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Characterization and treatment of organic constituents in landfill leachates that influence the UV disinfection in the publicly owned treatment works (POTWs)

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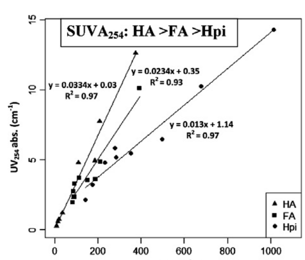
HIGHLIGHTS

- Leachates with a variety of age, location, waste acceptance and biological treatment.
- UV254 absorbance is more refractory than TOC in biological treatments.
- Fractionation into Humic acids, Fulvic acids and Hydrophilic fraction.
- Statistical analysis on the SUVA254 for the fractions shows that: HA > FA > Hpi.
- Biological treatment plus nanofiltration (1 kDa) is practical meet the UV requirement.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfill leachates strongly quench UV light. When discharged to POTWs, leachates can interfere with UV disinfection. To investigate the UV quenching problem of landfill leachates, a variety of landfill leachates with a range of conditions were collected and characterized. The UV blocking component was found to be resistant to biological degradation so they pass through wastewater treatment plants and impact the subsequent UV disinfection system. Leachate samples were fractionated into humic acids (HAs), fulvic Acids (FAs) and hydrophilic (Hpi) fractions to investigate the source of UV absorbing materials. Results show that for all leachates examined, the specific UV_{254} absorbance ($SUVA_{254}$) of the three fractions follows: HA > FA > Hpi. However, the overall UV_{254} absorbance of the Hpi fraction was important because there was more hydrophilic organic matter than humic or fulvic acids. The size distribution was also investigated to provide information about the potential for membrane treatment. It was found that the size distribution of the three fractions follows: HA > FA > Hpi. This indicates that membrane separation following biological treatment is a promising technology for removal of humic substances from landfill leachates. Leachate samples treated in this manner could meet the UV transmittance requirement of the POTWs.

1. Introduction

In 2010, about 135.5 million tons out of 249.9 million tons of municipal solid waste (MSW) generated in the USA were disposed to landfills [1]. The landfilled MSW decomposes through a

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series of biological and physical-chemical processes [2]. Soluble waste fractions and decomposition products are carried away by rainwater percolation and infiltration, generating a highly contaminated landfill leachate which threatens the surrounding surface and ground water. In modern sanitary landfills, impermeable liners and collection systems are installed to prevent the escape of leachate. It is estimated that 1 ton of landfilled MSW will produce 0.2 m^3 of leachate [2]. Hence, a large amount of collected landfill leachate must be treated before being discharged. Accordingly, governments of many countries and regions apply strict regulation for the discharge of landfill leachate.

Generally, the collected landfill leachate is either treated on-site, and then discharged directly to water bodies, discharged or transported to an off-site waste water treatment facility, or pre-treated on-site, then discharged or transported to a publicly owned treatment works (POTW) or other waste water treatment facilities. A variety of treatment technologies have been applied to landfill leachate. Among those treatment processes, biological treatment (on-site and off-site) is commonly used for the removal of bulk organic compounds, based on its reliability, simplicity and cost effectiveness [3]. Usually leachates are pretreated to avoid an impact on the downstream biological treatment process. Hence, transporting to local municipal sewer systems with appropriate pretreatment or co-treatment of leachate and wastewater in the wastewater treatment plants (WWTPs) is a favored option for landfill leachate disposal.

However, the unique characteristics of landfill leachate create some challenges for co-treatment of leachate and wastewater, such as the high concentration of ammonia [4] and low biodegradability [5]. In recent years, the presence of bio-refractory compounds in landfill leachate has gained attention [6–8]. Humic substances (humic acids and fulvic acids) are believed to be the main components that show recalcitrant properties [9]. Vegetation derivatives (paper and paperboard, yard trimmings and wood) are believed to be one of the sources of the lignin that act as the primary source for humic substances [10]. Food scraps in MSW can provide proteins, polysaccharides, lipids and nucleic acids for humification. In 2010, vegetation and its derivatives in MSW accounted for 48.3% (28.5% from paper and paperboard, 13.4% from yard trimmings and 6.4% from wood) of total MSW generation by weight [1]. Hence, landfills can provide suitable conditions for the formation of humic substances.

