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REVIEW ARTICLE

Characterization and bioreactivity of respirable airborne particles from a municipal landfill

Lata Koshy[1], Timothy Jones[2], and Kelly BéruBé[1]

[1]School of Biosciences, Cardiff University, Museum Avenue, Cardiff, UK, and [2]School of Earth and Ocean Sciences, Cardiff University, Park Place, Cardiff, UK

Abstract

With an increasing population and greater pressure on land-use, the possible problems of landfilling are of increasing concern. These concerns include the possible adverse health effects arising from living in the vicinity of municipal solid waste (MSW) landfills. Human exposure to potential landfill emissions by respiratory, gastrointestinal or dermal mechanisms warrants further investigation. PM_{10} and $PM_{2.5}$ from a UK landfill were physicochemically characterized and their bioreactivity screened by a plasmid scission assay in comparison with an urban PM collection. Preliminary data from human toxicology pathway-specific microarrays indicate landfill PM_{10} presents a comparable geobiological insult to urban PM_{10} in a human tracheobronchial tissue model.

Keywords: *Landfill; PM_{10}; toxicity; bioreactivity; plasmid scission assay*

Introduction

A recent study by Elliot et al. (2001) estimated that 80% of the UK population reside within 1.5 miles of a working or closed landfill site. The major municipal solid waste (MSW) landfill emissions from an operating site are particulate matter, leachate and landfill gas. Although there are many sources of literature available on landfill leachate and gas characterization, this mini-review will focus on the less reported field of ambient airborne particles related to landfills. Particulate matter (PM) with aerodynamic diameters of less than 10 or 2.5 μm (PM_{10} and $PM_{2.5}$) is recognized as an important cause of adverse human health (Englert 2004, Kappos et al. 2004, Brunekreef & Forsberg 2005). There is a current paucity of information on landfill PM, meaning conclusions about landfill PM require further research (Defra 2004).

Landfill dust is generated by a variety of mechanical and chemical processes. These include: the movement of heavy dustcarts and site vehicles over dry unpaved access roads and previously deposited waste; diesel exhaust fumes and brake emissions from on-site vehicles; action of tipping waste at the working face raises plumes of dust, notably on elevated ground, which are exposed to windy conditions; waste compaction by bulldozers and crushers; and stockpiles of bare earth required for daily waste coverage are susceptible to resuspension and dispersion by wind (Fitz & Bumiller 2000). Arid and windy conditions may lead to higher levels of entrained PM in the local atmosphere. Human exposure can occur via respiratory, dermal and ingestion pathways, and is sensitive to meteorological conditions. Vega et al. (2001) performed resuspension of surface dust from a Mexico City landfill, obtaining PM_{10} and $PM_{2.5}$ fractions for physicochemical analyses. Interestingly, their gravimetric analysis revealed a similar mass distribution to that of the UK landfill. However, their chemical analysis revealed a significantly different metal profile, with Al being the most significant metal component, whilst Fe was the most significant metal present in the UK landfill presented in this review.

In a literature-based modelling study, Macleod et al. (2006) estimated the amounts of airborne incinerator residual ash, which could be potentially released as particulates from landfills. Although these sites were not specific MSW sites in the UK, which no longer accept

Address for Correspondence: Lata Koshy, School of Biosciences, Cardiff University, Museum Avenue, Cardiff CF10 3AX, UK.

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such controlled wastes, their assessment positively identified the atmospheric dispersion of dusts as the main pathway for human exposure. The main route of exposure to landfill PM is by inhalation and possibly to a lesser extent, by ingestion. The re-dispersion of accumulated dust on clothing can increase personal exposure to PM; however this is more likely within the landfill workforce rather than public exposure (Poulsen et al. 1995).

It is important to find sensitive biological indicators of the potential harm that these emissions may cause following human exposure. Linking toxicological analysis to the geochemical data should help to determine accurately the degree of toxicity of environmental emissions produced by landfills. This study aims to determine the levels of respirable landfill particulates released from a UK MSW landfill, and to identify the acellular bioreactivity of these pollutants. We also present our preliminary data of transcriptional changes in a human epithelial tracheobronchial model upon exposure to landfill PM_{10}, and compare these observed effects to urban PM_{10} exposure.

