CHAPTER 1

INTRODUCTION

1.1 Introduction

The palm oil industry is the main leading industries in Malaysia with a production of more than 13 million tons per year of crude palm oil and plantations covering about 11% of the total Malaysian land area (Wu, T.Y. *et al*., 2009). Nowadays, Malaysia contributes about 47% of the world's supply of crude palm oil (Sumathi, S. *et al*.2008) due to its' favorable weather conditions which prevail throughout the year that is advantageous for palm oil cultivation. Thus, it is not surprising that the highest yields have been achieved from palms grown in this area. Malaysia will be the main contributor of world vegetable oil in the future. Even the palm oil industry contributes significantly towards the country's foreign exchange earnings and the increased standard living among Malaysians but it has been identified as the main source of water pollution in the country.

In the process of producing palm oil, large amount of water is required (Yacob, S. *et al*., 2005), leading to the generation of big volumes of wastewater known as palm oil mill effluent (POME). In Malaysia, palm oil extraction mill or process generates about 50 million tonnes of POME yearly (Chong, M.L., 2009). In addition, POME chemical properties differ widely throughout the year due to mill operations and seasonal croppings. The most important sources of wastewater generation from palm oil mill are hydrocyclone waste, sterilizer condensate and separator sludge. On an average 0.9–1.5 m^3 of POME is generated for each ton of crude palm oil produced (Sumathi, S. *et al*., 2008). If the untreated effluent is discharged into watercourses, it causes substantial environmental problems in the water quality and foul smell in the surrounding of factory because of its high biochemical oxygen demand (BOD) (25,000 mg/L), chemical oxygen demand (COD) (53,630 mg/L), oil and grease (O & G) (8370 mg/L), total solids (TS) (43,635 mg/L) and suspended solids (SS) (19,020 mg/L) (Wu, T.Y. *et al*., 2009). Therefore, the Environmental Quality (prescribed Premises) (Crude Palm Oil) Regulations 1977, promulgated under the enabling powers of Section 51 of the EQA, are the governing regulations and contain the effluent discharge standards. The effluent discharge standards ordinarily applicable to crude palm oil mills are presented in the appendix A.

Anaerobic digestion which is the decomposition of organic and inorganic substrate is carried out under the absence of oxygen. Prior to bacterial consortia that are responsible for the decomposition processes begin consuming on organic matters to grow, they require time adapting to the new environment. Hence this process is time consuming. Anaerobic digestion is a sequence of reactions in the process of degrading POME into methane (CH_4), carbon dioxide (CO_2) and water (Poh, P.E. and Chong, M.F., 2009). These reactions are hydrolysis, acidogenesis (including acetogenesis) and methanogenesis. Hydrolysis is where complex molecules (i.e., carbohydrates, lipids, proteins) are changed into sugar, amino acid and others. In the step of acidogenesis, these sugar, fatty acids and amino acids will be decomposed into organic acids which mainly consist of acetic acid (from acetogenesis) together with hydrogen (H_2) and carbon dioxide (CO_2) by acidogenic bacteria. In the step of methanogenesis, hydrogenotropic methanogens will use H_2 and CO_2 whereas acetoclastic methanogens will utilize acetic acid and CO_2 to produce methane as a final product. The rate limiting step in anaerobic digestion of POME is methanogenesis (Poh, P.E. and Chong, M.F., 2009). In order to ensure complete digestion of treated influent, anaerobic digesters require large reactors and long retention time.

In the anaerobic digestion process, the raw POME is first converted into volatile fatty acids (VFAs) by acid forming bacteria. The volatile acids are then converted into CH_4 and CO_2. Thus, significant attention has been focused on the relationships between VFAs concentration and anaerobic fermenter performance (Wang, Q.H. *et al*., 1999). It is known that VFAs are vital intermediary compounds in the metabolic pathway of methane fermentation. High VFAs concentrations in the system could cause the inhibition of methanogenesis (Irene, S. and Charles, B., 2005). This is due to the methanogen is unable to remove H_2 and volatile organic acids as fast as they could produce under the conditions of overloading and in the presence of inhibitors. Moreover, the accumulation of acids cause the depletion of buffering capacity and the depression of pH to levels that slow down the hydrolysis/acidogenesis phase. Therefore, the concentration of VFAs is a main consideration for high-quality performance of an anaerobic digestion process. Hence it is essential to examine the optimum conditions and the efficiencies of digesters by examining VFAs.

