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Investigation on micro-bubble flotation and coagulation for the treatment of anaerobically treated palm oil mill effluent (POME)

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ABSTRACT

The rapid expansion of the palm oil industry has led to the generation of large volumes of POME in Malaysia. Most conventional aerobic processes for post-treatment of POME are unable to consistently meet environmental discharge standard due to the susceptibility of microorganisms to variable climatic conditions. The main aim of this study was to investigate the potential use of micro-bubbles generated from a venturi tube and the coagulation with polyaluminium chloride (PAC) as a post-treatment method for POME. The micro-bubbles generated from the venturi are capable of removing 57.3% of total suspended solid (TSS) and 74.5% of oil and grease (O&G) and improve the chemical oxygen demand (COD) by 53.7% and biochemical oxygen demand (BOD) by 77.0% with a bubbling time of 12.5 min and a flow rate of 19.8 L/min. However, a single-stage micro-bubble flotation is unable to treat the POME to meet environmental discharge standard. Thus, different PAC coagulant dosage are investigated and the optimum dosage is 2 g/L resulting in at least 93% of COD removal.

Introduction

Palm oil mill effluent (POME) is a wastewater produced from palm oil milling activities and contains high concentration of oil and grease (O&G) and total suspended solids (TSS) with average values of 14,700 and 39,100 mg/L, respectively [1]. Conventionally, several steps of treatment are required to treat POME to meet the environmental discharge standard as stipulated in the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1977, involving anaerobic followed by aerobic digestion before discharge to watercourse [2,3].

Before anaerobic digestion (AD), POME is typically de-oiled in an oil trap to recover low-grade oil to gain additional revenue [1]. Nevertheless, the low-grade oil from the de-oiling process should be retained during AD as it could contribute to higher methane production through the digestion of lipids and thus providing higher electricity or steam generation within the palm oil mill in return. With regards to aerobic digestion, the energy requirement for aeration is intensive and the generation of sludge from this process leads to secondary waste disposal problems. Facultative or aerobic post-treatment that uses microorganisms to treat POME is also highly susceptible to environment changes and may not perform consistently. Furthermore, the dark brown coloured substances in POME – derived from molasses melanoidins (MM) generated from the heating of organics from oil extraction process [4] are hardly degraded or decolourized by aerobic and anaerobic activated sludge systems [5,6]. This might create a problem when the treated POME is discharged into watercourses as MM will prevent light from reaching the aquatic plants for effective photosynthesis. Hence, there is a need for a better post-treatment method for POME after AD that can effectively meet the environmental discharge standard.

Conventionally, physico-chemical treatment methods were implemented in primary POME treatment to remove significant amount of suspended solid before passing through membrane modules for filtration [7]. Nevertheless, several studies were conducted on the use of physico-chemical treatment methods (e.g. flocculation, flotation and electroflotation) in the treatment of anaerobically digested POME [8]. It was found that these methods could also effectively remove suspended solids of up to 97%. Furthermore, the application of physico-chemical treatment after anaerobic digestion produced a more consistent quality of treated water regardless of influent variations. These systems are easier to maintain and particulates can be completely removed as well. Out of all the available physico-chemical processes, flotation has a greater potential for the treatment of anaerobically digested POME because this processes has the ability of removing odour, decolourizing the wastewater as well as recovering valuable compounds from the wastewater, which is ineffective when other physico-chemical processes were used [9].

Dissolved air flotation (DAF) is a well-established method commonly used in industries for wastewater treatment mainly to remove oil and suspended solids [10,11]. Typical bubble sizes produced from DAF system are in the order of 100 μm [11]. This DAF method was

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reported to be able to remove more than 90% of oil and suspended solid (SS) from wastewater with the addition of coagulants [10,12,13]. However, recent researches have shifted to the use of micro-bubbles, with bubble sizes in the order of 10 μm, for wastewater treatment. This is due to the fact that micro-bubbles provide larger contact surface area and have longer residence time, improving the efficiency of oil and SS separation in wastewater treatment [14].

Micro-bubbles can be generated via several methods namely: acoustic cavitation, microfluidic oscillation, porous membranes and hydrodynamic cavitation [14,15]. Although DAF is common in wastewater treatment, the actual DAF system requires high energy to pressurize the air that is to be dissolved in water. In addition, the DAF pressure vessel also requires regular maintenance and inspection [16]. Such technical and operation complexities result in higher maintenance costs for the system. On the other hand, hydrodynamic cavitation generates micro-bubbles through the formation of cavities when liquid flows through a simple geometry such as a venturi tube or orifice plate [14]. The size of micro-bubbles generated through venturi tube can be varied to accommodate the variation in feed flow rate to achieve comparable treatment efficiency of wastewater. However, the use of micro-bubbles generated from venturi tube is yet to be tested as a method for wastewater treatment. The generation of micro-bubbles from venturi tube could potentially replace the conventional DAF systems as the setup for venturi-type micro-bubble generator is simple and does not require construction and maintenance of pressurized vessels.