Physicochemistry

Sample collection

The study site is a municipal solid waste landfill, located within a major UK city. Sampling at an urban location approximately 2.5 miles from the landfill was also undertaken. Two collecting systems were utilized in this study during October 2007. A Negretti selective-inlet system was used to collect PM_{10} on polycarbonate filters for characterization. The system operates at a flow-rate of 30 l min^{-1}, drawing air along a set of defined horizontal plates, through to the polycarbonate filter. Pre-calibrated settings prevent PM with a mean aerodynamic diameter of greater than 10 μm, from progressing through the elutriator (Greenwell et al. 2002). A Harvard high-volume collector, configured to collect particulates of 10–2.5 μm and 2.5–0.1 μm, was used to accumulate PM_{10} onto polyurethane foam substrates for bioreactivity assays (Jones et al. 2006).

PM characterization

Gravimetric and scanning electron microscopy (Moreno et al. 2004) analyses of landfill and urban PM revealed a similar size distribution of PM_{10} at these two locations; however, it also revealed significantly increased PM_{10} generation at the landfill compared with the urban city location, i.e. 42 and 13 μg m^{-3}, respectively. Airborne dust emissions are predominantly episodic, and highly dependent upon site operations and ambient conditions. This also means that extrapolation of gravimetric measurements to the long-term air quality indicators may not be the most appropriate use of this data (Macleod et al. 2006). Both sites generated PM_{10} with the vast majority of particles distributed within 2.5–0.1 μm aerodynamic

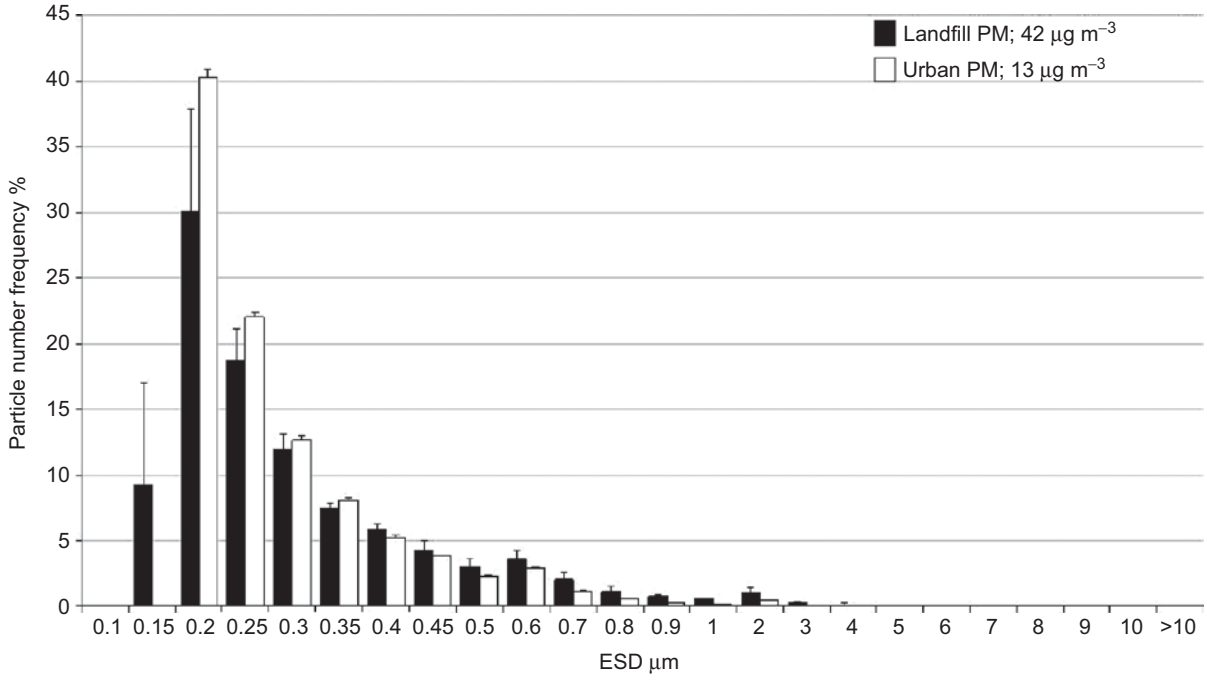

Figure 1. Skewed size distribution of PM_{10} collected from a municipal solid waste landfill and a nearby urban location, both located in the UK. The results indicate the vast majority of PM from both locations are respirable. Note the small fraction of PM 0.1-0.15 μm in the landfill collection. The landfill PM mass concentration was much higher than the urban location.

diameter (Figure 1). The dominant PM types were identified as either mineral or soot, with the dominant PM at the landfill site being mineral (98% particle number), whilst the urban PM_{10} sample comprised mostly, of anthropogenic soot PM (95% particle number).

