antara enapcemar kumbahan dan kek penyiring dapat meningkatkan pengeluaran biogas.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research and the writing of this thesis were done under our supervision;
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LIST OF ABBREVIATIONS

AD	Anaerobic digestion
AcoD	Anaerobic co-digestion
ASW	Acorn slag waste
BMP	Biochemical methane potential
CPO	Crude palm oil
C/N	Carbon/Nitrogen
CH_4	Methane gas
CO_2	Carbon dioxide gas
DC	Decanter cake
DM	Dairy manure
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
GC	Gas chromatography
H_2	Hydrogen gas
HCl	Hydrochloric acid
H_2SO_4	Sulphuric acid
I/S	Inoculum/substrate
MPOB	Malaysia Palm Oil Board
N	Nitrogen gas
NaOH	Sodium hydroxide
NH_4-N	Ammonia-nitrogen
POME	Palm oil mill effluent
PKS	Palm kernel shell
RSTP	Regional sewage treatment plant
RSM	Respond surface methodology

STP	Sewage treatment plant
SS	Sewage sludge
STP	Standard temperature and pressure
TS	Total solid
TCD	Thermal conductivity detector
TAN	Total ammonia nitrogen
VFAs	Volatile fatty acids
VS	Volatile solid
WWTPs	Wastewater treatment plants

CHAPTER 1

INTRODUCTION

1.1 Overview

Abundant of wastes has become a serious matter that should be a worry. This matter contributes to the greenhouse effect, global warming, thinning of the ozone layer, and pollutions include minimum spaces for waste disposal sites. Along with the rapid development in this developing country, wastes and residues were produced from municipal, industrial and agricultural sources (Nasir et al., 2012). Increased production of agricultural waste gives difficulty to the environment and economic to find the methods of disposal.

Biogas is usually used to generate electricity, used in cooking, heating and pipeline injection. Therefore, renewable energy production from wastewater has become interest (Kaosol & Sohgrathok, 2014). The volume of wastewater generated by municipal and industrial sectors is estimated at around 2.97 billion cubic meters per year. In Malaysia, there are only three basic standards of wastewater treatment types which are preliminary (removal of rags, rubbish, grit, oil, grease), primary (removal of settleable and floatable materials), and secondary treatment (biological treatment to remove organic and suspended solids). Due to high operation and maintenance costs, there is no tertiary treatment in Malaysia (Mat et al., 2013).

Sewage sludge is a semi-solid or slurry by-product of physical, chemical and biological processes from secondary wastewater treatment. The sewage sludge contain high organic compound and has increased dramatically from time to time due to the increase in the number of households connected to municipal wastewater treatment plants. Therefore, disposal management of sewage sludge has become a challenging matter to be done. This is 1because of limited space available for disposal in landfills, environmental protection that needs to be considered and more stringent environmental standards for sewage sludge disposal via a land application (Alqaralleh et al., 2016).

Apart from crude palm oil (CPO) that produced from fresh fruit bunch (FFB), fibre, shell, decanter cake (DC) and empty fruit bunch (EFB) were also produced for 30, 6, 3 and 28.5 % from the FFB respectively. It is estimated that about 26.7 million tonnes of solid biomass was generated from 381 palm oil mills in Malaysia in 2004 (Yacob et al. 2005). The abundance of this biomass waste needs sustainable management to deal with to decrease the environmental pollution issues.

Decanter cake (DC) is one of the solid wastes from palm oil mill and produced from three-phase of CPO purification process in oil palm mill plant. It is about 3-5 wt% of the rate of DC production from FFB and estimated about 3.6 million tonnes of DC generated by palm oil mill in the year 2012. DC contains 76 % of the water on a wet basis, 12% of residual oil on dry basis and cellulose, nutrients, lignin and ash (Pragas et al., 2013). Decanter cake mostly used as animal feed that made in grade pellets (Chavalparit et al., 2006) and as digestate which is used as fertilizer (Holm-Nielsen et al., 2009) but currently, DC has been utilized as feedstock for the production of cellulose and polyose, bio-surfactant, bio-butanol and bio-diesel (Dewayanto et al., 2014). Due to the small amount of utilization ways of DC, it has become a new abundance wastes problem that does not utilize completely.

