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Role of biogas recirculation in enhancing petrochemical wastewater treatment efficiency of continuous stirred tank reactor

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A B S T R A C T

Although the co-digestion of petrochemical wastewater (PWW) with activated manure (AM) is providing an improved production of bio-methane, still several researches are going on how the bio-methane generation and COD removal efficiency can be maximized? Therefore, a question strikes our research motivation to find out does biogas recirculation really play a part in enhancing bio-methane generation and COD removal efficiency? This work explains the continuous stirred tank reactor (CSTR) performance with and without biogas recirculation effect for better mixing during the anaerobic co-digestion of PWW and AM. Four distinct rates of biogas recirculation (10.15, 15.81, 24.14 and 36.25 Ld^{-1}) were examined for a trial period of 100 days. Bio-methane generation and COD removal efficiency were greatly improved as the biogas recirculation rate was increased. The newly incorporated CSTR arrangement with biogas recirculation effect achieved COD and VFA removal efficiencies up to 98.5% and 94% with a hydraulic retention time (HRT) of 9 days. The corresponding mean Biogas and methane generation were observed to be remained at 9.2 ± 0.5 and 6.08 ± 0.5 m^3 m^{-3} d^{-1}. It shows a maximum increase of 55% and 26% in biogas and methane generation efficiency compared to that of without biogas recirculation CSTR. Biomass retention efficiency of the CSTR showed an increment of 16.78%, 20% and 25% in biomass level with the gradual increment of biogas recirculation rates of 10.15; 15.81 and 24.14 Ld^{-1}. This work may depict the environmental and financial feasibility of renewable technology that will open the scope for deeper study in minimizing the environmental issues of petrochemical manufacturing in the future.

1. Introduction

Industrial waste waters play significant cause for the pollution of surface water schemes (Ozturk et al., 2015). As a wide variety of industries dumping effluent to water bodies cover a broad range of manufacturing branches the characteristics and, therefore, the consequential environmental impact of these waste waters is fluctuating (Khatri et al., 2014). Nevertheless, usually the industrial effluents are likely to carry a vast amount of organic and inorganic contaminants. In fact, organic contaminants not only present in industrial wastes at huge proportions but also carry a huge diversity in its molecular structures. Consequently, a high amount of organic pollutants, containing for instance insecticides, aliphatic and aromatic hydrocarbons, polychlorinated biphenyls, phosphorous- and sulphur comprising compounds had been recognized in industrial effluents, and their impact in water bodies had been examined moderately (Siddique et al., 2014a,b). Particularly, Petrochemical wastewater, carrying much oxygen undermining potential (COD 1–60 g/L) as industrial sewage, becomes conspicuous challenges to meet up the progressively strict environmental guidelines (Salehi et al., 2014). The lack of wastewater management (Rehan et al., 2014) absolutely affects natural divergence of the aquatic ecosystem; disordering the elementary integrity of total ecosystem. So, the prevention of the continuous pollution caused by petrochemical effluents is obligatory. Expedition of novel reliable energy replacements to gasoline has been a leading challenge throughout the current century to meet the imminent energy wants (Finn and Fitzpatrick, 2014). Anaerobic digestion (AD) (Ros et al., 2014) presents an outstanding opening for energy conversion and pollution minimization mutually (Tansel and Surita, 2014).

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Nomenclature

AD	Anaerobic digestion
PWW	Petrochemical wastewater
AM	Activated manure
ACD	Anaerobic co-digestion
CSTR	Continuous stirred tank reactor
OLR	Organic loading rate
RR	Recirculation rate
HLR	Hydraulic loading rate

Anaerobic digestion is the digestion of complex organic compounds under oxygen free environment (Yu et al., 2014). The whole process is time absorbing as microbial consortia are accountable for degradation. Anaerobic system consumes time to acclimatize to the new environment earlier to use organic compounds to propagate (Saidu et al., 2014). It has been applying to an extensive range of feed-stocks such as industrial and municipal waste waters, agricultural, food wastes and plant residues (Cesaro et al., 2014). The generation of biogas by anaerobic process (Serrano et al., 2014) presents substantial benefits compared to other methods, comprising:

i. Fewer biomass sludge is generated than aerobic method
ii. Effective for treatment of wet wastes of less than 40% dry matter
iii. Satisfactory pathogen removal. It is especially true for multi-stage digesters (Avery et al., 2014)
iv. Negligible odour emissions as 99% of volatile compounds are oxi-datively decomposed upon combustion
v. Great compliance with various national waste policies implemented to decrease the volume of biodegradable waste incoming land fill (Závodská et al., 2014)
vi. The digestate produced is an enriched fertilizer for both of its handiness to plants and rheology (Leiva et al., 2014)
vii. An option of carbon impartial energy is generated as biogas.

