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Performance of anaerobic hybrid reactors for the treatment of complex phenolic wastewaters with biogas recirculation

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HIGHLIGHTS

- ▶ Biogas recirculation employed for AHR treating coal wastewater.
- ▶ Higher phenolics and COD removal observed at 7.5 L d^{-1}.
- ▶ Simultaneous removal of all phenolics.
- ▶ Greater attachment of biomass (14.0 g VSS) to support medium.
- ▶ Higher methanogenic activity was observed.

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ABSTRACT

This study investigates the application of a novel anaerobic hybrid reactor (AHR) configuration, incorporating support media for biomass immobilisation and biogas recirculation for improved mixing towards the anaerobic treatment of complex phenolic wastewater. Synthetic coal wastewater with an average phenolics and COD concentration of 752 and 2240 mg L^{-1} was used as substrate. Biogas recirculation was employed at four different rates of 11.25, 16.87, 25.30 and 37.95 L d^{-1} for 100 days. Phenolics and COD removal improved with increase in biogas recirculation. After 120 days of continuous operation, the results revealed that a high amount (14.0 g VSS) of biomass was able to attach itself to the support medium. The investigated AHR configuration achieved phenolics and COD removal efficiencies of 95% and 92% respectively at a hydraulic retention time (HRT) of 0.33 d. The corresponding average methane production obtained in this study was 0.02 mol methane g^{-1} COD.

1. Introduction

Coal plays an important role as a substrate for electricity generation due to the rapid decline of petroleum resources and increase of crude oil prices across the globe. Coal gasification is predicted to continue in most of the developing world, with coal set to fuel 44% of electricity (IEA, 2010). Wastewaters from coal gasification contain 60–80% of phenolic compounds along with aromatic nitrogen and sulphur containing compounds and aliphatic acids (Singer et al., 1978). Concentration of phenolic compounds, ammonia and COD in the wastewater are 4000, 3000 and 20,000 mg L^{-1} respectively and the pH of the wastewater is 9–10.5. Due to the potential hazard of these compounds, many substituted phenols, including chloro/nitro and cresols have been listed as priority pollutants by the U.S. Environmental Protection Agency (EPA) (Keith and Telliard, 1979). The toxicity of these compounds not only helps them in resisting microbial degradation, but also assists them in inhibiting the degradation of other constituents of the wastewaters.

Pollution caused due to coal gasification wastewater is a serious environmental problem. The treatment process usually consists of stripping and extraction for the removal of phenols, ammonia and hydrogen sulphide and carbon dioxide before the biological treatment (Luthy et al., 1983). Biological treatment is a feasible option for phenolic compounds removal, as it consumes less energy and is cost effective. Anaerobic treatment of coal wastewaters was carried out initially employing activated carbon which served to adsorb the toxic pollutants and acted as a carrier for bacterial adhesion (Nakhla et al., 1990). Two research studies reported the continuous anaerobic treatment of phenolic compounds without activated carbon (Fang et al., 1996; Tawfiki et al., 2000). To guarantee a successful treatment of coal conversion effluents, there should be a simultaneous degradation of major phenolic substrates (phenols, cresols, and dimethyl phenols (DMPs). Extensive research has been conducted and documented on the application of upflow anaerobic sludge blanket reactors (UASB) process for one stage treatment of mixture of phenols (Fang and Zhou, 2000; Zhou and

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Fang, 1997; Razo-Flores et al., 2003; Puig-Grajales et al., 2003). Inconsistencies that are reported with UASBs include (i) their inefficiency for treating wastewater with higher concentration of suspended solids; (ii) poor granulation and (iii) sudden washout of biomass in extreme cases (Lettinga et al., 1980). Thus establishment of innovative anaerobic reactor configurations that can handle complex organic constituents at lower retention times will be a productive step towards effective exploitation of anaerobic digestion of complex phenolic wastewaters.

Anaerobic Hybrid reactor (AHR) configurations, combining a sludge bed in the lower part and an anaerobic filter (AF) in the upper part offers positive features of both suspended and attached growth (Tilche and Viera, 1991) and constitutes a promising alternative for the treatment of different wastewaters. Application of AHR for different industrial wastewaters, include distillery spent wash (Gupta and Singh, 2007), olive oil mill effluents containing phenols (3100–4025 mg L^{-1}) (Azbar et al., 2009), pharmaceutical effluents (Oktema et al., 2008) and low strength industrial cluster wastewater (Kumar et al., 2008). Few studies were also carried out to improve reactor configuration and operational parameters (Suvajittanont and Chaiprasert, 2003; Pendera et al., 2004). Anushuya and Gupta (2006) employed AHR for the treatment of simulated coal wastewater. After start-up, the hybrid reactors performed steadily with phenolics and COD removal efficiencies of 93% and 88%, respectively at volumetric loading rate of 2.2 g COD m^{-3} d^{-1} and hydraulic retention time of 24 h. Later, the reactors were operated at four different hydraulic retention times in the range of 36–18 h. Total phenolics removal efficiency decreased from 99% (corresponding to 744 mg/L) to 92% (corresponding to 689 mg/L) and COD removal efficiencies decreased from 93% to 83% as HRT was lowered from 36 to 18 h (Anushuya and Gupta, 2008a). Further the reactors were operated at varying COD/NO_3^-N ratio as 20.1, 14.85, 9.9, 6.36 and 4.45 at an input phenolics concentration of 752 mg/L and hydraulic retention time (HRT) of 24 h. Removal of phenolic mixture was found to increase with the lowering of COD/NO_3^-N ratio. Maximum phenolics removal of 98% was achieved at a COD/NO_3^-N ratio of 6.36 (Anushuya and Gupta, 2008c). However, phenolics removal got adversely affected when COD/NO_3^-N ratio was reduced below 6.36. In addition, effluent recirculation was employed to hybrid reactors at four different effluent to feed recirculation ratios (R/F) of 0.5, 1.0, 1.5 and 2.0 for 100 days Phenolics and COD removal was found to improve with increase in effluent recirculation. An effluent to feed recycle ratio of 1.0 resulted in maximum removal of phenolics and COD. Phenolics and COD removal improved from 88% and 92% to 95% each, respectively (Anushuya and Gupta, 2008b). Effect of shock loading on the reactors revealed that phenolics shock load up to 2.5 times increase in the normal input phenolics concentration in the form of continuous shock load for 4 days did not affect the reactors performance irreversibly. Challenges still prevail in the effective biomass retention and efficiency to treat toxic phenolic coal wastewaters at higher organic loadings and lower retention times. Therefore, as a part of a multifaceted and multi-disciplinary effort to address the current inconsistencies in the anaerobic treatment of coal wastewater, the objective of this study was to investigate the performance of the AHR process incorporating PVC rings as support medium for biomass immobilization and biogas recirculation for improved mixing in anaerobic digestion of simulated coal wastewater.

