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A modern solid waste management strategy – the generation of new by-products

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ABSTRACT

To benefit the environment and society, EU legislation has introduced a 'zero waste' strategy, in which waste material should be converted to resources. Such legislation is supported by the solid waste hierarchy concept, which is a set of priorities in waste management. Under this concept, municipal solid waste plants (MSWPs) should be equipped with sorting and recycling facilities, composting/incineration units and landfill prisms for residual bulk disposal. However, each of the aforementioned facilities generates by-products that must be treated. This project focuses on the leachates from landfill prisms, including modern prism (MP) that meet EU requirements and previous prism (PP) that provide for the storage of permitted biodegradable waste as well as technological wastewaters from sorting unit (SU) and composting unit (CU), which are usually overlooked. The physico-chemical parameters of the liquid by-products collected over 38 months were supported by quantitative real-time PCR (qPCR) amplifications of functional genes transcripts and a metagenomic approach that describes the archaeal and bacterial community in the MP. The obtained data show that SU and especially CU generate wastewater that is rich in nutrients, organic matter and heavy metals. Through their on-site pre-treatment and recirculation via landfill prisms, the landfill waste decomposition process may be accelerated because of the introduction of organic matter and greenhouse gas emissions may be increased. These results have been confirmed by the progressive abundance of both archaeal community and the methyl coenzyme M reductase (mcrA) gene. The resulting multivariate data set, supported by a principal component analysis, provides useful information for the design, operation and risk assessment of modern MSWPs.

1. Introduction

EU solid waste legislation has introduced a 'zero waste' strategy designed to promote the extended responsibility of producers and households and stimulate the development of new waste treatment technologies. Considerable effort has been undertaken to emphasize the importance of waste prevention, reuse, recycling and recovery (nutrients and energy), with waste disposal as an option of last resort. The above solid-waste hierarchy concept is supported by Directive 1999/31/EC, which requires European member states to progressively reduce the landfilling of biodegradable waste to 75% of the 1995 level by 2006, 50% of the 1995 level by 2009, and 35% of the 1995 level by 2016. However, Poland, which landfilled more than 80% of its municipal waste in 1995, was given a four-year extension (75% by 2010, 50% by 2013, 35% by 2020), as were several other member states (Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Ireland, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia and the UK).

As a result, significant increases in municipal waste recycling and composting have been observed among all EU members (from 18% in 1995 to 42% in 2012); however, the statistics indicate a widening gap between Central and Eastern EU members (including former Eastern Bloc nations) and Western EU members (Eurostat, 2014). For example, in 2012, 13% of the municipal waste was recycled, 12% was composted, <1% was incinerated and 75% was landfilled in Poland (Eurostat, 2014). Similar trends have been observed in other former Eastern Bloc countries, where the majority of municipal waste is still landfilled.

Because of EU legislation, each municipal solid waste plant (MSWP) should be equipped with sorting and recycling facilities, composting/incineration units and landfill prisms for the residual bulk disposal. However, the by-products generated by the sorting units (SUs) and composting units (CUs) as well as by the modern

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prisms (MPs) are not well understood for the post-2010 operations in Poland, which meet EU requirements and are biochemically influenced by low-organic waste deposition. Such reductions in the disposal of organic matter may limit methane generation by MPs and the potential use of methane in energy production. However, many former Eastern Bloc countries have experience managing MPs and previous prisms (PPs), which were usually ad-hoc arranged without liners or pollution-control systems and unlimited disposal of organic wastes. In terms of landfill leachates, their quality and quantity may depend on several factors, including the raw solid waste composition, the effectiveness of sorting, the composting technology, and the age of the landfill prism. However, landfill leachates generated by PPs are suspected to differ from that generated by MPs. The typical composition of the leachates generated by PPs are provided in Table 1.

Moreover, the introduction of sorting and composting processes at MSWPs generates additional technological wastewaters that are usually neglected. In SUs, the recyclable materials are separated through a combination of manual and mechanical sorting, and the wastewater is generated during polyethylene terephthalate (PET) waste crushing as well as during the washing and cleaning of waste disposal sites, equipment and trucks. In the case of CUs, the wastewater is mainly generated during solid waste biodegradation, which is occasionally supported by irrigation.

Determining the proper (qualitative and quantitative) characteristics of all liquid by-products generated by modern MSWPs is of special concern, particularly when identifying the appropriate on-site or off-site treatment operations and predicting the potential harmful effects of these by-products on the environment.

