Experimental Study of Electric Field Assisted Bioaerosol Collector

Seungkyung Park, Seungmo Kim, Dongho Shin, Geum-Su Yeom

Abstract**:** ***Analysis of airborne biological particles essentially requires an efficient sample collection method. In this paper, we have designed and tested a small scale bioaerosol collector based on cyclone and external electric field. The efficiency of the system was evaluated by model particles, potassium chloride. Several parameters including cyclone geometry, flow rate, and applied voltage have been experimentally tested and the effects on the collection efficiency were studied. As a result, the presented bioaerosol collector showed a collection efficiency of approximately 65% for 0.3 μm sized particles at the flow rate of 400 lpm and 25 kV voltage. Demonstrating the potential for high efficiency bioaerosol collector.***

Index Terms**:** ***Bio-Aerosol, Electrokinetic, Cyclone, Filtration.***

I. INTRODUCTION

As the importance of air quality control has been emphasized, the analysis of biological risks from airborne particles is also in great demand. Analysis of aerosols typically requires well maintained biological and chemical analytic procedure and facilities. While a number of standard processes are developed, efficient and simple sample collection methods are still limited due to the size and concentration of bioaerosols. In general, bioaerosol has sub-micrometer size, and fine dust has few micrometer size. Recently, ultrafine particles have become major concerns in several countries (1, 2). Bioaerosol collection techniques for removing suspended particles from airflow include fibrous media based filtration, electrostatic removal, and cyclone method. Fibrous media, consisting of randomly arranged fibers, can physically remove airborne particles by the principle of inertia collision, diffusion and blocking, and exhibit high collection efficiency more than 99%. (3) However, the filter is required to be repeatedly replaced due to an increase in operating pressure and deterioration in performance depending on the use. (4) On the other hand, electrostatic collecting technology removes fine particles with low power. By applying external electric field, target particles can be charged, then collected with second electric field with opposite polarity. (5) However, the electrostatic precipitator generally requires large installation area and high maintenance cost as compared with the filter. Meanwhile, cyclone has a structure in which the inflow fluid is directed to make a downward helical motion. Particles move to the cyclone wall by the centrifugal force and settle down on the bottom side, while air is discharged to the outlet by the upward rotational flow. Cyclone based collection provides several advantages such as simple operation, low pressure requirements compared to filters, and less maintenance without periodic filter replacement. However, the removal efficiency of cyclone is limited and also varies greatly depending on the size of target particles. The collection efficiency of cyclone generally increases with the particle size, and goes upto 50% or more, if the particle size is 5 μm or more. But it usually shows very low efficiency for sub-micrometer particles. (7) Among many techniques for increasing the fine particle collection efficiency of cyclones, application of external electric field has shown potential for simple and efficient design. (8) External electric field can be created inside cyclone body, and opposite polarity electrodes such as sawtooth and thread-like electrodes generate corona through unequal electric field, resulting in high collection efficiency of more than 90%. Corona, however, generates ozone, a toxic substance. (9) Thus, in order to utilize electric field assisted cyclone, it is important to minimize ozone generation with high dust collection efficiency.

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II. PROBLEM STATEMENT

Cyclone based bioaerosol collection method can provide simple operation and low maintenance, but low collection efficiencies for sub-micrometer particles generally limits its application to bioaerosol collection.

III. THE AIM OF RESEARCH

In this paper, we experimentally study the effect of electric field on the collection efficiency of cyclone, and examine the possible use for bioaerosol collector. The developed system is tested and optimized for removal of ultra-fine particles of 0.3 μm size.

IV. METHOD OF RESEARCH

The schematic and photograph of experimental setup in this study is shown in Figure 1. Air intake was designed to neutralize the 0.3 μm KCl particles, and spray them into the tube.

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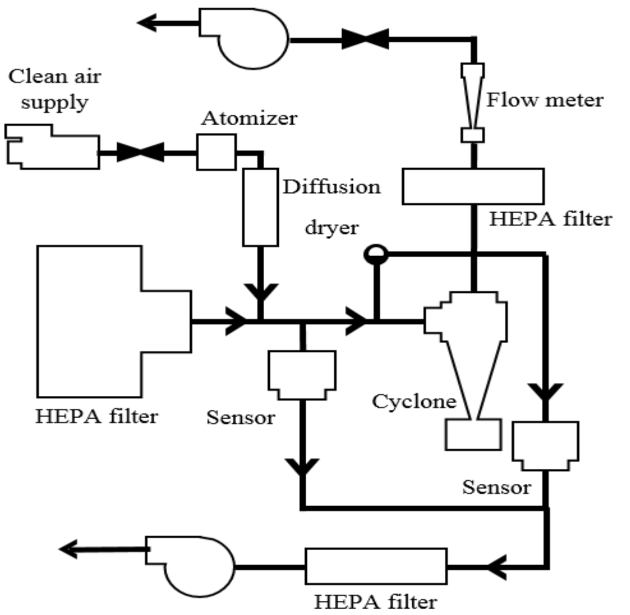
Inflow stream to cyclone was mixed with particles at controlled flow rates, and the number of particles at inlet and outlet of cyclone were measured by using particle couneter. Particle collection efficiency of the cyclone was then calculated by following equation:

$$\eta = \left(1 - \frac{N_{outlet}}{N_{inlet}}\right) \times 100$$

Where, □ is the particle collection efficiency in percent value, N_{inlet} and N_{outlet} are the particle counts at inlet and outlet, respectively.

