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Start up performance of biochar packed bed anaerobic digesters

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ABSTRACT

The development of microbial biofilm community in biochar packed anaerobic digesters was explored during start up at demonstration scale on high strength grease trap waste wastewater. Total and soluble chemical oxygen demand reduction reached 68% and 69%, respectively, after just fifty nine days at an HRT of 1.8 days. Methane head space gas compositions averaged across all reactors exceeded 60% and total methane production rates approached the theoretical maximum per kilogram of chemical oxygen demand reduced. Aggressive consumption of volatile organic acids correlated linearly with an increase in pH from 5.86 in the mixing reactor to a value of 7.61 in the final effluent. Both soluble and total phosphorous and total nitrogen were relatively unaffected by the treatment. Active methanogenic microbial biofilm communities possessing high proportions of methanogens were established despite the presence of feed wastewater streams possessing significantly different populations of planktonic bacteria. In sum, these results indicate that biochar alone can support the rapid development of robust well balanced methanogenic microbial biofilms that effectively minimize the impact of influent microbial communities on the reactor microbial biofilm communities.

1. Introduction

The complete anaerobic digestion of organic waste requires a well-working and balanced cascade of trophic levels of bacteria (acido and acetogens) and archaea (methanogens) [1,2]. These microorganisms are both diverse with respect to their growth rates, pH optima, and inhibitors. They are also symbiotically dependent upon each other in terms of metabolite consumption and production. Methanogens are relatively slow growers optimized for pH values around 7.0 and sensitive to reactor conditions while acido and acetogens are relatively fast growers that prefer pH values between 5.5 and 6.0 [1,3]. For these reasons a properly balanced population is difficult to achieve during start up. It is also difficult to maintain during continuous operation – particularly when fed wastewaters populated with complex and poorly balanced microbial communities. Establishing a balanced biofilm population during the start-up phase is, therefore, critical. The benefits to biofilms, attached community of microbes, include proximity to maximize resource utilization, decreased competition, resistance to stress, and increased metabolic activity. Not surprisingly the start-up process, especially under overload and stress operations, has gained increased interest, with several procedures proposed and evaluated to inoculate the reactor with a sufficient mass of a well-balanced methanogenic microbial community.

The most direct technique is the inoculum ratio (v/v) which should be at least 5% of the total reactor volume [4]. Another is to pre-aerate the feed substrate to reduce easily degradable organic carbons which otherwise might lead to a disproportionate production of volatile organic acids and a sudden drop in pH [5]. Sudden drops in pH can lead to a substantial growth spurt of faster growing acido and acetogens at the expense of the slower growing methanogens which prefer pH values closer to 7.0. Charles et al. (2009) demonstrated that pre-aeration for five days significantly improved the start-up process [6]. Additional methodologies include the source of the inoculum [3,7], the initial mode of operation of the digesters in terms of mixing/stirring intensity [8], the organic loading rate (OLR) and hydraulic and solid retention time [9], and the adaptation and pre-incubation of the biomass prior the anaerobic digestion process [9–11].

More recently the seeding of the reactors during the start-up phase with specialized inocula that can metabolize high concentrations of acetate has been proposed [12,13]. Acetate is both the end product and substrate for acetoclastic methanogens to produce methane and is therefore a key metabolite produced during

