ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Comparative analysis of the digestibility of sewage fine sieved fraction and hygiene paper produced from virgin fibers and recycled fibers

Dara S.M. Ghasimi [a,*], Marcel H. Zandvoort [b], Michiel Adriaanse [c], Jules B. van Lier [a], Merle de Kreuk [a]

[a] Faculty of Civil Engineering and Geosciences, Department of Water Management, Sanitary Engineering Section, Delft University of Technology (TU Delft), Stevinweg 1, 2628 CN Delft, The Netherlands

[b] Waternet, Korte Ouderkerkerdijk 7, P.O. Box 94370, 1090 GJ Amsterdam, The Netherlands

[c] Centre of Competence Paper and Board (KCPK), IJsselburcht 3, 6825 BS Arnhem, The Netherlands

ARTICLE INFO

Article history:
Received 24 August 2015
Revised 29 April 2016
Accepted 29 April 2016
Available online xxxx

Keywords:
Anaerobic digestion
Thermophilic
Mesophilic
Biomethane potential
Virgin pulp
Toilet paper
Fine sieved fraction

ABSTRACT

Sewage fine sieved fraction (FSF) is a heterogeneous substrate consisting of mainly toilet paper fibers sequestered from municipal raw sewage by a fine screen. In earlier studies, a maximum biodegradation of 62% and 57% of the sewage FSF was found under thermophilic (55 °C) and mesophilic (35 °C) conditions, respectively. In order to research this limited biodegradability of sewage FSF, this study investigates the biodegradation of different types of cellulosic fibers-based hygiene papers including virgin fibers based toilet paper (VTP), recycled fiber based toilet paper (RTP), virgin pulp for paper production (VPPP) as a raw material, as well as microcrystalline cellulose (MCC) as a kind of fiberless reference material. The anaerobic biodegradation or digestibility tests were conducted under thermophilic and mesophilic conditions. Results of the experiments showed different biomethane potential (BMP) values for each tested cellulose fiber-based substrate, which might be associated with the physical characteristics of the fibers, type of pulping, presence of lignin encrusted fibers, and/or the presence of additive chemicals and refractory compounds. Higher hydrolysis rates (K_h), higher specific methane production rates (SMPR) and shorter required incubation times to achieve 90% of the BMP ($t_{90\%}CH_4$), were achieved under thermophilic conditions for all examined substrates compared to the mesophilic ones. Furthermore, the biodegradability of all employed cellulose fiber-based substrates was in the same range, 38–45%, under both conditions and less than the observed FSF biodegradability, i.e. 57–62%. MCC achieved the highest BMP and biodegradability, 86–91%, among all cellulosic substrates.

1. Introduction

At the sewage treatment plant (STP) Blaricum, the Netherlands, a 350 μm mesh size fine sieve (Salsnes Filter, Norway) for raw sewage pretreatment is installed, immediately after the 6 mm coarse screen. The fine sieve is implemented as a compact alternative to primary clarification to separate suspended solids from sewage prior to biological nutrient removal. The produced cake layer or fine sieved fraction (FSF) has a very heterogeneous composition but is presumed to contain mainly cellulosic fibers originating from toilet paper (Ruiken et al., 2013). Considering its nature and high energy content, FSF receives growing interest in countries like the Netherlands, either for cellulose fiber recovery or as feedstock for energy recovery (STOWA, 2010). Regarding the latter, increasing effort is put on onsite energy recovery for closing the energy balance, eventually realizing an energy neutral or energy producing STP.

Toilet paper or toilet tissue is one of the mostly used hygiene products, particularly in Northern Americas, and European countries, whereas it is less used in large parts of Asia and Africa (http://www.worldwatch.org/node/5142). The major component of all hygiene papers is fibrous cellulose, mostly from tree origin. Toilet papers are available in different qualities; they are generally smooth and can be embossed, unprinted or patterned, tinted, purely white or off-white (Holik, 2006).

Toilet paper is either made from virgin pulp, which is mainly extracted from wood and partly from non-wood cellulose (e.g., bamboo) and is called virgin fibers based toilet paper (VTP), or it is made from recycled paper fibers, which is known as recycled fibers based toilet paper (RTP). The type of pulp and paper chemicals used has an influence on the final quality of the tissue paper,

* Corresponding author.
E-mail addresses: S.M.D.Ghasimi@tudelft.nl (D.S.M. Ghasimi), marcel.zandvoort@waternet.nl (M.H. Zandvoort), m.adriaanse@kcpk.nl (M. Adriaanse), J.B.vanLier@tudelft.nl (J.B. van Lier), M.K.deKreuk@tudelft.nl (M. de Kreuk).
URL: http://www.kcpk.nl (M. Adriaanse).

http://dx.doi.org/10.1016/j.wasman.2016.04.034
0956-053X/

Please cite this article in press as: Ghasimi, D.S.M., et al. Comparative analysis of the digestibility of sewage fine sieved fraction and hygiene paper produced from virgin fibers and recycled fibers. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.04.034

e.g. softness, strength, absorbency and appearance. In the process of making virgin pulp as a raw material for paper production (VPPP), one type of wood is generally usually used, i.e. either soft or hard wood. However, in the production of VTP a combination of soft (long fiber for strength) and hard wood (short fiber for softness) is employed. Depending on the required specifications, paper makers choose their fiber source (long fibers, short fibers and combinations). RTP, which completely or partially consists of recycled fibers, may originate from different sources, such as mixed office waste, or old newsprints. Paper production using recycled fibers in the paper mill follows various process steps such as pulping, screening and de-inking stages (Kamali and Khodaparast, 2014). The majority of paper tissue used in the Netherlands is recycled fibers based. The ratio virgin fibers relative to recycled fibers determines the level of softness of the end product. However, application of specific chemicals and process steps can improve the strength, softness, brightness, etc., of any tissue product, regardless the fibers used (WRAP, 2005). During pulp making, pulp processing and paper-making, certain types of chemicals are used as presented in Table 1. However, every papermaking factory deviates according to their applied raw materials, desired products and process optimization. Generally speaking, these additives can be divided in two categories: (1) additives used during the process (2) additives for product improvement (Table 1). Theoretically, both could end up within the product, which however, is more likely for the 'product additives' (Bos et al., 1995). Therefore, there is no standard composition of toilet paper and very likely, also the biodegradability will vary with its composition.

