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Sorption and diffusion of bisphenol-A (BPA) through a geosynthetic clay liner (GCL)

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ABSTRACT

Partitioning of bisphenol A (BPA) to geotextile (GTX), and geosynthetic clay liner (GCL) is investigated. BPA distribution coefficients range from 3.3 to 5.0 mL/g for the geotextile component of the GCL and 10 −16 mL/g for the entire GCL. The diffusion of BPA through the GCL is also investigated and the diffusion coefficient is estimated to be 1.5×10^{-10} m^2/s at a bulk void ratio of 4.4. The estimated parameters are used to study the potential mass transfer of BPA through a composite liner of a municipal solid waste landfill for a number of scenarios. The results show that HDPE geomembrane is an excellent diffusive barrier for BPA but the advective transfer of BPA through the composite liner needs to be limited by minimizing the number of holes and length of the wrinkles in the geomembrane.

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1. Introduction

Bisphenol A (BPA) is an organic compound used in the production of polycarbonate plastics and epoxy resins. Polycarbonate plastics have been used in beverage bottles, baby bottles, microwave ovenware, etc. and epoxy resin containing BPA have been used in lining of food cans, drink cans, etc (FAO/WHO, 2010; Nataraj and Aminabhavi, 2010). Polycarbonate plastics have also been used in the production of construction hardware, safety equipment, electrical and electronic devices, etc. BPA has been produced in large quantities world-wide (Nataraj and Aminabhavi, 2010).

BPA can leach from polycarbonate plastics under normal usage conditions and the rate increases with increasing temperature (Vandenberg et al., 2007; Yamamoto and Yasuhara, 1999; Mansilha et al., 2013). BPA can degrade by more than 90% in a few days under aerobic condition in the presence of some specific bacteria but under anaerobic conditions virtually no biodegradation was observed after a few months (Dorn et al., 1987; Kang and Kondo, 2002; Chang et al., 2011). Even though BPA can be degraded by bacteria under aerobic condition, its slow leaching from consumer products makes it a continuous source (Crain et al., 2007). BPA has been reported in fresh water, seawater, fish tissue (Vandenberg et al., 2007; Crain et al., 2007; Couderc et al., 2015), and landfill leachate (Table 1).

BPA is an endocrine disruptor and has shown estrogen like behaviour. BPA exposure during early pregnancy can affect the brain and cause behavioural problems in children (NTP-CERHR, 2008; FAO/WHO, 2010; Erler and Novak, 2010; Wolstenholme et al., 2011). At low doses, BPA has been reported to cause developmental disruption in prostate and mammary glands in rats and early puberty in female mice (NTP-CERHR, 2008; FAO/WHO, 2010). It has also been shown that BPA can affect sex differentiation, sexual behaviour, and the reproductive cycle in fish (Crain et al., 2007; Shanthanagouda et al., 2014). The Ontario Ministry of Environment set 5 μg/L as the provincial water quality objective for BPA (Government of Canada, 2008).

The release of contaminants from an engineered municipal solid waste (MSW) landfill is controlled by a barrier system below the waste. Since the regulations for landfill design were established before the identification of the potential health hazards of contaminants of emerging concern, such as BPA, the performance of the barrier systems with respect to containing these contaminants needs to be investigated. Geosynthetic clay liners (GCL) are now widely used as an alternative to compacted clay liners as a part of

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Table 1
BPA concentration in the landfill leachate.

Location	Min (ppb)	Max[a] (ppb)	Reference
Japan	1.3	17,200	Yamamoto et al. (2001)
Japan	26	8400	Urase and Miyashita (2003)
Germany	800	5800	Lyko et al. (2005)
China	13	2920	Li et al. (2006)
India, Japan, South East Asia	0.18	4300	Teuten et al. (2009)
Canada	0.2	1940	Environment Canada (personal contact, 2009)
Norway	Below DL	693	Morin et al. (2015)

[a] Rounded to 3 significant digits where more were given in the source document.

the composite liner in a modern engineered landfills (Rowe et al., 2004). There have been many recent studies related to the performance of GCLs (e.g. Acikel et al., 2015; Ashe et al., 2015; Bannour and Touze-Foltz, 2015; Brachman et al., 2015; Di Emidio et al., 2015; Fox and Stark, 2015; Hanson et al., 2015; Liu et al., 2015; Mazzieri and Di Emidio, 2015; Puma et al., 2015; Rouf et al., 2016, 2015b; Take et al., 2015a,b in 2015 alone) but relatively few previous studies have examined the diffusion through GCLs. The latter include consideration of diffusion of sodium and chloride (Lake and Rowe, 2000), some volatile organic compounds (Lake and Rowe, 2004; Rowe et al., 2005), metals (Lange et al., 2009), and some phenolic compounds (Mendes et al., 2013) through GCLs. In particular, the diffusion coefficient of BPA through a GCL after contact with a synthetic leachate has been reported in a conference paper (Mendes et al., 2014) and these results will be discussed and compared with the current study later.