Anaerobic co-digestion (AcoD) is now a very common practice for methane production. The purpose of anaerobic co-digestion is to improve the biogas production and methane yield. AcoD is the process of mixing two or more substrates to overcome the disadvantages of AD due to higher methane production. There are some benefits of AcoD which are it can improve the stabilization of the process, dilution of inhibitory substances, a balanced nutrient, the moisture content in the digester feed can be required, reducing the emission of greenhouse gases to the atmosphere, synergetic effects of microorganisms, a load of biodegradable organic matter can be increased and economic strategy by sharing apparatus and cost (Hagos et al., 2017). Anaerobic co-digestion can improve biogas production from 25 to 400 % over a single resource of a substrate. However, anaerobic co-digestion of decanter cake has more studied in Thailand compared to Malaysia. Therefore, anaerobic co-digestion of sewage sludge and decanter cake will become a new finding in the biogas production field in Malaysia.

1.2 Problem statement

Large quantities of disposal of organic wastes from domestic, agricultural sources and industrial have become a concern along with the need to reduce greenhouse gas emissions. Therefore, the development of anaerobic digestion technology has become an interest to researchers all over the world. They are working hard to find as many as good ways to utilize wastes by the anaerobic digestion process. Anaerobic digestion is very limited when its work alone with a single resource such as sewage sludge. Anaerobic digestion of sewage sludge has been done in most wastewater treatment plants (WWTPs) all over the world including Malaysia. According to the Sustainability Report 2011 of Indah Water Konsortium, only 13 of their regional plants has been practising the reuse of sewage by-products to conserving water, energy and the environment. However, the reuse of the treated effluent is limited to internal housekeeping or non-potable use such as sewage treatment plant (STP) compound cleaning, vehicles cleaning and watering of plants for landscaping purpose (Mat et al., 2013). Disposal of sewage sludge also representing up to 50 % of the overall operating costs of WWTP. Sewage sludge has relatively low biodegradability which makes it hard to digest since it has a high content of organic compound (Sosnowski et al., 2003; Alqaralleh et al., 2016).

Decanter cake as one of the solid waste in palm oil mill industry has not been utilized completely. It can be a fire hazard to the mill when it dried. There is some usability of the decanter cake in the area of bio-fertilizer, biofuels and cellulose. It is also used as animal feed but not as much as other waste such as palm oil mill effluent (POME) and EFB. Decanter cake uses in anaerobic digestion has not been fully developed. Addition of decanter cake into anaerobic digestion is another way to utilize more of the waste from palm oil mill and to create sustainable and cleaner society. This way not only solve the present environmental issues but also can enhance economic benefits since decanter cake has low interest in the utilization of palm oil mill waste.

In addition, there are not many research about anaerobic co-digestion of sewage sludge and decanter cake. As stated before, Thailand is the only country used decanter cake in their biogas production research. Furthermore, decanter cake in Malaysia also have the same problem of utilization and it becomes new interest or finding in biogas production field in Malaysia. The optimize I/S ratio is one of the important operating parameters in anaerobic co-digestion. A small numbers of study makes this research more challenging. Therefore, biochemical methane potential (BMP) is the best way to determine the best I/S ratio for anaerobic co-digestion of sewage sludge and decanter cake.

1.3 Objectives

The aim of this study is to investigate the production of methane from co-digestion of sewage sludge and decanter cake. The objectives of this study are:

(1) To optimize the best I/S ratio for methane production from co-digestion of sewage sludge and decanter cake using Biochemical Methane Potential (BMP) in batch fermentation.

(2) To determine the maximum methane yield by using the best I/S ratio from BMP test in an up-scaled anaerobic digester.

(3) To analyze methane yield from anaerobic digester using Excel Solver between theoretical yield and experimental yield by using the Gompertz Equation.

1.4 Limitation of study

The scope of the study is to investigate the best I/S ratio from BMP test for methane production from co-digestion of sewage sludge and decanter cake at different ratio of 2:1, 1:1, 1:2 and sewage sludge alone as control experiment with control of temperature 38ºC and initial pH 7 in batch fermentation with only single test. The period for batch fermentation was 30 days. Other than that, the best performance of methane production from co-digestion of sewage sludge and decanter cake was chosen to perform in an up-scaled anaerobic digester of volume 6 L with the same control temperature and initial of pH value and was fermented for 30 days too. Methane production obtained from anaerobic digester was then analyzed using Gompertz Equation in Excel Solver with reference to the theoretical value.

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