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# Emission of bacterial bioaerosols from a composting facility in Maharashtra, India

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ABSTRACT

This study was undertaken to quantify and characterize size-segregated bacterial bioaerosols both on-site and off-site of a waste treatment facility (WTF) in Maharashtra employing windrow composting. Viable bacterial bioaerosols on nutrient agar (NA) and actinomycetes isolation agar (AIA) were quantified after sampling using Anderson-six stage impactor. Viable bacterial bioaerosols were identified based on 16S rDNA sequencing. Approximately, 16–34% of the total viable bacteria collected at the WTF were in the size range 0.65–2.1 μm that can penetrate deep into the respiratory tract and also represents bacteria present in free form. Thus, 66–84% of bacterial bioaerosols were associated with coarse airborne particles greater than 2.1 μm. A total of 24 bacterial species were isolated and characterized through gram staining. Among these 25% were gram negative and 75% were gram positive. The predominant bacterial genera were *Bacillus*, *Streptococcus*, *Staphylococcus*, *Acinetobacter* and *Kocuria*. The mean on-site concentration of total viable bacteria on NA and AIA and airborne particles ($PM_{2.5}$ and $PM_{10}$) were higher than the corresponding off-site values. The mean on-site concentration of viable bacteria on NA and AIA were in the range of $3.8 \times 10^3$ to $5.4 \times 10^4$ CFU/m$^3$ and $9.8 \times 10^3$ to $1.2 \times 10^5$ CFU/m$^3$, respectively, during activity period. Good correlation ($R^2 = 0.999$) was observed between total bioaerosols and aerosols ($PM_{10}$) collected using Anderson impactor and High volume sampler, respectively. Sampling size segregated aerosols using the Siotus personal cascade impactor indicated higher association of bacteria with the coarse fraction (greater than 2.5 μm).



## 1. Introduction

In India, more than $1.27 \times 10^3$ ton of municipal solid waste (MSW) is generated every day in urban areas, although only a small fraction of it (~12.5%) is processed and treated daily (CPHEEO, 2014). Although composting is considered as a sustainable waste management option, possible release of infectious bioaerosols during composting may pose a health risk for plant workers and residents living in the vicinity of compost plants. In India composting is used widely with greater than 70 cities employing either vermicomposting or windrow composting (Annepu, 2012). Most of these composting facilities are designed to handle between 100 and 1000 tonnes/day of MSW. The biodegradable fraction of solid waste that is used for composting is a potential source of airborne pathogenic/non-pathogenic microorganisms including thermophilic and thermotolerant microorganisms (Goff et al., 2012; Grisoli et al., 2009; Hryhorczuk et al., 2001; Pankhurst et al., 2012). However, in India no studies have been performed on release and health effect of bioaerosols from composting plants. Bioaerosol consists of pollen, microorganisms (bacteria, fungi, viruses) and organic compounds of microbial/plant origin, such as, endotoxin, mycotoxins, metabolites and other microbial fragments (Mandal and Brandl, 2011). Bioaerosols may contribute ~24% of the count of total airborne particles and 5–10% of the total mass of suspended particulate matter (Adhikari et al., 2006). Although bacterial bioaerosols constitute only a fraction of bioaerosols, they potentially pose a high health risk. Inhalable airborne particles of size less than 2.5 μm ($PM_{2.5}$) is of primary importance because of their harmful effects on the respiratory system (Vestlund et al., 2014). Exposure to bioaerosols may also occur through ingestion and dermal contact and the adverse health effects may include allergenicity, toxicity and pathogenicity (Nasir et al., 2012). Several diseases have been linked with exposure to bioaerosols in different parts of the world including, Q fever, Legionnaire's diseases or pontiac fever, asthma, allergic rhinitis, bronchitis, atopical conjunctivitis, and organic dust toxic syndrome (Mehdinejad et al., 2011; Strum, 2012). Occurence of gastrointestinal symptoms, fever, respiratory symptoms, skin disorders, eye irritation, headache, fatigue, pneumonia, asthma,

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bronchitis, rhinitis, respiratory discomfort and rash on face and scalp have been widely reported among waste management workers (Epstein et al., 2001; Grisoli et al., 2009).

Bioaerosols that are generated from composting plants are reported to contain a high abundance of microorganisms which includes bacteria, fungi, protozoa and viruses (Byeon et al., 2008; Pankhurst et al., 2012; Strum, 2012; Taha et al., 2007a). The concentrations are found to be highest in the vicinity of composting plant and decrease with distance downwind depending on meteorological factors (Jones and Harrison, 2004; Pankhurst et al., 2011). Hryhorczuk et al. (2001) reported the concentration of bacteria and actinomycetes in the range $1.6 \times 10^2$ to $1.7 \times 10^4$ CFU/m$^3$ and 0 to $1.2 \times 10^3$ CFU/m$^3$, respectively, within a distance of 1–10 m from a compost pile. Fungal concentration in various zones of a composting facility in Italy was in the range $6.2 \times 10^3$ to $2 \times 10^4$ CFU/m$^3$ (Cimmuto et al., 2010). Folmsbee and Strevett (1999) measured the 95% confidence interval of total viable bacteria, gram-negative bacteria, fungi, and actinomycetes in the range of $5 \times 10^4$ to $9.6 \times 10^4$ CFU/m$^3$, $2.6 \times 10^4$ to $6.8 \times 10^4$ CFU/m$^3$, $9.6 \times 10^2$ to $1.9 \times 10^2$ CFU/m$^3$, and $1.8 \times 10^3$ to $4.2 \times 10^3$ CFU/m$^3$, respectively, at a outdoor composting facility in Oklahoma, USA. The concentrations of bioaerosols, such as, *Aspergillus fumigatus* and *actinomycetes*, have been reported to increase by 3-log units during activities such as active turning of windrows (Taha et al., 2006).