Metal analysis

The $PM_{10\text{-}2.5}$ and $PM_{2.5\text{-}0.1}$ from both study sites were microwave acid-digested and analysed for total trace metals by ICP-MS (Moreno et al. 2004). The elements of toxicological concern, Fe, Zn, Ni and Pb, were prevalent in all samples. Both PM fractions, $PM_{10\text{-}2.5}$ and $PM_{2.5\text{-}0.1}$, collected at the landfill contained higher overall levels of metals than the corresponding urban samples (Figure 2A, B). Landfill $PM_{10\text{-}2.5}$ was found to be significantly Fe-rich compared with the accompanying landfill $PM_{2.5\text{-}0.1}$ fraction, or the urban PM_{10} fractions (SPSS 15.0 statistics package; one-way ANOVA, $p < 0.01$). The landfill $PM_{2.5\text{-}0.1}$ fraction contained significantly higher levels of Zn and Pb than the other samples ($p < 0.01$).

Bioreactivity

Plasmid scission sssay

Particulates were screened by the plasmid scission assay (PSA), as an *in vitro* measurement of oxidant PM-bioreactivity upon DNA (Donaldson et al. 1997). Aliquots (200 ng) of Φ X174 RF plasmid DNA were exposed to PM_{10}, $PM_{10\text{-}2.5}$ and $PM_{2.5\text{-}0.1}$. The PM_{10} sample was derived from proportional masses of $PM_{10\text{-}2.5}$ and $PM_{2.5\text{-}0.1}$. Exposure of the supercoiled DNA to damaging, oxidative PM caused a conformational change in the tertiary structure of the plasmid, to the relaxed and/or linear forms. This resultant damage was detected by gel electrophoresis and semiquantified as a proportion of the total DNA present (Koshy et al. 2007).