The objectives of this paper are to: (1) evaluate BPA partitioning to GCL and geotextile in individual experiments, (2) experimentally estimate the BPA diffusion coefficient with respect to a GCL, and (3) use the GMB diffusive properties from a separate study (Saheli et al., 2016) and the GCL diffusion coefficients from the experiments reported herein to calculate the potential migration of BPA through a typical landfill composite liner to assess the potential for BPA to escape to the environment through a modern composite liner.

2. Diffusion theory through GCL

Considering one dimensional diffusive transport of a contaminant from the source to the receptor through a saturated GCL with linear sorption, transport is described by (Rowe et al., 2005; Lange et al., 2009):

$$n\frac{\partial c}{\partial t} = -\frac{\partial f_s(t)}{\partial z} - \rho_d K_d \frac{\partial c}{\partial t} \tag{1}$$

where c [ML^{-3}] is the concentration of the contaminant at time t, n is the GCL porosity [−], $f_s(t)$ [$ML^{-2}T^{-1}$] is the mass flux of contaminant in the GCL at time t, z is the distance from the contaminant source [L], ρ is the GCL dry density [ML^{-3}], and K_d is the distribution coefficient [$M^{-1}L^3$]. In the special case of zero Darcy flux the mass flux $f_s(t)$ is given by:

$$f_s(t) = -nD_e\frac{\partial c(t)}{\partial z} \tag{2}$$

where D_e is the effective diffusion coefficient [L^2T^{-1}], hereafter presented as D_{GCL}. Considering mass balance at any time t, the contaminant mass in the source solution, $c_s(t)$, is equal to the initial mass of contaminant in the source minus the mass diffused through the GCL up to time t. Similarly the contaminant mass in the receptor, $c_r(t)$, is equal to the initial mass in the receptor (usually zero) plus the mass that has diffused through the GCL into the receptor up to time t:

$$c_s(t) = c_{s0} - \frac{1}{h_s}\int_0^t f_s(\tau)d\tau \tag{3}$$

$$c_r(t) = c_{r0} + \frac{1}{h_r}\int_0^t f_r(\tau)d\tau \tag{4}$$

where c_{s0} is the initial concentration in the source [ML^{-3}], c_{r0} is the initial concentration in the receptor [ML^{-3}], h_s is the height of the source compartment (volume of the fluid in the source per unit area of the GCL in the diffusion test reported herein) [L], h_r is the height of the receptor compartment (volume of the fluid in the receptor per unit area of the GCL in the diffusion test) [L], $f_s(\tau)$ is the mass flux of the contaminant into the GCL at time t [$ML^{-2}T^{-1}$], and $f_r(\tau)$ is the mass flux of the contaminant into the receptor at time t [$ML^{-2}T^{-1}$].

Linear contaminant removal process due to sorption at equilibrium can be described by a distribution coefficient, K_d (Rowe et al., 2004; Lange et al., 2009):

$$K_d = \frac{c_s}{c_{aq}} \tag{5}$$

where c_s is the concentration of the contaminant in the soil [−] (mass of contaminant per mass of dry soil/geotextile) and c_{aq} is the contaminant concentration in the solution [ML^{-3}].

Distribution coefficients of BPA to GCL and its components (geotextile and bentonite clay) were obtained by performing batch tests as will be described later. Using these parameters and experimental data from a diffusion test, Equations (1)–(4) were solved using a model (POLLUTE; Rowe and Booker, 2004) and the diffusion coefficient was estimated by fitting the model to the experimental data.

3. Materials and methods

3.1. Geosynthetic clay liner (GCL)

The GCL examined in this study (Terrafix® Bentofix® SRNWL) was composed of a layer of fine granular Wyoming sodium bentonite (average dry mass/area of 4600 g/m^2, Hosney, 2014), encapsulated between a scrim-reinforced nonwoven carrier geotextile (GTX) (a woven slit-film geotextile and a nonwoven geotextile needle punched together) and a nonwoven cover GTX. GTXs were needle punched together and the needle punched fibres were thermally treated on the carrier GTX to enhance the bond between the cover GTX and the carrier GTX. The measured masses per unit area of the carrier and the cover geotextiles were ~250 g/m^2 and

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