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In-situ regeneration of activated carbon with electric potential swing desorption (EPSD) for the H_2S removal from biogas

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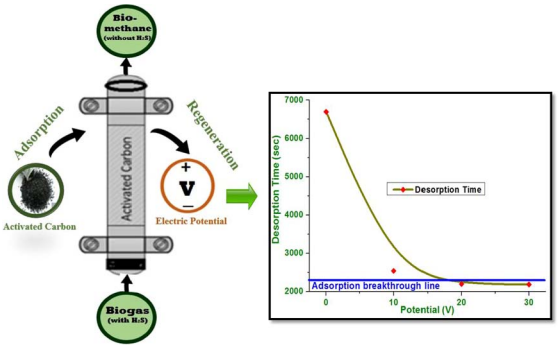
GRAPHICAL ABSTRACT



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ABSTRACT

In-situ regeneration of a granular activated carbon was conducted for the first time using electric potential swing desorption (EPSD) with potentials up to 30 V. The EPSD system was compared against a standard non-potential system using a fixed-bed reactor with a bed of 10 g of activated carbon treating a gas mixture with 10,000 ppm H_2S. Breakthrough times, adsorption desorption volume, capacities, effect of regeneration and desorption kinetics were investigated. The analysis showed that desorption of H_2S using the new EPSD system was 3 times quicker compared with the no potential system. Hence, physical adsorption using EPSD over activated carbon is efficient, safe and environmental friendly and could be used for the in-situ regeneration of granular activated carbon without using a PSA and/or TSA system. Additionally, adsorption and desorption cycles can be obtained with a classical two column system, which could lead towards a more efficient and economic biogas to bio-methane process.

1. Introduction

Based on current biodegradable resources, bio-methane from anaerobic digestion (AD) could supply 60% of the total energy need. The key obstacle for high AD implementation of raw biogas is the upgrade into bio-methane, where the removal of hydrogen sulphide and

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carbon dioxide is required. (Farooq et al., 2017; Morero et al., 2015; Nakada et al., 2014; O'Shea et al., 2016; Wu et al., 2016b). Development of cost-effective bio-gas to bio-methane upgrading technologies is a key step to ensure that renewable gas produced from domestic feedstocks increases energy security (Department for Business, 2017; Ofgem, 2017; Thrän et al., 2014; Wu et al., 2016a). This study proposes electric potential swing desorption (EPSD) as a step towards affordable bio-gas upgrading (Lijó et al., 2017; Parkin, 2016; Pascal et al., 2015; Roy et al., 2015). Bio-methane is typically 86–96% CH_4 and 2–6% CO_2 with H_2S < 10 ppm and can be used in vehicles or injected in national natural gas grids (Cao et al., 2017; Farooq et al., 2016; Kanjanarong et al., 2017). The necessity to reduce the H_2S concentration to be in compliance with grid injection standards is a challenge. Hence, for many European countries the H_2S concentration in the bio-methane is allowed to be 5–10 ppm (Dai et al., 2017; Posadas et al., 2017; Wu et al., 2017). Adsorption by activated carbon (AC) is one the most efficient and techno-economic method for biogas to biomethane if AC can be cost-effectively regenerated in-situ (Awe et al., 2017; Ning et al., 2017). This offers attractive advantages in term of applicability, environment, safety and low energy usage. Activated carbons owing to their higher surface areas pore volume and water resistance of the surface are less costly as compared to zeolites, alumina, silica or other inorganic sorbents (Farooq et al., 2012; Shanmugam et al., 2017; Singhal et al., 2017). The only associated issues with the activated carbon (AC) is its operational cost and time for regeneration of the adsorbent, where the current industry practice is to simply replace with fresh AC (Farooq et al., 2017; Skouteris et al., 2015; Tao et al., 2017).

Adsorbent materials is yet to gain widespread use for bio-gas upgrading due to the energy penalty associated with regeneration of the adsorbents that is typically achieved via temperature swing adsorption (TSA) and/or pressure swing adsorption (PSA) with an estimated 25–40% energy penalty (Lyndon et al., 2013; Wang et al., 2016). Regeneration of activated carbon using PSA need high-pressure compressors which leads to high power consumption and installation costs (Jribi et al., 2017; Zhao et al., 2017b). With TSA, desorption is achieved by increasing the temperature by means of direct heat, microwave swing (MSA) or through electric swing adsorption (ESA). In standard TSA, a hot gas such as air and/or N_2 heats the bed. Due to the low heat capacity of gases, a large volume of gas is needed in this process, which leads to desorption of the adsorbate diluted in the heating gas (Creamer and Gao, 2016). A recent variation of the TSA regeneration is the use of microwave swing adsorption (MSA), which provides selective volumetric heating, fast heating rates and no contact between heating source and adsorbent (Foo and Hameed, 2012; Jafari et al., 2017; McGurk et al., 2017). However, MSA can lead to overheating, hot spots and a non-uniform temperature profile. MSA is more efficient in comparison with traditional TSA, but still energy intensive process in terms of cooling the bed after desorption. In the ESA process the heat is generated in-situ by the Joule Effect by passing an electric current through the bed material using a conductor or using the bed material as the conductor (Ntiamoah et al., 2016; Zhao et al., 2017a). However, inhomogeneous electrical conduction and heating may be expected when employing particulate adsorbents. A main concern is the temperature gradient, which may not be linearly proportional to the power input. Both TSA and PSA utilise changes in physical properties to desorb the adsorbent from the surface of the adsorbate. Directly interfering with the active adsorption sites might be a cost-effective route to achieve rapid desorption and this could be achieved through electric potential swing desorption (EPSD).