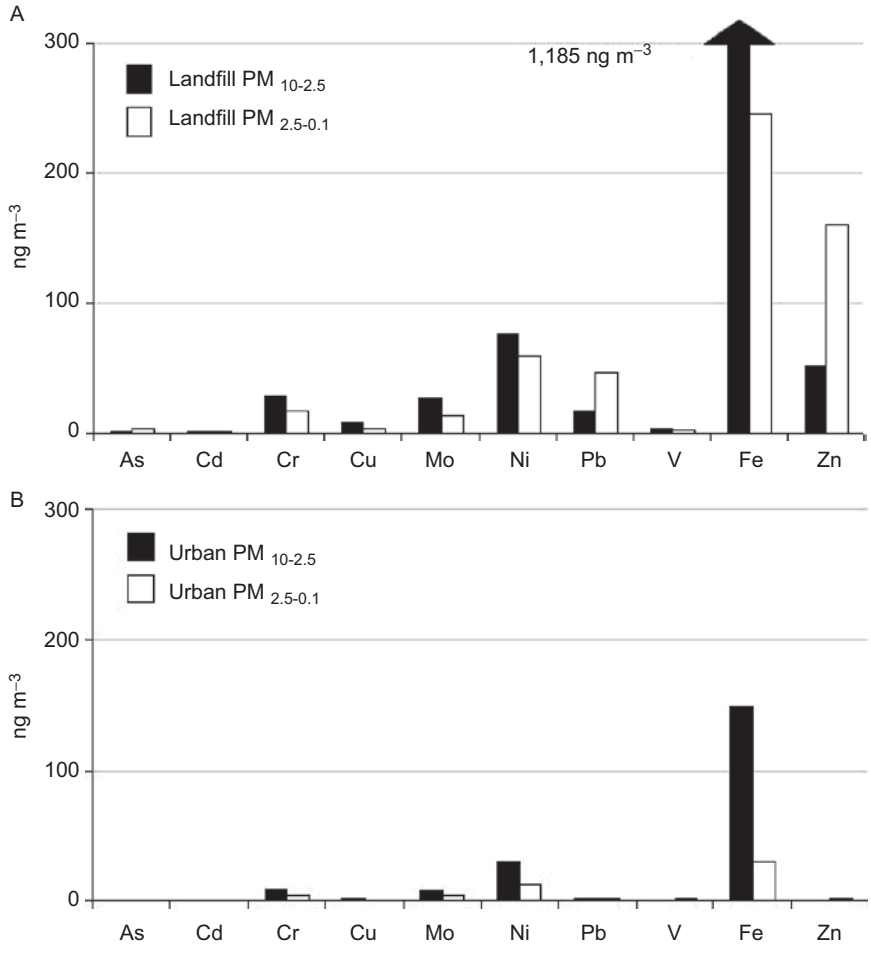

Figure 2. (A) Landfill PM; (B) urban PM. The results show that Fe is the most abundant metal in landfill and urban PM. and in the case of the landfill $PM_{10\text{-}2.5}$ fraction, this was highly significant. The other dominant metals in both size fractions of landfill PM were Zn and Pb. The urban PM contained lower metal concentrations in both fractions compared with their respective landfill samples. However, as in the landfill collection, Fe was also the most abundant metal in the urban collection.

Data were compared for statistical significance between PM sizes intrasite, and between corresponding PM sizes of the two different sites (SPSS 15.0 statistics package; two-way ANOVA and least significant difference *post-hoc* testing). The $PM_{2.5\text{-}0.1}$ fractions at both the landfill (Figure 3A) and urban sites (Figure 3B) were found to be significantly more reactive than their corresponding $PM_{10\text{-}2.5}$ or PM_{10} fractions ($p<0.01$). This finding is in agreement with other studies which report smaller sizes of PM as being more reactive (Risom et al. 2005, Diociaiuti et al. 2001). Landfill $PM_{2.5\text{-}0.1}$ exhibited a much higher oxidative capacity than the urban $PM_{2.5\text{-}0.1}$ ($p<0.05$), with the former causing 50% damage (TD_{50}) at 28 μg ml^{-1}, whilst urban $PM_{2.5\text{-}0.1}$ elicited the same level of damage at 185 μg ml^{-1}. The landfill $PM_{2.5\text{-}0.1}$ fraction was the dominant contributor to bioreactivity in the landfill PM collection. It was noted that there was no significant difference between the landfill PM_{10} and $PM_{10\text{-}2.5}$ fractions. The trend of bioreactivity of the landfill samples was in the order of $PM_{2.5\text{-}0.1} > PM_{10} = PM_{10\text{-}2.5}$.

In contrast, a positive dose–response was observed with all fractions from the urban site, in which the extent of bioreactivity was significantly dependent upon the size fraction. The trend of bioreactivity of the urban site was in the order of $PM_{2.5\text{-}0.1} > PM_{10} > PM_{10\text{-}2.5}$. All the urban size fractions, excluding $PM_{10\text{-}2.5}$, exhibited significantly higher oxidative capacity when compared with their counterparts in the landfill collection ($p<0.05$). Overall, the landfill PM_{10} bioreactivity was dominated by the less reactive $PM_{10\text{-}2.5}$ fraction, whilst the urban PM_{10} bioreactivity was dominated by the more reactive $PM_{2.5\text{-}0.1}$ fraction.

