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Treatment of the biodegradable fraction of used disposable diapers by co-digestion with waste activated sludge

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ABSTRACT

The results presented in this paper are part of a project aimed at designing an original solution for the treatment of used disposable diapers permitting the recycling of materials and the recovery of energy. Diapers must be collected separately at source and transported to an industrial facility to undergo special treatment which makes it possible to separate plastics and to recover a biodegradable fraction (BFD) made up mainly of cellulose. The methane yield of BFD was measured and found to be 280 ml CH_4/g VS_{fed} on average. 150 kg of dry BFD can be retrieved from the treatment of one ton of used disposable diapers, representing an energy potential of about 400 kW h of total energy or 130 kW h of electricity. As the treatment process for used diapers requires very high volumes of water, the setting up of the diaper treatment facility at a wastewater treatment plant already equipped with an anaerobic digester offers the advantages of optimizing water use as well as its further treatment and, also, the anaerobic digestion of BFD. The lab-scale experiments in a SBR showed that BFD co-digestion with sewage sludge (38% BFD and 62% waste activated sludge on volatile solids basis) was feasible. However, special attention should be paid to problems that might arise from the addition of BFD to a digester treating WAS such as insufficient mixing or floating particles leading to the accumulation of untreated solids in the digester.

1. Introduction

Disposable diapers are absorbent products for personal hygiene designed to absorb and retain urine and faeces from babies or from adults with incontinence problems. Nowadays, it is estimated that disposable diapers for babies are used in more than 95% of families in advanced economies (EDANA, 2008) and that a child, before being toilet-trained, requires 3796 diapers (EDANA, 2008) with an average of 4.16 a day in the UK for example (Environmental Agency, 2008). The French national survey on household waste conducted in France by ADEME (2010) highlighted that the sanitary textile fraction (including diapers, sanitary towels, tissue papers, cotton, wet wipes, paper towel, paper tablecloths and napkins, etc.) represented 9% by mass of total municipal solid waste, amounting to 34 kg of waste per inhabitant per year. Colón et al. (2010) estimated that the specific generation of waste from disposable diapers in Europe in 2007 was 4,278,461 tonnes which is 1.66% of total municipal waste generated and 3% of the organic fraction. According to Espinosa-Valdemar et al. (2011), diapers accounted for 6% of urban solid waste generated in Mexico in 1997 and in the range 5–15% in 2008.

An unused disposable diaper generally consists of (EDANA, 2008): (i) a liquid-permeable membrane lining the inside surface, made of non-woven polypropylene (PP) or polyethylene (PE); (ii) a watertight membrane on the outer surface made from PP, PE, starch, woven cloth or rubber; (iii) an absorbent core (pulp fluff) made up of a fibrous material (cellulose, hemp or synthetic materials) enclosed in water-resistant paper; (iv) the absorbent part also contains a super-absorbent polymer material (sodium polyacrylates), which has a high capacity for bonding with water, making it possible to retain urine within the absorbent part. The efficiency of a diaper is highly dependent on its capacity to absorb and retain urine; (v) finally, a diaper also contains minor amounts of tapes, elastics and adhesive material. The typical composition of a disposable baby diaper has been described by EDANA (2011): fluff pulp 36.6%, SAP 30.7%, PP 16%, LDPE 6.2%, tape, elastic and adhesive 10.5%. A used baby diaper will contain excreta made up of faeces and urine. The quantity of excreta per diaper was first evaluated to be about 96 g but the results of a small survey and analysis of bins showed that it was much higher with 192 g of excreta per diaper composed on average of 18% faeces and 82% urine (Environmental Agency, 2008). Close results were reported by Colón et al. (2010) for the average quantity of excreta per diaper (171 g) but with a different distribution (6% faeces and 94% urine). At present, diapers are generally not collected separately and are disposed of as solid municipal waste for further treatment,

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mainly by incineration, land filling (Mirabella et al., 2013) and, to a lesser degree, by composting (Colón et al., 2010, 2013) or anaerobic digestion. Used disposable diapers for babies are generated in family houses but also by collective institutions, such as day nurseries or maternity hospitals, which are a strategic key element to introduce separate collection of used diapers and alternatives to the conventional treatments. The quantity of diapers generated by licensed child care arrangements varies a lot among the European countries. Indeed, it was estimated to represent 6.63% of the total used diapers in France but up to 16.36% and 20.72% in Sweden and Denmark, respectively (Colón et al., 2013).

A process has been patented for the treatment of absorbent sanitary paper products, including disposable diapers, which makes it possible to separate such products into their different components in a form suitable for recycling or re-use (Conway et al., 1996). The patent describes different possible equipment and designs for the entire treatment-process line. It comprises a first step of soaking in an aqueous solution to remove particulate and/or soluble matter from the products to be treated. The soaking operation is run under conditions conducive to the non-destructive separation of the constituents. In the recommended process set-up, the product obtained is then treated with an aqueous washing solution and a further solution which includes bleaching and antimicrobial agents. Finally, plastics and the cellulosic material are recovered in separate streams.

