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High-rate fermentative hydrogen production from palm oil mill effluent in an up-flow anaerobic sludge blanket-fixed film reactor

Parviz Mohammadi[a,c], *Shaliza Ibrahim*[a,*], *Mohamad Suffian Mohamad Annuar*[b]

[a] *Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[b] *Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[c] *Department of Environmental Health Engineering-Kermanshah, Health Research Center (KHRC), Kermanshah University of Medical Science, Kermanshah, Iran*

ABSTRACT

The major problem associated with UASB reactors for biotransformation of organic matter to hydrogen is the long start-up period (2–4 months) required for the growth of the microbial granules. In this study, an integration of granular sludge system and a fixed film reactor in a single reactor was applied to overcome this problem. An up-flow anaerobic sludge blanket-fixed film (UASB-FF) reactor was initially inoculated with heat pretreated seed sludge as inoculum and operated as closed-loop fed-batch for five days (HRT = 24 h; 38 °C; pH 5.5). The reactor was continuously fed with fresh pre-settled POME in order to shorten the start-up period. The organic loading was gradually increased from 4.7 to 51.8 g/L d. Granular sludge rapidly developed within 22 days. Specific hydrogen production rate was 0.514 L H_2/g VSS d at the end of the start-up period. Speedy development of bio-granules was attributed to biomass recirculation and the establishment of a fixed film at the upper section of the UASB-FF reactor that resulted in improved interactions among the bacterial consortium.

Keywords: Fermentative hydrogen production; Granulated sludge formation; UASB-FF; Bioreactor start-up; Palm oil mill effluent; COD removal

1. Introduction

Microbial hydrogen production has received widespread attention from many researchers due to the fact that hydrogen (H_2) is a renewable energy source along with its non-polluting and environmental friendly nature. Biological H_2 production, which can be operated at ambient temperature and pressure is a less energy intensive alternative to processes like water electrolysis (Najafpour et al., 2004; Lin and Lay, 2004; Atif et al., 2005; Mohan et al., 2008; Younesi et al., 2008; Leite et al., 2008; Mohammadi et al., 2012a). The biological technique requires specific conditions where acidogens (H_2 producing bacteria) and methanogens (H_2 consuming bacteria) are imbalanced in their activities resulting in rapid accumulation of H_2 (Zadariana et al., 2009; Mohammadi et al., 2011). H_2 producing bacteria can utilize various forms of substrates. Glucose (Mizuno et al., 2000; Fang and Liu, 2008; Hallenbeck and Benemann, 2002; Morimoto et al., 2004), sucrose (Chen et al., 2001; Lee et al., 2008) and starch (Shu et al., 2002; Akutsu et al., 2009; Su et al., 2009) were mainly used as substrates for fermentative H_2 production. On the other hand, rice winery wastewater (Yu et al., 2002), palm oil mill effluent (Atif et al., 2005; Chong et al., 2009; Mohammadi et al., 2012b), food waste (Ginkel et al., 2005; Kim et al., 2008), and dairy wastewater (Mohan et al., 2007; Yang et al., 2007) were also investigated as substrates in the biological processes of H_2 production

* *Corresponding author*. Tel.: +60 3 79675219; fax: +60 3 79675318.
E-mail addresses: shaliza63@gmail.com, shaliza@um.edu.my (S. Ibrahim).
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due to their ready availability, low cost, high carbohydrate content and biodegradability (Atif et al., 2005; Ginkel et al., 2005; Younesi et al., 2008).

Palm oil mill effluent (POME) is rich in organic carbon with biochemical oxygen demand (BOD) value higher than 20 g/L and nitrogen content around 0.2 and 0.5 g/L as ammoniacal-nitrogen and total nitrogen, respectively (Yang et al., 2007). Three main sources of the POME are sterilization run-offs (36%), clarification (60%) and hydrocyclone (4%) units. Raw POME as a colloidal suspension contained 95–96% water, 0.6–0.7% oil and 4–5% total solids (Ma, 2000; Krishnan and Desa, 2006; Mohammadi et al., 2012c). It is estimated that 5–7.5 tons of water are required for each ton of crude palm oil production; which accounts for more than 50% of the used water converted to POME (Najafpour et al., 2006).