The EPSD system, as proposed in this current research, targets a rapid in-situ desorption of H_2S compared to other conventional desorption systems, leading to H_2S desorption time being shorter than the adsorption breakthrough time. This system could have inherent advantage over the TSA, PSA and other technologies for regeneration, since regeneration can be achieved without altering the system pressure or applying significant external energy. Hence, adsorption and desorption cycles can be obtained with a classical two column system, which could lead towards a more efficient and economic biogas to biomethane process.

2. Materials and methods

2.1. Activated carbon characteristics

A commercial granular activated carbon (GAC) sample was used for this study in the regenerative activated carbon unit. The GAC sample has an elemental composition of Carbon, Hydrogen, Nitrogen and Oxygen of 68.2, 0.6, 0.3 and 8.6 wt.%, respectively and 22.3 wt.% ash on dry basis. The BET surface area and the micropore volume were found to be 457 m^2/g and 0.11 cm^3/g, respectively, from the adsorption isotherms using Micrometrics Gemini VII. The proximate analysis of the GAC were conducted in accordance with the ASTM D7582 method, in term of moisture content, volatile matter, fixed carbon and ash content calculated as 9.6, 10.4, 60.2 and 19.8%, respectively. The conductivity of the GAC was 0.39S/m, measured using digital Multi-meter (Keithley 2700 Bench Digital Multimeter), whereas, potential of 0–30 V was applied with Farnell Stablised Power Supply L30B.

2.2. Regenerative activated carbon unit

Fig. 1 shows the regenerative activated carbon unit (290 mm length, 21.5 mm ID) of the adsorption desorption experimental setup. Glass wool was used above and below the granular activated carbon to avoid slippage and ensure fixed packing of the bed. An internal non-conductive polymer coating was used to force potential through the AC bed. The N_2 (99.99%) used as carrier gas and a special gas cylinder with 99% N_2 with 10,000 ppm H_2S gas was purchased from BOC gases. The system was connected with a low volt potentiometer. Mass spectrometer (Hiden Analytical Ltd.) was used to analyse the gas composition during desorption (Fig. 1).

2.3. Method for adsorption and regeneration analysis

For a typical cycle, a 99:1 vol% N_2/H_2S special gas with a flow of

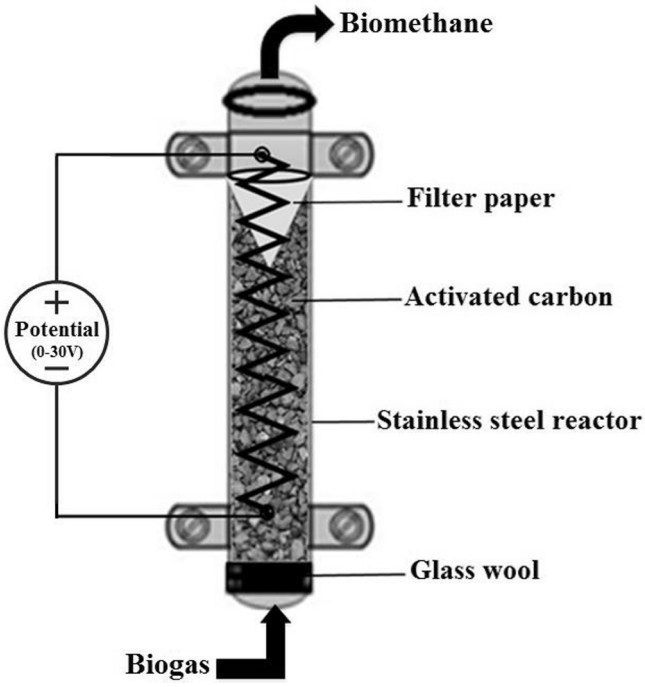

Fig. 1. Regenerative activated carbon unit.