A research programme, based on the Conway patent, has been launched and the results presented in this paper were obtained during this programme. The aim is to divert used diapers from municipal solid waste streams and classic disposal methods such as incineration or land filling by designing an original approach involving material recycling and energy recovery. In this approach, used disposable diapers must be separated at source, collected separately and sent to an industrial center for treatment according to the process patented by Conway et al. (1996). The main steps are: coarse shredding, pulping and separation of plastics, separation of the super-absorbent polymer (SAP) and recovery of the biodegradable fraction of diapers (BFD). As this treatment process requires the use of large volumes of water, the industrial center could be set up at a wastewater treatment plant (WWTP) to optimize water use and further post-treatment. Indeed, the effluent at the outlet of the WWTP could be used in the treatment of the diapers and then recycled back to the start of the wastewater treatment line for pollution removal. Furthermore, the biodegradable fraction of diapers could be co-digested with waste activated sludge for energy recovery in pre-existing anaerobic digesters. Co-digestion would be an advantageous option for anaerobic digesters treating waste activated sludge, particularly in the case of under-loaded digesters, as it should make it possible to increase the anaerobic treatment's overall methane production. Co-digestion of waste activated sludge has been successfully investigated with several kinds of co-substrate such as fruit and vegetable waste (Rizk et al., 2007, Bouallagui et al., 2009), meat industry waste (Buendía et al., 2009), the organic fraction of municipal waste (Zupancic et al. (2008), Derbal et al. (2009)) and, of course, residues containing fat, oil and grease which are particularly suitable thanks to their high methane potential (Davidsson et al. (2008), Wan et al. (2011), Girault et al. (2012)).

The work presented in this paper was part of the research programme aimed at evaluating the technical feasibility of the treatment at an industrial center of used disposable diapers for the recovery of their plastic fraction for recycling as raw material and of their biodegradable fraction for energy production. The experiments focused first, on the assessment of the methane yield of the biodegradable fraction of diapers (BFD); and second, on the co-digestion of the BFD with waste activated sludge in a lab-scale reactor.

2. Materials and methods

2.1. Separation of the constituents of the diapers at lab-scale

For the application of the patented process (Conway et al., 1996) to the separation of the constituents of used disposable diapers, the following process, made up of three major successive steps (see Fig. 1), was set up. (i) First step: coarse shredding to open up the diapers and facilitate subsequent separation of constituents. It should produce plastic pieces large enough in size for them to be removed easily in the second step. Diapers were crushed to a size of approximately 1 cm using a Blik BB 230 crusher equipped with stainless steel rotating blades. (ii) Second step: pulping of the shredded materials and recovery of the plastics. In this step, water was added to reduce dry matter content to a low level (1–2% total solids (TS)) and an adapted mixing was used to permit the "solubilization" of faeces, cellulose and SAP. To prevent the SAP from swelling, a chemical agent was added to the pulping water (dosage used is confidential information). After a few minutes of treatment, the SAP became reticulated and formed small hard particles. At pulper outlet, a screen retained the plastic elements while letting the water containing faeces, cellulose and SAP go through for further treatment. A simple domestic washing machine was used at laboratory scale with a ten-minute washing cycle. Emptying the machine enabled the faeces, cellulose and SAP to be recovered, the plastics remaining in the machine drum. (iii) Third and final step: SAP separation from others components (faeces and cellulose). A simple 100 l tank equipped with a mechanical stiring system was used. Gentle agitation allowed the cellulose to be maintained in suspension whereas the SAP settled to the bottom of the tank where a draining pipe permitted its recovery. The biodegradable solid fraction of diapers (BFD), mainly cellulose, was recovered with a 60 μm screen installed along a water recirculation loop on the top part of the 100 l tank. This BFD fraction had a TS concentration of around 10%. Faeces and urine were eliminated with the water flow.

2.2. Protocol for biochemical methane potential assessment

The biochemical methane potential (BMP) was measured in anaerobic flasks. The volume of each flask was 570 ml, with a working volume of 400 ml, the remaining 170 ml volume serving as head space. The following solutions were added to the contents of each flask: (i) 3.4 ml of a solution of NH_4Cl at 26.6 g/l, KH_2PO_4 at 10 g/l, $MgCl_2$ at 3 g/l; (ii) 4 ml of a solution of $FeCl_2$ at 2 g/l, $CoCl_2$ at 0.5 g/l, $MnCl_2$ at 0.1 g/l, $NiCl_2$ at 0.1 g/l, $ZnCl_2$ at 0.05 g/l, H_3BO_3 at 0.05 g/l, Na_2SeO_3 at 0.05 g/l, $CuCl_2$ at 0.04 g/l, Na_2MoO_4 at 0.01 g/l; (iii) 20.8 ml of a solution of $NaHCO_3$ at 50 g/l. The anaerobic sludge was added to the flasks at a concentration of 5 g VS/l. The initial substrate concentration (S0) over the initial volatile suspended solids (VSS) concentration (X0), i.e. the S0/X0 ratio, was 0.5. Once the flasks were prepared, degasification with nitrogen was carried out to obtain anaerobic conditions and the bottles were closed with red butyl rubber septum-type stoppers which were air tight. Duplicate bottles were incubated at 35 °C. Biogas volume was monitored by the water displacement method. Acidified water (pH = 2) was used to minimize the dissolution of carbon dioxide in water. At each volume measurement, biogas composition was analysed.

2.3. Description of the reactors

Reactor experiments were carried out in double-walled glass reactors of 6 l effective volume, maintained at 35 °C by a regulated water bath. Mixing was done by a mechanical stirring system