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Capture of bacterial bioaerosol with a wet electrostatic scrubber

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ABSTRACT

This paper investigates the use of wet electrostatic scrubbing as a way to remove bacterial bioaerosol from air. This process is based on the electrical interactions between naturally or artificially charged bacteria and charged droplets. Two configurations were explored: CDES (Charged Droplet Electrified Scrubber) and OPES (Opposite Polarity Electrified Scrubber). Tests were performed with *Staphylococcus epidermidis*, a common bacterium of human skin flora.

The process successfully remove the bioaerosol. When operated as a CDES, the removal efficiency is > 90% by operating with a liquid-to-gas ratio of 2.4 L m_{gas}^{-3}. The OPES efficiency is > 99% when the liquid-to-gas ratio is > 0.8 L m_{gas}^{-3}.

1. Introduction

The exposure risk correlated to anthropogenic and natural aerosols has been expanding in the last thirty years due to the increased fraction of world population living in densely inhabited areas. A range of pathologies, from the mildest to the most acute arise from the exposure to both toxic mineral or carbonaceous aerosols generated by industrial processes and transportation (e.g. Refs. [1–12]) as well as to infectious bioaerosols, as bacteria and viruses (e.g. Refs. [13–22]). Specific constraints can be imposed to aerosols emissions by introducing regulations to limit quantities and concentrations at the points of emission of industrial plants, power plants, engines or domestic utilities. On the contrary, apart from excluding some specific cases (e.g. some wastewater treatment plants, biogas plants, fermentation plant etc.), the sources of bioaerosols are in vast open spaces and their control is not feasible. Indeed, the only way to reduce the exposure of bioaerosol for population is filtering the air intake entering indoor environments (buildings or vehicles) or using individual protection devices in open spaces.

Three types of filters are mostly adopted: fabric filters (e.g. the HEPA, ULPA ones), packed beds and electrostatic devices. Woven or non-woven filtering media are largely adopted because of their capacity to retain high fractions (> 99%) of the aerosols and to treat high gas flow rates. Usually, the filtration velocity of a HEPA unit is within 1.2–2.5 m s^{-1}, which allows treating up to 9000 $Nm^3 \cdot h^{-1}$ for each square meter of the filter. Electrostatic systems handle similar gas velocities, while packed beds of granular materials (e.g. activated carbon) operate at velocity smaller than 1 m s^{-1} (e.g. Ref. [23]), corresponding to 4000 $m_{gas}^3\ m_{filter}^{-2} \cdot h^{-1}$.

In spite of their high removal efficiency, fabric filters and packed beds have the drawback of becoming incubation points for bacteria and viruses. Therefore, the removal efficiency measured in terms of bioaerosol filtration is not an accurate evaluation of the actual inactivation efficiency. In this sense, electrostatic systems, eventually aided with UV or plasma, may assure better performances since the processes include destruction of the cellular membranes [21,24–26].

In recent years, an innovative particle removal device, named Wet Electrostatic Scrubber (WES) was proved to be a viable solution to remove submicron and ultrafine aerosols of several sources [27–33]. Wet electrostatic scrubbers remove aerosols due to the effects of electromagnetic forces between particles, either charged or uncharged, and electrified droplets, purposely sprayed in a contact chamber. The highest efficiencies usually occur with particles and droplets charged with opposite polarities and operating the scrubber with a ratio of water and gas flow rates high enough to guarantee that the average distance between charged droplets is lower than a characteristic range of interaction of the electric field. If a reliable liquid-solid filtration unit is included downstream the WES, the liquid can be recirculated many times before being discharged. WES systems have the advantage of being effective in assuring more than 90% removal efficiency with charging potential far lower than that applied to conventional electrostatic precipitators, with as much as 1 L of water per Nm^3 of gas and

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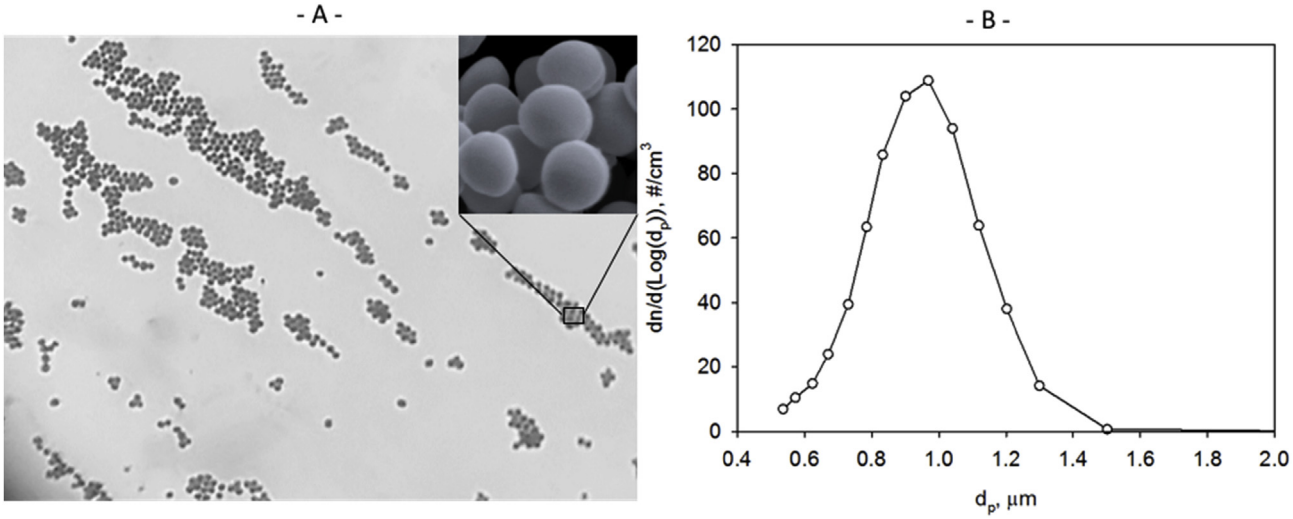