2. Methods

2.1. Reactor seeding

The reactors were seeded with a mixture of anaerobic digester sludge (3 L) and partially granulated sludge (1 L). Granular sludge obtained from a UASB reactor treating distillery spent wash was acclimated to phenolic compounds (*o*-, *m*- and *p*-cresols) for 8 months (Gupta and Singh, 2007). Digester sludge was obtained from M/S. Jackson Dairy Works, Hutchinson, Kansas. Three litres of digester sludge containing 72.6 g of total solids (with a sludge volume index (SVI) of 32 mL g^{-1} SS^{-1}) and 1 L of granular sludge containing 62.1 g of total solids (with a SVI of 27 mL g^{-1} SS^{-1}) was mixed and stored at 4 °C prior to use. The mixed anaerobic culture was filtered through a screen of 0.05 inch (1.2 mm) mesh size and concentrated by settling for 2 h before being used as inoculum. The total solids content of the reactor to 134.7 g. The total suspended and volatile suspended solids added to the reactor were 130 and 80 g L^{-1} respectively.

2.2. Experimental set-up

The schematic diagram of the AHR is shown in Fig. 1. The length, wall thickness and effective volume of the AHR were 1.5 m, 0.006 m and 13.5 L, respectively. A hopper bottom 0.15 m length along with a feed inlet pipe (φ = 0.025 m) was provided to prevent avoid choking during operation. The inlet end leads towards the reactor bottom which allows feed to first strike at the bottom and get evenly distributed during its upward motion in a hopper bottom. An outlet pipe (φ = 0.015 m) was provided at the top and connected to the effluent tank. Three litres of PVC support medium with a diameter of 25.4 mm, length of 25.4 mm, thickness of 6.4 mm, dry weight of 102.9 g/L and specific surface area of 628 m^2/m^3 was added to the AHR. The reactors were provided with six equidistant sampling ports (φ = 2.5 cm) along its height to facilitate sampling. A portion of the biogas produced was recirculated through a square pyramid shaped gas distributor with 1 mm openings using peristaltic pump (Watson Marlow 601 147 S). A wet tip gas meter was connected to the reactor to monitor gas production.

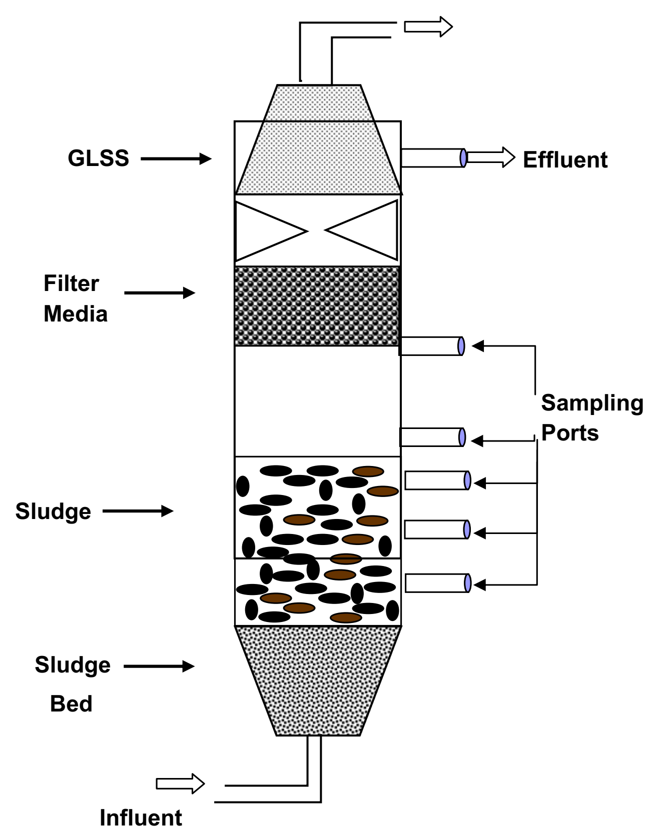

Fig. 1. Schematic diagram of anaerobic hybrid reactor.