The aim of this work was to determine the physical and chemical variables of all liquid by-products generated at MSWPs over the course of a long-term (38 months) study. Additionally, a principal component analysis (PCA) was employed to determine the relationships in the obtained data set for the MPs, and a metagenomic approach was used to analyse the bacterial and archaeal succession in selected leachate samples.

2. Methods

2.1. Site description and sampling

In this study, PP and MP landfill leachates as well as SU and CU wastewaters were collected from an MSWP situated in the Pomerania region of northern Poland (Fig. 1). The MSWP serves a metropolitan area of approximately 460,000 people and receives ca. 190,000 Mg of waste per year, of which 130,000 Mg is municipal and 97,000 Mg is biodegradable. In recent years, the studied MSWP has undergone extensive modernization to achieve the mandated reduction in the landfilling of biodegradable waste, reaching 25% and 50% of the 1995 level (63,493 Mg) in 2010 and 2013, respectively. In spring 2010, the sorting and recycling of solid wastes and the composting of their organic fraction were introduced (Fig. 1). However, it should be noted that solid waste segregation (into paper, glass, plastic and mixed) was made a household obligation in the tested area in January 2013.

The studied MSWP is equipped with a municipal solid waste SU with a capacity of 150,000 Mg per year in a three-shift operation. The solid wastes delivered to the MSWP are initially pre-sorted to remove large elements (e.g., furniture, electronics, foil and cardboard) and then directed to the sorting line, where the waste stream is divided into four fractions: the >160 mm fraction is sent directly into the cabin for manual waste sorting together with the 90–160 mm fraction after preliminary air and magnetic separation; the 20–90 mm fraction, which primarily consists of biodegradable components, is sent to an indoor CU; and the 0–20 mm fraction is landfilled. All of the wastewater generated in the sorting process (ca 0.7 m^3/d) was initially directed to the PP; however, since March 2012, it has been directed to the MP (Fig. 1).

The organic wastes are directed to the indoor CU, which was designed for the biological treatment of 30,000 Mg of biodegradable waste per year (75,000 m^3). The main part of the composting hall is a bioreactor, which consists of compost heaps located at nine stations. Each station is equipped with aeration and irrigation systems as well as a temperature prism controlling system. After 28 days, the composted material is transported outside and directed to the yard, where further maturation is conducted for 40 days. The stabilized biodegradable wastes are subjected to sieving to remove non-biodegradable contaminants (diameter > 20 mm), which are intended for landfilling. This stabilized waste is usually sold to external customers or used for the recultivation of old prisms (see below). The wastewater generated during composting (ca. 15 m^3/d) is collected and directed to either the PP (before March 2012) or the MP (after March 2012) (Fig. 1).

Two types of leachate are currently collected from disposed solid waste: one from the MP and one from the PP. The PP was in operation from January 2003 to October 2011 (Fig. 1).

Table 1
Comparative summary of the selected parameters of leachates generated by landfills implemented before the introduction of Council Directive 1999/31/EC (Council of the European Union, 1999).

Type (age) of leachate		Young (<1 year)	Intermediate (1–5 years)	Stabilized (>5 years)
Parameter[a]		Min–max		
pH	–	5.8–6.5	5.6–7.5	7.5–8.1
Conductivity	mS/cm	2.5–35		
BOD_5	mg/dm^3	12,000–24,000	1600	150–260
COD		23,800–6200	4000–10,000	100–4000
BOD_5/COD		0.39–0.5	0.1–0.3	0.04–0.2
$N–NH_4$		790–1400	1500	230÷841
TP		1–80	1–17	0.5–4.2
Cl^-		150–4500		
SO_4^{2-}		8–7750		
TSS		200–1200	400–2390	100–2980
Zn		0.53–170	0.18–38.0	0.19–0.37
Cr		0.13–8.40	0.12–0.20	0.04–0.23
Cu		0.08–0.30	0.02–0.78	0.03–0.12
Cd		0.02–0.45	0.02–0.08	0.01
Ni		0.42–6.11	0.01–0.02	0.09–0.47
Pb		0.05–1.6	0.02–0.08	0.01–0.14

[a] Ranges are based on Fudala-Ksiazek et al. (2014), Kulikowska and Klimiuk (2008), Renou et al. (2008), Wiszniowski et al. (2007), Alvarez-Vazquez et al. (2004), Christensen et al. (2001), and Lema et al. (1988).

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