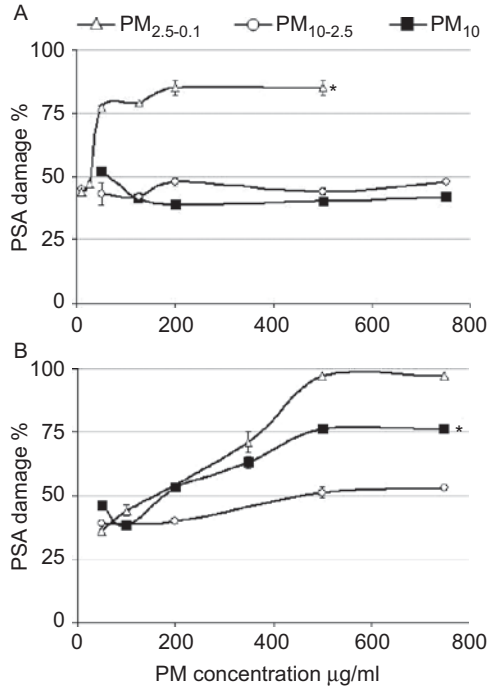

Figure 3. (A) Landfill PM; (B) urban PM. Plasmid scission assay of the different PM fractions collected at the landfill and urban locations. Data are expressed as mean ± SD ($n=3$). *Statistical significance between corresponding size fractions from the two study sites ($p<0.05$). The $PM_{2.5\text{-}.01}$ samples from both locations were the most bioreactive, with the landfill collection exhibiting the greatest oxidative capacity.

Exposure of landfill PM to human tracheobronchial epithelial cells in vitro

The commercially available EpiAirway-100 3-D model (MatTek Corp., Ashland, MA, USA) was exposed to $PM_{10\text{-}2.5}$, $PM_{2.5\text{-}0.1}$ and PM_{10} from the landfill, and the PM_{10} fraction from the urban collection (500 μg ml^{-1}; 24 h). Conventional toxicology and genomics were performed. The MTT assay was used to determine cell viability (mitochondrial activity), whilst the transepithelial electrical resistance (TEER) measurements for structural integrity were taken pre- and post-exposure. Genomic analysis of the exposed tissue was performed according to the GEArray Human Toxicology and Drug Resistance microarray protocol (SABiosciences, Frederick, MD, USA). Gene expression was determined by Significance Analysis

Table 1. Distribution of upregulated genes, grouped into gene families by percentage (landfill $PM_{10}=66$ genes; urban $PM_{10}=57$ genes).

Gene family	Examples of genes expressed in EpiAirway-100(≥ 1.5 fold, $p<0.05$)	Landfill PM_{10}	Urban PM_{10}
Drug metabolism	N-Acetyl transferase 2, glutathione peroxidase 1, peroxiredoxins 1and 2, glutathione S-transferase, cytochrome P450 11B2	29	28
Transcription factors and regulators	Retinoic acid receptor α, MYST histone acetyltransferase, NFKB1, v-rel reticuloendotheliosis viral oncogene homolog B	15	14
Stress response	Superoxide dismutases 1 and 2, NADPH dehydrogenase 1, paraxonase 3, nudix type 1, DNA damage-inducible transcript 3	11	9
Cell growth, proliferation and differentiation	Cyclin-dependent kinases, V-erb-b2 erythroblastic leukaemia viral homolog, macrophage migration inhibitory factor	12	7
Chaperones and heat shock proteins	Chaperonins, heat shock proteins and transcription factors, suppression of tumorigenicity 13, crystallin αA	27	28
Apoptosis	BCL-like 2, tumour necrosis factor receptor superfamily 1A, E2F transcription factor, NF-κB inhibitor α	5	5
Cell cycle	Breast cancer 2, cyclin-dependent kinases 2 and 4, DNA-damage-inducible transcript 3	2	9

of Microarrays software (Stanford University), in which changes of greater than 1.5-fold ($p < 0.05$) were considered to be relevant. There were no significant adverse effects detected by TEER measurements, or by the MTT viability assay upon exposure to any of the three landfill PM fractions, or from the urban PM_{10}. However, preliminary microarray data of the landfill and urban PM_{10} indicated a significant trend of upregulation in several transcription factors and drug metabolism enzymes (Table 1).

Conclusions

PM_{10} collected at a municipal UK landfill displayed a highly skewed size distribution, with the majority of particles residing in the $PM_{2.5\text{-}0.1}$ fraction, as amorphous particulates. The study here also demonstrated that acellular ROS-induced bioreactivity of the landfill $PM_{2.5\text{-}0.1}$ fraction was shown to be significantly higher than a corresponding urban $PM_{2.5\text{-}0.1}$ sample. To our knowledge, no other publications target MSW landfill PM_{10} toxicity, and this preliminary data should be reported.

Acknowledgments

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