Biological H_2 production from POME have been accomplished using different reactor configurations such as up-flow anaerobic contact filter (Najafpour et al., 2006), anaerobic sequencing batch reactor (ASBR), batch reactors (i.e. fermentors and serum bottles) (Atif et al., 2005; Krishnan and Desa, 2006; Pakarinen et al., 2008; Chong et al., 2009; Ismail et al., 2010; Rasdi et al., 2012; Leaño and Babel, 2012), up-flow anaerobic sludge blanket (UASB) (Singh et al., 2013). The up-flow anaerobic sludge blanket (UASB) system is the most commonly used high rate anaerobic treatment process. The UASB reactor is capable of retaining high microorganism concentration and high rate of waste stabilization and could be an option for a reactor to generate biological H_2. This reactor presents positive features, such as allowing high organic loading rate (OLR), short hydraulic retention time (HRT) and has a low energy demand (Metcalf and Eddy, 2003). Granulated sludge is the distinct characteristic of UASB reactors as compared to the other anaerobic treatment systems (Thaveesri et al., 1994; Lettinga, 1995). The growth of granulated sludge is affected by the wastewater characteristics, pH, nutrients availability and up-flow velocity (Annachhatre, 1996). However, long start-up period (2–4 months), extreme variation in the up-flow velocities, and granules washout at hydraulic stresses are major issues associated with the conventional UASB reactors (Lin and Lay, 2004). Therefore, modification of the UASB process is needed to eliminate the existing problems in order to encourage high performance H_2 production from POME. In this study, a combination of up-flow anaerobic sludge blanket (UASB) and up-flow fixed film (UFF) in a single reactor was applied as modified up-flow anaerobic sludge blanket-fixed film (UASB-FF) reactor. Several variations of UASB-FF bioreactor have been studied for treatment of different industrial wastewaters, like slaughterhouse, distillery spent wash, starchy, fiberboard manufacturing, whey wastewater, and POME (Fernandez et al., 2001; McHugh et al., 2005; Ismail et al., 2010).

In this study, application of a modified UASB-FF reactor to produce H_2 from POME was investigated. The main objectives of this research were to shorten the start-up period and accelerate the formation of granular sludge in the UASB-FF reactor.

2. Materials and methods

2.1. Experimental set-up

A schematic diagram of the laboratory-scale UASB-FF reactor (total volume 3.5 L, working volume 2.55 L, liquid height 80 cm) rig set-up used in this study is shown in Fig. 1. The glass reactor column was fabricated with an internal diameter of 55 mm at the bottom and middle parts and 75 mm at top part. The reactor comprised three sections. The lowest section of the UASB reactor's column with the height of 60 cm

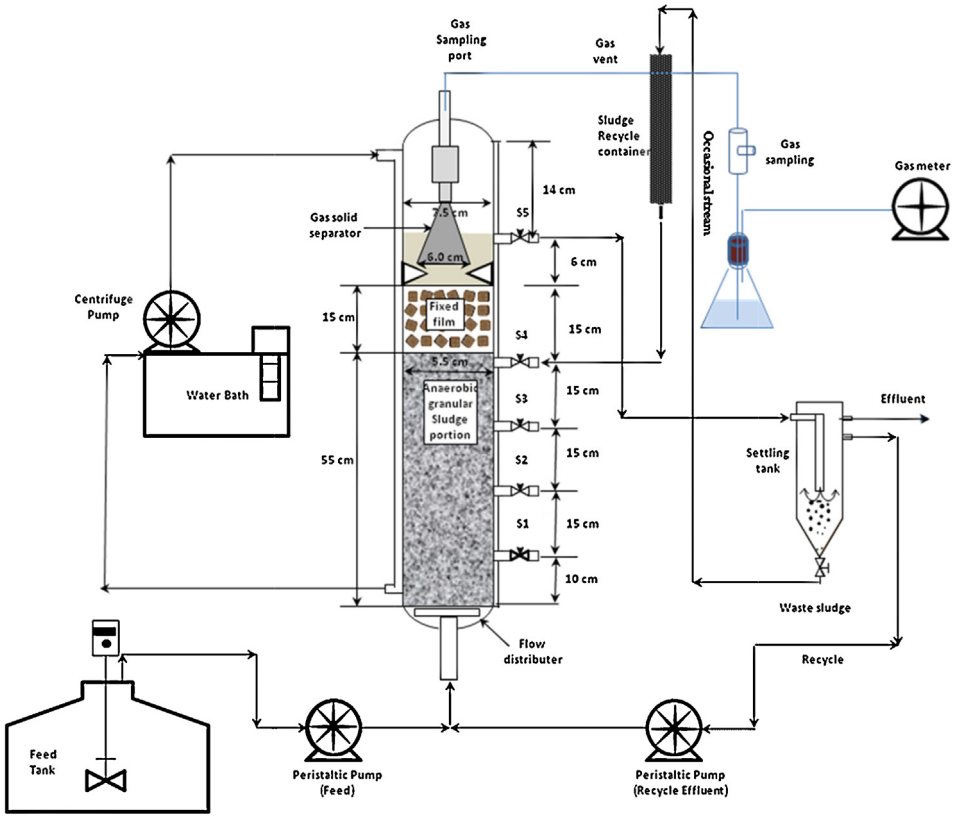

Fig. 1 – Schematic diagram of the experimental set-up.