Over the last four decades, disinfection by-products (DBPs) produced during chlorination has been of concern [11–14] due to their carcinogenicity [12,15]. There has been a regulatory trend toward lower residual chlorine level, but with the same pathogen kill requirement, forcing WWTPs to turn to alternative disinfectants [16]. UV disinfection has become more popular for waste water treatment because it eliminates the formation of regulated DBPs, has small footprint and results in less risk for toxic/hazardous chemical leakage. Though $\lambda = 260$ nm is the most effective germicidal wavelength, in practice, WWTPs utilize $\lambda = 254$ nm instead as it is readily generated by mercury lamps [17].

Recently, it was reported that humic substances can influence the UV disinfection in surface water treatment plants by diminishing the effect of UV radiation on bacteria due to UV light absorption [18]. In practice, landfill leachates discharged to WWTPs are reported to interfere with their UV disinfection performance since landfill leachates have been found to strongly quench UV light [19]. However, there have been limited investigations into the influence of bio-refractory organic matter, such as humic acids and fulvic acids on UV disinfection.

In this study, a variety of landfill leachates were collected from 3 landfills to examine their biodegradability, physical-chemical treatability and UV quenching characteristics. UV absorbance and organic matter level in terms of total organic carbon (TOC) were examined for bulk leachates. Then, the dissolved organic matter (DOM) in each leachate sample was fractionated into humic acids (HAs), fulvic acids (FAs) and hydrophilic (Hpi) fractions. UV quenching characteristics were examined for each fraction. Thereafter, the size distribution of each fraction was characterized to provide information for membrane separation and filtration. This study provides insight into the short term biodegradation characteristics in the engineered biological treatment of different fractions of DOM in landfill leachate and their long term bio-decomposition characteristics in landfilling.

2. Materials and methods

2.1. Leachate sample locations and processes

Leachates samples investigated in this research were collected from landfills located in Pennsylvania (PA), New Hampshire (NH) and Kentucky (KY), USA. Leachates before and after the on-site biological treatment were collected from the PA and NH landfills. Details about the on-site biological treatment facilities, the technical specifications of PA and NH landfills and leachate characteristics have been described Zhao et al. [19].

The KY landfill is comprised of eight separate units, designated Units 1 through 8. Leachate samples collected for this study were from Units 3, 5, 7 and 8 (KY-3, KY-5, KY-7 and KY-8). Unit 3 is an inactive landfill unit that is not receiving waste. Unit 5 has had no input for over a decade, but was operated as a bioreactor landfill for a period of time. Unit 7 was closed in 2005 and was operated as a bioreactor landfill. Unit 8 is an active permitted landfill unit. The landfill has been used for solid waste disposal for 35 years. The average ages of Units 3, 5, 7 and 8 are 30, 16, 9 and 2.5 years, respectively. The landfill has a total property of approximately 782 acres. Characteristics of the KY leachates are shown in Table 1.

The leachate samples were shipped directly from the landfills in 20-l polyethylene buckets and stored in a refrigerator at 4 °C to reduce microbial activity. Leachate buckets were shaken well to resuspend settled particles before sampling.

Biological treatment of the KY leachates was conducted by continuous aeration in the lab. Since leachates contain microorganisms from the waste layer of the landfill, no external seed was added. Biological flocs similar to activated sludge flocs were observed during the aeration process. Each leachate was aerated using a porous ceramic air diffuser and distilled water was added to compensate the water lost by evaporation. KY-8 and KY-7 leachate samples were aerated for 53 days and aerated leachates were sampled on the 21st, 38th and 53rd days for fractionation and analysis. KY-5 and KY-3 leachate samples were aerated for 21 days, then sampled for fractionation and analysis.

2.2. Fractionation

Landfill leachate samples were fractionated into HAs, FAs and Hpi fractions based on their hydrophobic nature and solubility characteristics. Methods developed by Thurman and Malcolm [20], Leenheer [21] and Christensen et al. [22] were used in this study since they have long been a standard method for the isolation and separation of humic substances from aquatic samples. This method uses chemical precipitation to remove humic acids followed by the XAD resin to sorb fulvic acids. The remaining organic matter is considered to be the hydrophilic fraction.

The XAD-8 resin (currently Supelite DAX-8 resin, Sigma–Aldrich, St. Louis, MO) was cleaned following the method described by Leenheer [21]. Approximately 3.5–4.5 mL bed volume of cleaned XAD-8 resin slurry was packed in a borosilicate glass column (1.0 cm × 10 cm, Thomas Scientific, Swedesboro, NJ).