This study was conducted to characterize and determine the concentration of size segregated bacterial bioaerosols in the vicinity of a composting plant at a 500 ton/day waste treatment facility (WTF) near Mumbai (Maharashtra, India), primarily receiving vegetable market waste and MSW. The biodegradable components were separated and subjected to windrow composting in the outdoor facility. Bacterial bioaerosols were characterized and quantified at various locations within the facility and at various times of the day. The main objective was to determine the concentration of bioaerosols at the various activity centres in the WTF where the workers may be exposed and at potential receptors where the general public may be exposed. Hence, monitoring was done inside the facility, on the boundary of the facility and in a nearby slum area having high population density. Since there were no other major sources of bioaerosol near the slum area, it was felt that the bioaerosol concentration in this area would be primarily impacted by the WTF. An attempt was also made to correlate bacterial bioaerosols and airborne particulate matter. Size Segregated aerosols were collected using an Anderson-six stage impactor for determination of the size fractions that can penetrate up to the tracheobronchial region of the human respiratory tract.

## 2. Material and methods

### 2.1. Operations at WTF

Typical composition of MSW entering the WTF was as follows: organic matter (68.15%); plastic (13.4%), rubber (0.45%), cloth (2.83%), wood (2.28%), paper (3.39%), glass (3.79%), metal (0.28%) and sand/stone (5.43%) (Personal communications). Processes at the 500 tonnes/day WTF (190 m $\times$ 130 m) included weighing the MSW in a weigh bridge and segregation of recyclable and non-recyclable fractions in automated trommels having sieve size of 100 mm in the waste receiving and pre-sorting (WRP) section; treatment of the organic fraction by windrow composting in the compost windrow (CW) section; drying of the compost by spreading it out on a concrete floor followed by refinement and bagging in the compost refinement and bagging (CRB) section. In the CW section, the waste was kept for a week without turning. Subsequently, the waste was turned and shifted to another row, nutrients were sprayed and turning of windrows was performed twice a week to maintain aerobic conditions for facilitating biodegradation. After four weeks in the CW section the compost was transported to the CRB section for preparation of manure. Over time the temperature in the windrow was found to increase, and the maximum temperature observed was 70 °C. The temperature of the final compost was in the range of 35–40 °C. The location where sampling was conducted in the CW section had multiple compost windrows of varying age in its vicinity. In the CRB section, a series of automated trommels (with sieve size, 35 mm, 14 mm and 4 mm) were employed for size segregation before bagging of the compost for use as fertilizer. Windrow composting was done in an open space (60 m $\times$ 50 m) while all subsequent processing steps were carried out within a single partially open shed. The WTF was surrounded by mining and industrial area on the east, slum habitat on the west and a sanitary landfill on the north and south as shown in Fig. 1. The meteorological data collected from the online meteorological monitoring station at the WTF over the sampling period (Dec 2014 to March 2015) is shown in Table S1 (electronic supplementary information, ESI). The temperature ranged from 22.9 to 35.5 °C and the atmospheric pressure showed negligible variation (1009–1016 hPa). Relative humidity was in the range of 23.9–82% and solar radiation was in the range of 73.1–313.8 (W/m$^2$). There was no precipitation event on the days in which sampling was conducted. The wind rose diagram prepared on the basis of data collected from the online meteorological monitoring station at the WTF shows that the prominent wind directions were from N-S and NE-SW during Dec 2014 to March 2015 with an average wind speed range from 0.14 to 3 m/s (Fig. S1, ESI). Sometimes E-W and other directions mostly in the first quadrant were also observed. The high variation in wind speed and wind direction observed is likely to cause high variation in off-site bioaerosol concentration.

### 2.2. Bacterial bioaerosol sampling, characterization and quantification

Sampling was conducted over the period December 2014 to March 2015, i.e., in the winter season. In India, typically the concentration of air pollutants (e.g., $SO_x$, $NO_x$, CO, aerosols and secondary organic aerosols) is higher in winter compared to summer (April–May) (Fu et al., 2016; Gaur et al., 2014; NEERI, 2004–2013), while the concentration of air pollutants is lowest in the monsoon season (Kumar et al., 2016). Bioaerosol concentration may be expected to follow the same trend such that the concentrations reported are indicative of a worst case scenario. On-site, bacterial bioaerosol sampling at various locations within the WTF was conducted at three different times of the day, i.e., 11:30–12:30 pm, 1:00–2:00 pm (no activity) and 3:00–4:00 pm based on the schedule of activities at the facility. During 10:30 am to 12:30 pm most of the activity was carried out in the WPR section, while during 2:00–5:00 pm most of the activity happened at the CW and CRB sections. The 1:00–2:00 pm lunch break was a low activity period in all sections of the WTF. Off-site sampling was conducted between 3:00 and 4:00 pm at distances of ~200 m, 120 m and 190 m on the east, northwest and southeast side from the centre of the composting plant. Moreover, sampling (between 1:00–2:00 pm and 2:00–3:00 pm) was also performed inside the slum area on the west side (at a distance of approximately 150–200 m from the centre of the WTF) and near the online monitoring station of WTF on the southeast side (at a distance of approximately 300 m from the centre of the WTF) to determine the level of exposure to bacterial bioaerosol caused by the WTF.

Bacterial bioaerosol sampling was conducted using the Anderson-six stage impactor (MC#1060056 Anderson Impactor, Thermo scientific, USA) which was controlled by a rotameter (R50A, Scientific Devices, Mumbai, India) through a valve and vac-

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