(a)



(b)

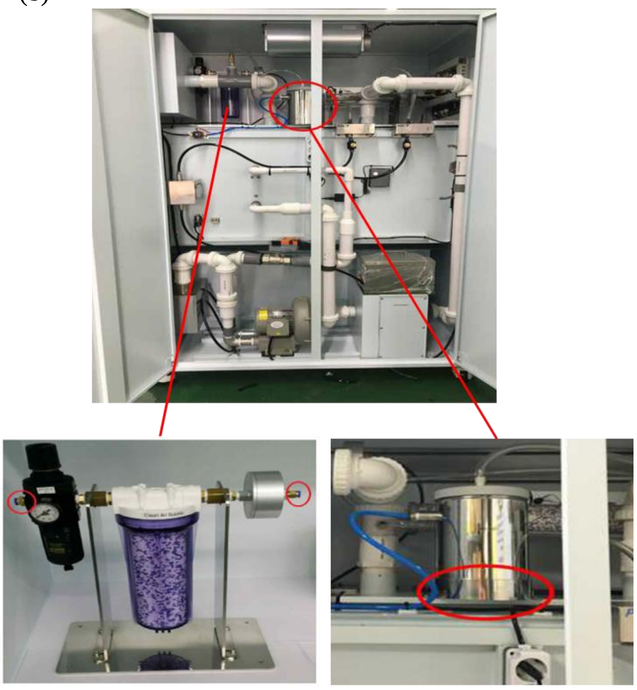


Figure 1. Schematic and photograph of experimental setup

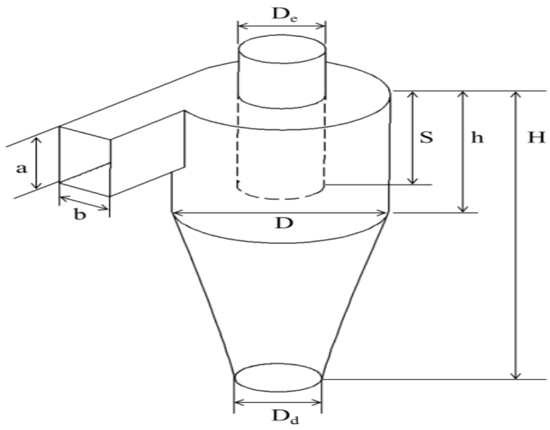


Figure 2. Schematic of cyclone

A cyclone with a diameter of 60 mm as shown in Figure 2 was designed and tested. Cyclones were designed using 3D CAD (SolidWorks, Dassault Systems) and fabricated with 3D printer for experimental tests. The cyclone body was divided into three parts, consisting of a cylinder part, a vortex tube part, and a conical part. In order to test various design of cyclones, multiple parts with different geometries were fabricated and assembled. Initial dimensions of the tested cyclone is summarized in Table 1.

Table 1. Dimensions of initial test model

Dimensions	Ratio
a/D	0.4
b/D	0.2
s/D	1.5
D_e/D	0.47
h/D	1.5
H/D	4
D_d/D	0.38

Stainless steel electrodes were installed on the inner part of the cyclone cylinder and the outer part of the vortex binder, then the wire was attached and fastened by bolt connections as shown in Figure 3.

Figure 3. Cylindrical SUS electrode connections

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High voltages up to 30 kV were supplied by a high-voltage transducer (BT-GP, Ultravolt). The supplied voltage through the electrodes was monitored with a 1:1000 magnification probe (P6015A, Tektronics), and the uniform electric field was maintained without any discharges between the electrodes. Inner tubes with multiple lengths were prepared to adjust the tube dimensions. Cyclone efficiency was calculated by measuring the concentration of KCl particles in the flow toward the cyclone and the concentration in the upward flow through the inner tube.

V. Analysis and Discussion

Under the static electric field, particles with charges experience the electric force proportional to the charge of the particle and electric field magnitude. Thus, for the consideration of the electrostatic forces on the particles, static electric field magnitude inside the cyclone should be modeled first. The electric field, E, between two cylindrical electrodes where the external potential U is supplied can be given as (10):

$$E_r(\mathrm{r}) = \left[\frac{1}{ln(R/R_e)}\right]\frac{U}{r}$$

where R and R_e are the radial locations of inner and outer electrode, respectively. By using the equation, the relation between supplied voltage and electric field magnitude is shown in Figure 4. For the design optimization in this study, the variation of electric field magnitude by the geometric change was minimized with the compensation of supplied voltage through the electrodes.