However, controlled anaerobic fermentation of biomass produces a gas that can be used to produce electrical–thermal energy because of its high percentage of methane (Harsono et al., 2014).

Continuous stirrer tank reactor works on the principle of medium rate anaerobic process and it is still widely used for anaerobic digestion (Yang et al., 2013). To intensify this simple technology and maintain a viable population of the slow growing methanogens, the CSTRs (Reungsang et al., 2013) are usually combined with an internal or external biomass separation and recycling system. Numerous solid waste portions can also be treated in CSTRs after slurring with liquid (Lindmark et al., 2014). In CSTR, feeding frequency has to be uninterrupted to attain extreme performance; however, reactor is fed discontinuously because of real reason; mostly used rate of feeding is one time/day (Castrillón et al., 2013). Mixing yields better interaction between microorganisms and substrates, decreases hindrance to mass transmission, reduces accumulation of resistant intermediates and balances required conditions (Chong et al., 2013). Inefficient mixing makes overall performance impaired.

Although the co-digestion of petrochemical wastewater (PWW) with activated manure (AM) is providing an improved production of bio-methane, still several researches are going on how the bio-methane generation and COD removal efficiency can be maximized? Therefore, a question strikes our research motivation to find out does biogas recirculation really play a part in enhancing bio-methane generation? Furthermore, no earlier research on the effectiveness of biogas recirculation rate has been executed. Consequently, this manuscript may help to meet up the increasing energy demand of the society. Several trials and observations were done with and without biogas recirculation effect on CSTR to attain an enhanced bio-methane production that can make the process cost-effective. Each of them included variation of operating hydraulic loadings, variation of organic loadings, and biogas recirculation etc.

Therefore, to determine the influence of biogas recirculation rate on the bio-methane generation and the degradation of waste waters from the petroleum refinery at Tarranganu, Malaysia using a continuous CSTR-type bio-digester was the key objective of this present study.

2. Materials and methods

2.1. Seeding

The digester was seeded with a combination of anaerobic reactor waste activated sludge (2 L) and partially granulated waste activated sludge (1.2 L). Both of the waste activated sludge was obtained from a commercial scale CSTR digester treating petroleum wastewater was acclimatized to degrade petroleum compounds for 10 months situated in Terenganu, Malaysia. Two litres (L) of digester waste activated sludge comprising 75.5 g of total solids (TS) and 1 L (L) of waste activated granulated sludge comprising 65.2 g of TS was blended and preserved at 4 °C in cold room. The blended anaerobic microbial culture was filtered by passing through a 0.05 inch mesh size screen and thickened by settling for 2.5 h before to be used as inoculum. The TS content of the CSTR was 132.5 g. A 128 and 78 g/L of total suspended and volatile suspended solids were fed to the CSTR.

2.2. CSTR setup and operation

An auto CAD aided schematic drawing of the CSTR and photograph of the total experimental setup were shown in Fig. 1 and Fig. 2. The conventional CSTR design is not capable enough to maintain the pH and temperature in an appropriate way. We installed pH, temperature sensor and digital pressure display to obtain a good control over the system. The reactor was fabricated in university workshop. The dimension of CSTR reactor used in this study was measured determining the reactor's total (4.5 L) and working volume (2.7 L). The main digester is constructed of glass and stainless steel. It has been strictly sealed with steel plate capping in conjunction with 6 nuts. The stirrer motor was installed over the plate. It could also be controlled with a speed control device. It has a range from 100 to 260 rpm. To maintain the temperature, a heater has also been installed in the system. Feeding tank to serve feeding has also been added. Biogas could be collected through a biogas collection tank. A partial fraction of the biogas generated in the digester was recirculated by a triangular shaped biogas distributor having approximately 1 mm openings connected to a pump (230V, Deng Yuan). A digital gas flow meter was installed with the digester to monitor biogas generation. The CSTR was tested for blockage and media degradation before biogas recirculation was started. The CSTR was operated at mesophilic state 28–37 °C with an electric heater. The effectiveness of the CSTR was examined by determining biogas generation, COD removal efficiency mainly. The properties of PWW and AM used in this work are shown in Table 1. The operational design for the experimental runs was shown in Table 2. Each value of the experimental parameters has been validated by triplicated experimental trials (Fig. 3).