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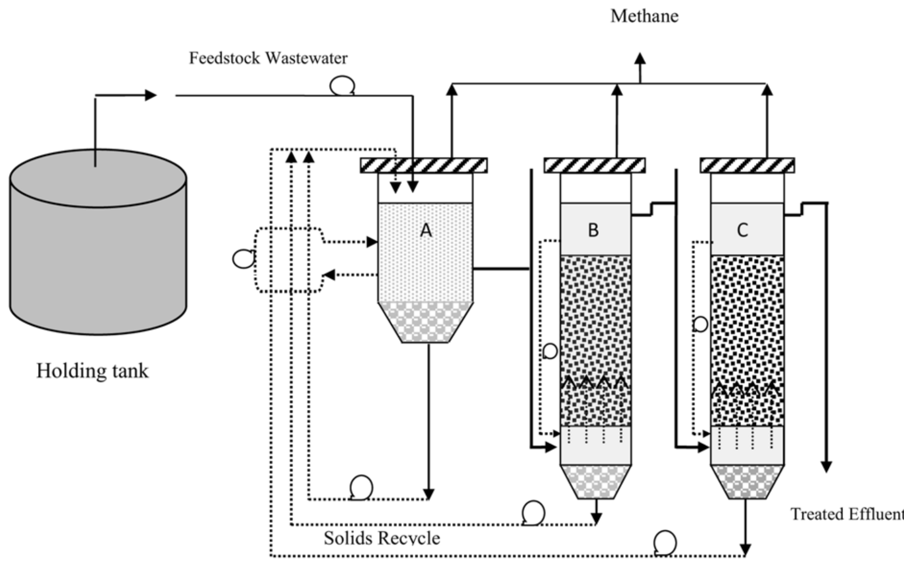

Fig. 1. HRAD schematic. RXR A: 900 L (working volume 600 L), RXR B: 1500 L (working volume 1200 L), RXR C: 1500 L (working volume 1200 L), holding tank: 7570 L (working volume 5500 L).

the anaerobic digestion of carbohydrates. If the start-up phase does not achieve an effective balance between fermentative acid-producers and methanogens, however, the concentration of acetate will exceed a specific critical upper threshold and the reactor will fail. To address this scenario, the step wise addition of a specific acetate degrading enrichment culture over a six week period was tested against controls and a faster start-up period under high acetate concentrations was achieved [12,13]. Despite these positive initial results, however, the authors noted the need for further research with regard to fermenter designs and cultivation conditions.

The pretreatment steps described above are also problematic to execute at commercial scale. It would be of great benefit, therefore, if well-balanced methanogenic microbial biofilm communities could be achieved rapidly during the start-up phase and with minimal treatments. Previously, the authors tested, at lab scale, the capacity of biochar packed upflow column reactors to treat high strength wastewaters at relatively low hydraulic retentions times [1]. Their results suggested that biochar alone could support the rapid development of biofilms possessing balanced populations acido, aceto, and methanogens. In this work this strategy was tested during start-up at demonstration scale on non-sterilized wastewater that possessed both high concentrations of volatile organic acids (including acetate) and high proportions of microorganisms that threaten to upset the population balance.

2. Materials and methods

The packed bed anaerobic reactor system is presented as diagramed in Fig. 1 and as installed in Fig. 2. Wastewater separated on site from grease trap waste was transferred from wastewater holding tanks in one thousand gallon increments and stored in a 7570 L feedstock holding tank. The characteristics of the grease trap waste wastewater feedstock were measured intermittently over the full period of operation (Tables 1 and 2). The total chemical oxygen demand (COD) was higher than its soluble counterpart at 15.36 ± 1.76 vs. $13.02 \pm 1.7\,g\,L^{-1}$. The total suspended solids was fairly constant at $1.4 \pm 0.14\,g\,L^{-1}$ as was the total volatile organic solids at $4.29 \pm 0.37\,g\,L^{-1}$. The COD/N ratio was $45.0\,g\,L^{-1}$ (total) and $49.4\,g\,L^{-1}$ (soluble). The COD:N:P ratios over this period were relatively consistent at 100:2.2:1.38 (total) and 100:2.17:1.27 (soluble) and in general agreement with the previous work of Lopez et al. (2013) who evaluated grease trap waste wastewater obtained from the same plant.

Fig. 2. Installed pilot scale HRAD system.

Agitation in the mixing tank (Fig. 1A) was accomplished by pumping fluid out through the bottom via an aggressive chopper style pump and returning it to the tanks upper section. Temperature was controlled at 37 °C by passing the returned fluid through a set-point controlled heat exchanger. The pH in the mixing tank was measured and maintained at a set-point of 5.8 through addition of concentrated N_aOH using a dosing controller and metering pump. The grease trap waste wastewater feedstock was metered from the feedstock holding tank to the initial mixing tank (Fig. 1A) via a