Fig. 1. A. Grape-like cluster of Staphylococcus epidermidis with Gram staining. Observation with Leica DM. E optical microscope with 100X oil Magnification. B. Cell size distribution [24].

with a pressure drop of less than 2 mbar (2 10^2 Pa) [28,31–33]. The typical gas velocity in a WES unit is around 1 m s^{-1}, similar to packed beds [31,32,34]. Besides, WES units have the advantage of providing an effective and simultaneous removal of acid gases, as SO_2 [34,35].

An electrified scrubber is mainly composed of two devices: a vessel equipped with an electrified spray (ES) and, optionally, a corona charging unit (PCU), adopted to charge the particles with polarity opposite to that of the sprayed droplets. When the PCU is switched off, the WES is operated as a CDES (Charged Droplets Electrified Scrubber); when the PCU is in switched on, the WES is operated as an OPES (Opposite Polarities Electrified Scrubber) [32,36]. The higher intensity of electric forces in OPESs make them more efficient than CDES systems, but this last can be a valuable option when the aerosol has a sufficiently high natural charge. This is the case of many bacterial bioaerosols, which may carry more charges than mineral particles of the same size [37–42].

In light of these features, we think that WES may be a viable option for bioaerosol removal but, at the best of our knowledge, it has not been considered for this application until now. Indeed, the use of a liquid to collect the bioaerosol opens a set of possibilities. On the one hand, the WES can be operated to remove and inactivate the bioaerosol by using a water based solution containing a biocide, as sodium hypochlorite. On the other hand, the WES can be operated to sample bioaerosols for analytical reasons, by using simple water or a water based solution acting as culture media for specific bacteria.

In this paper, we report experimental results on a lab-scale WES unit used to remove a model bacterial bioaerosol from a gas stream. For this purpose, it was used *Staphylococcus epidermidis*, a member of coagulase negative staphylococci group, belonging to the commensal skin flora of every human individual [43]. The electrified spray in this paper was produced by electrospray, an atomization technique in which an electric filed is generated between a metallic nozzle and a counter-electrode that is commonly either a ring or a plate. The electric filed can be imposed by connecting the nozzle to a high voltage generator, while the counter-electrode is grounded or vice-versa.

The electric field leads to additional mechanical stresses on the liquid jet that modify the atomization process. For a given geometry, the electrospray is able to generate a spray of controlled droplet mean diameter, droplet generation frequency and droplet charge, by controlling the high voltage potential and the liquid flow rate. Different spraying modes appear by varying the applied electric field and the liquid flow rate [44–46]. Bioaerosol charging required to operate the unit as an OPES was carried out by corona discharge.

Experiments were performed to investigate the performances of the WES in removing *S. epidermidis* by operating the unit either as an OPES and a CDES. Different values of liquid flow rate and electric potential applied to charge the bioaerosol and the droplets have been investigated.

2. Materials and methods

2.1. Bacterial strain, preparation and analytical techniques

In the present study, experiments were performed using *Staphylococcus epidermidis* clinical strain isolated from dental plaque. The identification of clinical isolate was performed by mass spectrometry using the Matrix Assisted Laser Desorption/Ionization (MALDI) mass spectrometer (Bruker Daltonics, MALDI Biotyper, Fremont, CA, USA), a high-throughput proteomic technique for identification of a variety of bacterial and fungal species [47,48]. This microorganism is a harmless commensal of the human organism and it is commonly found in both indoor and outdoor environments; its handling is not dangerous to human health and does not require special personal protective measures. *S. epidermidis* is a gram-positive bacterium with spheroidal shape with a size lying between 0.5 and 1.5 µm and a mean diameter close to 0.8–0.9 µm [24,49–52]. *S. epidermidis* is usually arranged in grape-like clusters (Fig. 1A).

Before each experiment, *S. epidermidis* was cultured on Brain Heart Infusion Agar (BHI-Infusion Agar, OXOID) at 37 °C for 16–18 h. The bacterial suspension used in the experiments was prepared by suspending the bacterial colonies in 50 mL of deionized sterile water (pH 4.73; electric conductivity 0.75 S m^{-1}) until the OD_{600nm} reached 2.5. To evaluate viable bacterial counts at time 0 and at every stage of assay, serial dilutions were plated on BHI-Infusion Agar and incubated at 37 °C for 24 h. After growth, cell viable counts were determined by the CFU method.

For the determination of viable bacterial count at each sampling time, cellulose ester filters (Millipore) were used. The filters were soaked in 1ml of 1X phosphate-buffered saline (PBS, containing 140 mM NaCl, 2.7 mM KCl, 10 mM Na_2HPO_4, 18 mM KH_2PO_4, pH 7.4) in a centrifugal tube. Vortexing was performed for 2–3 min with a vortex touch mixer (Heidolph REAX 2000) to evaluate viable bacterial count CFU method was carried out.

The bacterial count was also evaluated in the WES washwater. The cells were collected by centrifugation at 2200 rpm for 10 min (Multifuge 1 S-R, Heraeus) and were suspended in 1ml of BHI-Infusion