Moreover, anaerobic digestion is also a degradation process of organic substrates in the absence of oxygen, via enzymatic and bacterial activities producing biogas that could be used as a renewable energy source. The end products of the anaerobic digestion of POME are mainly CH_4 and CO_2 in the ratios of 65:35, hydrogen sulphide (H_2S) and nitrogen (N_2) concentrations are insignificant and H_2 are not detectable and around 28 m^3 of gases are released from 1 tonne of POME (Yacob, S. *et al.,* 2006a). On the other hand, the CH_4 emission may be different because of the variations in POME treatment practices. Additionally, the CH_4 composition from anaerobic digestion was also found to be more consistent in the gaseous mixture. However, mill activities and seasonal cropping of oil palm influence CH_4 emission in anaerobic ponds (Yacob, S. *et al.,* 2006a). Since anaerobic digestion can produce renewable energy, valuable digested residues, liquid fertilizer and soil conditioner, it is becoming more and more attractive for the treatment of high strength organic POME.

1.2 Statement of Problems

Large amounts of organic waste are generated by palm oil mills. A fraction enters wastewater; another part is utilized for steam and power generation. Every ton of oil palm fruit bunches produced 0.5-0.75 ton of POME, containing about 5 kg/ton organic matter, contribute into the POME (Yacob, S. *et al.,* 2006b). Therefore, direct discharges of POME into receiving water have resulted in the degradation of various ecosystems on which human life relies on. To combat this increasing burden on our aquatic environment, increasingly strict regulations on pollution discharge are being implemented by various governmental bodies, with focus primarily on waste reduction. The treatment systems developed by palm oil mill industries are commonly regarded as a regulatory requirement, yielding negative economic returns and increasing capital and running costs. In order to comply with stringent environmental legislation, low cost treatment technology such as anaerobic digestion should be developed.

Every day life including industrial activities, agriculture, lighting health care, drinking water and telecommunication require energy. Moreover, energy demand has been increased due to increasing income and rising populations. Although fossil fuels that serve as a primary energy source replenish the world's energy requirement, the unregulated use of fossil fuels is causing severe effects on the world climate. Global warming and acid rain are caused by the emission of green house gases from fossil fuels (Vijayaraghavan, K. and Ahmad, D., 2006). For these reasons, researchers are looking at other type of fuels to combat both the mentioned problems. Hence, this concern has encouraged researches into economically viable and more environmentally friendly alternatives such as biogas which is a mixture of colorless combustible gases.

Therefore, this study would be focusing on the anaerobic digestion system since anaerobic digestion process has well benefit over other treatment methods in terms of energy requirement and capital cost. Besides that, anaerobic digestion treatment can produce biogas that could be used as a renewable energy source. Nonetheless, the three significant drawbacks of anaerobic treatment are long retention time, long start-up period and large area required for treatment (Metcalf, E., 2003). The longest retention time required for anaerobic ponds in ponding system is around 20–200 days (Chan, K.S. and Chooi, C.F., 1984). The vital problem for most palm oil mill industries is long HRT due to their high production capacity. Short HRT will reduce the time of contact between substrate and biomass. Various studies have proven that lower HRT will reduce COD removal efficiency in wastewater treatment systems (Wong, Y.S. *et al*., 2009). However, decreased HRT will increase gas production until a stage when methanogens could not work quick enough to convert acetic acid to CH_4. In addition, a number of cases of reactor failure reported in studies of wastewater treatment are due to accumulation of high VFA concentration, causing a drop in pH which inhibited methanogenesis (Irene, S. and Charles, B., 2005).

As a result, this study is needed to examine the COD removal efficiency and the efficiency of biogas production from closed anaerobic digestion through laboratory suspended closed anaerobic reactor (SCAR) under various hydraulic retention times (HRTs) at mesophilic temperature. In addition, it is also necessary to examine the behavior of VFA in closed anaerobic digestion at mesophilic temperature over different HRTs since the VFA concentration is an important parameter to monitor the reactor performance (Buyukkamaci, N. and Filibeli, A., 2004). Therefore, a new anaerobic pond system or revamp the existing anaerobic pond system of POME wastewater can be developed by a firm scientific and engineering basis which is offered by the results of the study.