Though micro-bubbles (generated from DAF) and coagulation are common processes for wastewater treatment, they are mostly employed as a pre-treatment step for POME [15]. In the view that higher oil content should be retained for AD to boost methane production, the use of micro-bubbles generated via venturi tube for anaerobically treated POME should be investigated to evaluate the possibility of replacing aerobic process as a post-treatment method to reduce energy consumption and to produce a discharge that consistently meet the stipulated environmental discharge standards. Furthermore, high volume of coagulant dose is required for anaerobically treated POME to meet the stringent discharge limit imposed by Department of the Environment Malaysia (DOE). The maximum limit imposed by DOE is 50 mg/L for oil and grease, 100 mg/L for BOD and 400 mg/L of TSS.

To the best of our knowledge, studies on bubble size distribution in flotation systems are scarce. In addition, there were no studies that utilize micro-bubble flotation for the separation and recovery of residual oil from anaerobically digested POME. Although precipitate flotation has higher efficiency in the treatment of anaerobically digested POME by destabilizing and aggregating colloids, the potential hazardous voluminous sludge will be the main drawback for commercialization. This study investigates the bubble sizes for its effectiveness as micro-bubbles for the post treatment of POME and also assesses the effect of bubbling time of micro-bubbles on the treatment efficiency of anaerobically treated POME. Furthermore, the optimum dosage of polyaluminium chloride (PAC) to achieve the stipulated environmental discharge standards will be also investigated.

Materials and methods

Anaerobically treated POME

Samples of anaerobically treated POME were obtained from Sime Darby West Oil Mill, located in Carey Island, Selangor. The characteristics of the anaerobically treated POME are listed in Table 1. The samples obtained from the palm oil mill were refrigerated at 4 °C if not immediately used to prevent sample degradation.

Experimental setup

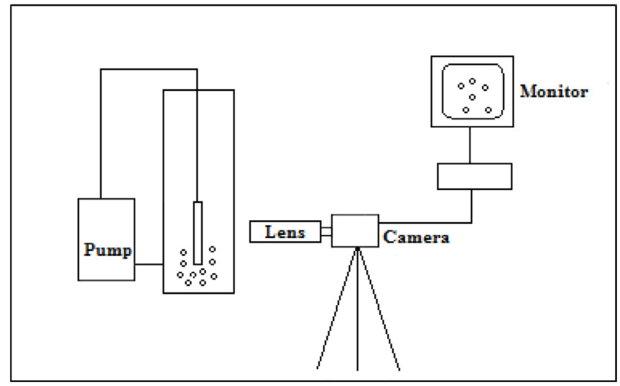

Fig. 1. Setup of the microbubble generation system.

Fig. 1 shows the setup of the micro-bubble generation system, which consists of a 2 L measuring cylinder, a centrifugal pump and an ejector type venturi device which functions to generate micro-bubbles for flotation. The measuring cylinder was filled with 1 L of anaerobically treated POME. When the pump was turned on, the cylinder containing anaerobically treated POME is filled with micro-bubbles that will adhere to the contaminants in POME. The gas holdup of this system is controlled via the flow rate of the water because water determines the volume of air drawn into the throat of the venturi that is eventually broken into micro-bubbles. The bubbles carry the contaminants to the surface of the cylinder forming a layer of foam that is only removed manually using a skimmer after treatment.

The pump was operated at three different water flow rates of 10.2, 19.8 and 26.4 L/min to investigate the effect of water flow rates on bubble sizes and operated under different bubbling times (i.e. 2.5, 5, 10 and 12.5 min) to investigate the effect of bubbling time on the efficiency of contaminant removal. The raw and treated POME samples were analysed in terms of BOD, COD, TSS and O&G in accordance to the standard methods prescribed by the American Public Health Association [17].

Bubble size measurement

Bubble size imaging was done using the charge coupled device (CCD) camera. The images were obtained with the aid of a precision borescope (Brand Hawkeye, U.S. Patent 5,361,166) and a digital camera (QIMAGING RETIGA 200R). The illumination was done using an optic fibre light guide of 50 Hz, 200 W light source (Dolan-Jenner Fibre-Lite MH-100) which was positioned opposite to the camera. The camera was connected to an imaging software (Q-Capture Pro 6.0) to acquire image data from the camera. A sample of the captured image is illustrated in Fig. 2.

Each image captured by the camera contains at least 1 micro-bubble. The micro-bubbles included for size distribution should be positioned in the middle of the image. This is to prevent taking measurements of bubbles from a different plane. Diameters of the micro-bubbles captured with the camera were determined by converting the pixels of the bubbles into the μm scale by comparing with the number of pixels from a reticle scale of 1 mm. A total of 240 micro-bubbles were taken for measurements and the size distributions of the micro-bubbles were plied accordingly.

Jar test

Polyaluminium chloride (PAC) (ACME Chemicals, Malaysia) was used as the coagulant in this study. The PAC used is a fine powder (off-white colour) with 95% min pass through standard 40 mesh (0.42 mm). Coagulation was conducted on the wastewater samples that had undergone bubbling according to methods as described in