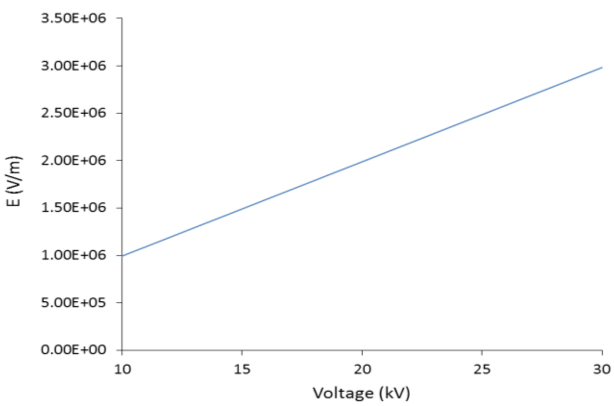

Figure 4. Electric field magnitude inside the collector

Figure 5 shows the change of cyclone efficiency with inlet flowrate with and without the application of 25 kV voltage to the cyclone electrode. In the absence of external electric field, the collection efficiency of the cyclone increased proportionally to the flow rate as the inertial force is proportional to flow speed and flow rate. After the application of voltage, it can be observed that the efficiency is increased in all cases. Electrical forces on particles are only proportional to electric field strength and surface charges. However, if the flow rate increases, the particles reside in the electric field more shorter time. Thus, overall collection efficiency is not changing proportionally with flow rate after the application of electric field. It can be observed that the efficiency of the electric cyclone is maximized in the flow rate range of 400 ~ 500 lpm. Pressure drop across the cyclone was measured as 1320 Pa.

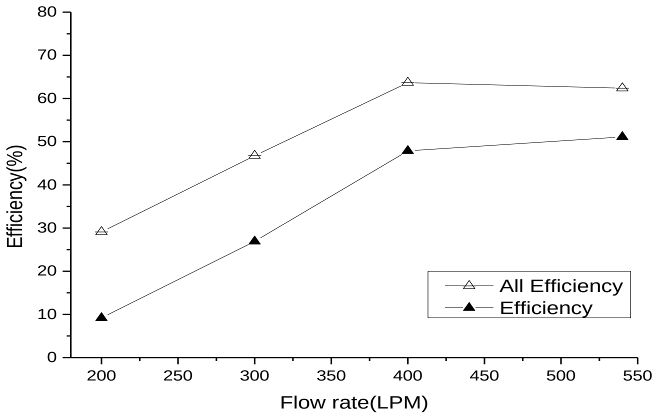

Figure 5. Collection efficiency of cyclone with increased flowrate. (Filled triangle – 0 kV, empty triangle – 25 kV)

Figure 6 shows the effect of external electric field on the collection efficiency. The increase of collection efficiency compared to the 0 kV case, cyclone without electric field, is plotted. As expected, the increase of applied voltage amplifies electrical forces on particles, and about 15% increase in collection efficiency has been achieved.

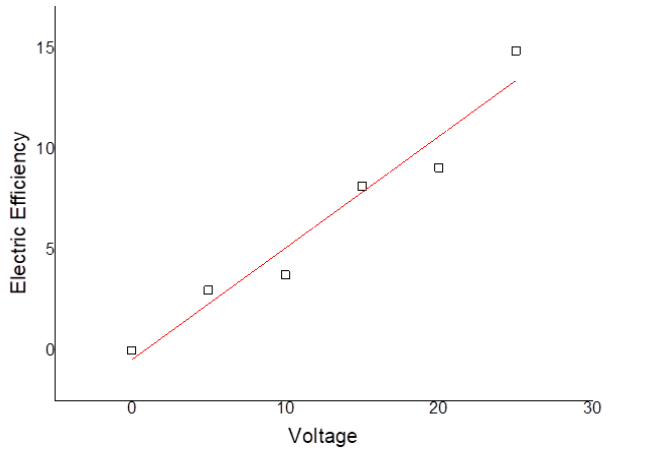

Figure 6. Increase of collection efficiency with the application of electric potential (in kV)

VI. Conclusion

With the application of external electric field and inducing electrokinetic forces on particle, we have demonstrated the high collection efficiency of cyclone based device. After design modification of cyclone, operating parameters including flow rate, pressure, and voltage are experimentally studied. The presented electric cyclone collector have shown the highest efficiency of 65 % at a relatively low pressure of 1320 Pa, thus can be applied to micro or sub-micrometer sized particle collection and bioaerosol sampling.

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