In recent times, a great deal of attention is focused on results of research on advanced anaerobic treatment such as anaerobic filtration (Borja, R. and Banks, C.J., 1995), fluidized bed reactor (Borja, R. *et al*., 2001), up-flow anaerobic sludge blanket (UASB) reactor (Borja, R. and Banks, C.J., 1994), up-flow anaerobic sludge fixed-film (UASFF) reactor (Najafpour, G.D. *et al.,* 2006), continuous stirred tank reactor (CSTR) (Ugoji, E.O., 1997) and anaerobic contact digestion (Ibrahim, A. *et al*., 1984) for the treatment of POME. But there is scarceness of information in the literature about the closed anaerobic digestion system which can produce biogas as a valuable end product.

1.3 Objectives of the Study

This study aims to examine the COD removal efficiency of closed anaerobic digestion tank for POME wastewater, the optimization of biogas production from closed anaerobic digestion tank of POME treatment and the degradation of VFA of POME by highly efficient anaerobic digestion at mesophilic temperature. The detailed targets of the study are specified below:

a) To observe COD removal efficiency of closed anaerobic digester at mesophilic temperature over different HRTs.
b) To examine the behavior of VFA in closed anaerobic digester at mesophilic temperature over different HRTs.
c) To study the efficiency of biogas production from closed anaerobic digester at mesophilic temperature under various HRTs.

1.4 Scope of the Study

Currently, the demand of energy met by fossil fuels (i.e. coal, petroleum and natural gas). As energy consumption grows, emissions of greenhouse gases will be increased causing significant impact on global climate change. Furthermore, the high COD and low pH of POME wastewater, together with the colloidal nature of the suspended solids leads to environmental pollution issues. Thus, the anaerobic digestion process which is capable of treating POME wastewater and producing biogas is the main focus in this study. In this research, POME wastewater is treated under various HRTs in the SCAR. At the same time, the COD removal efficiency, behavior of VFA in the SCAR and efficiency of biogas production are observed over different HRTs as 12, 10, 8, 6, 4 and 2 days.

The COD removal efficiency of SCAR and the efficiency of biogas production from SCAR are based on raw and effluent COD and biogas production rate and biogas composition, respectively at each batch of HRT. Whereas the behavior of VFA in the SCAR based on acetic acid concentration at each batch of HRT.

1.5 Organization of the Thesis

This research study focuses on the COD removal efficiency of closed anaerobic digestion tank for POME wastewater, the optimization of biogas emission from closed anaerobic digestion tank of POME treatment and the degradation of VFA of POME by highly efficient anaerobic digestion at mesophilic temperature. This thesis consists of six chapters. A brief introduction about the condition of palm oil industry in Malaysia, wastewater generation in the palm oil mill, environmental problem of POME, environmental regulations, anaerobic digestion treatment systems, VFAs of POME and biogas production from POME treatment system are given in Chapter 1 (Introduction). The problem statements, objectives, scope and organization of this thesis are also given in this chapter.

Chapter 2 presents a relevant literature review on the development of palm oil industry in Malaysia, palm oil production processes, POME wastewater characteristics, POME wastewater treatment, theoretical background of anaerobic digestion, biogas production and behavior of VFAs of anaerobic digestion. This is intended to provide background knowledge and research motivation to conduct this study.

Chapter 3 describes general materials and methods employed during the study. The wastewater source and detail of the experimental set-up are involved in this chapter. This followed by the detail experimental procedures, which include SCAR operation and analytical methods.

Chapter 4 consists of the four main sections. Details of reactor start-up as well as its progress can also be found in the first section. In second section, COD removal efficiency of SCAR over various HRTs is discussed. Then, behavior of VFA in SCAR under different HRTs is investigated in the third section. Moreover, the biogas production rate and biogas composition under various HRTs are also studied and presented in the last section of this chapter.

Finally, Chapter 5 provides conclusion of the thesis. Based on the objectives of this study, the findings from the current studies are concluded in this chapter. Recommendation and directions for further research are also included.