Cellulose is the main constituent of toilet paper and its biodegradability likely depends on its fibrous content and its crystallinity. Maximum biodegradability is expected when no fibers are present, i.e. when the cellulose consists of powdered cellulose (PC) or microcrystalline cellulose (MCC). The chemical composition and physical structure of MCC fully depend on the characteristics of the virgin material from which the cellulose is obtained as well as on the manufacturing conditions (Landin et al., 1993). As a result, several grades of MCC are available on the market with different physicochemical and thermal properties, exhibiting different functional parameters and applications (Azubuike and Okhamafe, 2012). MCCs are prepared by acid hydrolysis under mild conditions of native cellulose to a critical degree of polymerization (DP) (Shcherbakova et al., 2012).

Fibers originating from tissue paper can be screened from the waterline before biological sewage treatment, in order to reduce aeration energy requirements and to generate possibilities to (re-)use these fibers or its energy content. One of the processing routes of the FSF of sewage influent is digestion (Ghasimi et al., 2015). Although the exact composition of our FSF substrate was not measured, an approximate composition can be deduced from Appliedcleantech (www.appliedcleantech.com, accessed on 22 December 2015): 60–80% of cellulose, 5–10% of hemi-cellulose, 5–10% of lignin, 5–10% of oil and the rest accounted for inorganic salts (5–10%) ".

The FSF biodegradability was investigated in our previous researches in batch reactors, applying mesophilic and thermophilic conditions. Results of our previous study revealed a maximum biodegradability of 57% and 62% for mesophilic and thermophilic FSF digestion, respectively (Ghasimi et al., 2016). These low biodegradabilities raised the question about the actual biodegradability of the source materials used in the different toilet papers and the contribution of other organic matter to FSF digestibility. Therefore, series of batch anaerobic digestion tests were conducted under both thermophilic and mesophilic conditions to investigate the ultimate methane potential yield (BMP), specific methane production rate (SMPR), apparent hydrolysis rate (K_h), incubation time needed to achieve 90% of the BMP ($t_{90\%}CH_4$) as well as anaerobic biodegradability (AnBD) of designated cellulose fiber-based substrates including VPPP, VTP, RTP and MCC as a fiberless reference material. The results were compared with FSF digestion results from previous studies.

2. Materials and methods

2.1. Cellulose fibers-based substrates

VPPP, VTP and RTP samples were supplied from Dutch paper factories and were considered the cellulose fiber-based substrates in our experiments, whereas MCC was purchased from Sigma Aldrich (98% purity, Germany). Prior to conducting the experiments, VPPP, VTP and RTP were cut into 1–2 mm pieces. These pieces were mixed with demineralized water and blended for about 15 min to form a soft bulky substrate (Fig. 1). Table 3 presents the characteristics of these substances.

2.2. Fine sieved fraction (FSF)

FSF was collected from the 350 μm mesh fine sieve (Salsnes. Norway) at the sewage treatment plant (STP) Blaricum, the Netherlands, and was stored at 4 °C prior to conduct the BMP tests. Total solids (TS) and volatile solids (VS) were measured on weight base (g/L) according to the standard methods for the examination of water and wastewater (APHA, 2005). Chemical oxygen demand (COD) was measured using Merck photometric cell tests (500–

Table 1
Types of additive compounds used in the papermaking process (Bos et al., 1995).

Kind/sort	Example	Purpose	Main effect
Defoamers	Alcohol derivatives	Process	Suppress foaming during processing and in the paper itself
Binders	Starch, carboxymethylcellulose	Product	Increase of the strength of paper
Bleaching	Sodium peroxide	Product	Increase whiteness of the paper
Dispersants	Alcohol ethoxylate	Process	Prevention of coagulation or precipitation of pigments
Fixers	Various polymers	Process	Adhesion of several additives to the fibers
Dyes	Methyl red, violet	Product	Colouring or shading of the paper
Adhesives	Resin adhesive	Product	Reduction of water absorption of paper
Wet strength agents	Urea formaldehyde resin	Product	Improving the wet strength of paper
pH-regulators	Caustic soda	Process	Changing the acidity of pulp or paper
Cleaning agents	Solvents, acid, base	Process	Cleaning of machinery, piping, sieves and such during process interruption
Retention means	Polyamidoamide	Process	Reduction of fiber and filler fall-through in the sheet forming process
Slimicides	Methylene bis(thiocyanate)	Process	Inhibition of bacterial growth in pulp and process water
Felt detergents	Ethylene oxide	Process	Cleaning of machine clothing
Flocculants	Poly acrylate	Process	Promoting dewatering of rejects and sludge
Fillers	China clay	Product	Opacities to improve printability of paper
Water treatment	Polyphosphate	Process	Preventing deposition of dissolved salts

Please cite this article in press as: Ghasimi, D.S.M., et al. Comparative analysis of the digestibility of sewage fine sieved fraction and hygiene paper produced from virgin fibers and recycled fibers. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.04.034