Numerical Analysis and Experiment for Micro Particle Collector Using Dielectrophoretic Force

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***Abstract*—The motion of dielectric micro particles in the proposed particle collector is modeled and analyzed with coupled equations of electromagnetics, fluidics and particle dynamics. The main forces acting on micro particles are obtained using distributions of electric field and fluid velocity field, both of which are numerically calculated by finite element method. The external forces acting on the particles are driving terms in the Newton's equation for the particle motion analysis. To validate analysis method, a particle collector is designed, and the experiment is carried out using standard micro particles under a circumstance of a given airflow.**

***Index Terms*—Dielectrophoresis, particle dynamics, coupled equation, electrostatic precipitator, finite element method**

I. Introduction

Electrostatic precipitators have been developed to remove minute contaminants in manufacturing, environmental and engineering field. Most of electrostatic precipitators make use of corona discharge. The corona discharge is used to generate electric charges for charging contaminant particles of neutral dielectric material. The charged particles pass through electric field between electrodes and are attached on one electrode surface. This precipitation technique needs process of corona generation, particle charging and particle attachment [1].

The electric force acting on dielectric material under non-uniform field is called dielectrophoretic (DEP) force. Recently, the dielectric micro particles, motion of which is controlled by the DEP force, play an increasing role in various areas, ranging from biomedical field to engineering. For example, many biotechnology devices have been being developed to manipulate micro particles such as red blood cells, DNA, viruses, marker particles, etc. [2].

This paper proposes a new micro particle collector, which does not require the corona discharge and only makes use of the dielectrophoretic force. To assess its performance of particle collection and improve its design, a micro particle motion for particle attachment is analyzed. Dielectric micro particle experiences forces by fluid stream and electric field. The motion of the particles is determined by the distributions of electric field and fluid velocity. Thus, the characteristic of the particle motion is a kind of coupled problem of electromagnetic, fluidics and particle dynamics.

All possible forces acting on the micro particle include electric force, fluidic force, gravity force, buoyancy force. Among them, the dominant forces are the DEP force and the fluidic drag force. The DEP force is related to both dielectric material properties and non-uniform electric field, and the drag force is determined by fluid velocity. The gravity force and the buoyancy force can be simply calculated using the particle property.

The experiment and measurement are carried out with standard micro particles of uniform size. The collecting rate is assessed using a particle counter, which can measure particle size and number in air. A particle motion is visualized using a laser visualization device.

II. Modeling of Particle Motion

The force acting on dielectric material located in non-uniform electric field is generated by interaction of imposed field with induced dipole moment. The DEP force on the dielectric particle, which is lossless in DC electric field, can be obtained using the effective dipole moment [3]:

$$\mathbf{F_{DEP}} = 2\pi\varepsilon_1 R^3 K \nabla E_0^2 \tag{1}$$

where ε_1, R, and E_0 are fluid permittivity, particle radius and applied electric field, respectively, and K, known as the Clausius-Mossotti(CM) factor, can be expressed as

$$K = \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1} \tag{2}$$

where ε_2 is particle permittivity. The CM factor provides a measure of the magnitude of the DEP force, and its sign determines whether the particle moves toward strong electric field intensity or not.

The moving particles suspended in fluid experience the drag force as follow:

$$\mathbf{F_D} = 6\pi\eta(\mathbf{u} - \mathbf{v})R \tag{3}$$

where η, $\mathbf{u}$ and $\mathbf{v}$ are viscosity, fluid velocity and particle velocity, respectively. The drag force can be calculated from relative velocity between fluid and particle velocity. Gravity force is easily obtained with its mass density and size.

To analyze motion characteristic of the particles, these three forces on the particles are substituted into Newton's motional equation:

$$\mathbf{F_E} + \mathbf{F_D} + \mathbf{F_G} = m\frac{d\mathbf{v}}{dt} \tag{4}$$

where m is particle mass. The electric force, $\mathbf{F_E}$, consists of Coulomb and dielectrophoretic force. The nonlinear ordinary differential equation of (4) can be solved using the Runge-kutta algorithm.

III. Numerical Analysis

A. Analysis Model for Particle Dynamics

The analysis model for the micro particle motion is shown in Fig. 1. The diameter of electrodes is 2mm, which is coated with dielectric material of 1.5mm thickness. The upper flow direction is the same as the gravity. Since the field pattern is repeated, a column region is taken as the analysis region as in Fig. 1. The forces on the particles are calculated from equations (1) and (3) using the electric and fluid field distribution, respectively.

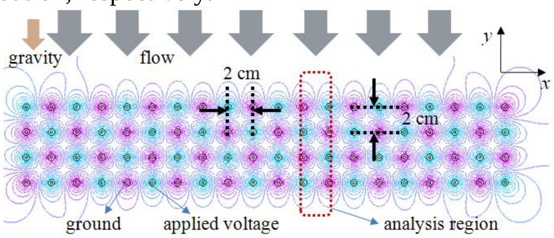


Fig. 1. Analysis model for micro particle motion

B. Analysis Results

The micro particles are released with initial velocity 0, and experience the external forces; gravity, electric and drag force. The particle motion as time is shown in Fig. 2. In this case, most of the particles is attached to the first row of collector because the electric force is dominant.

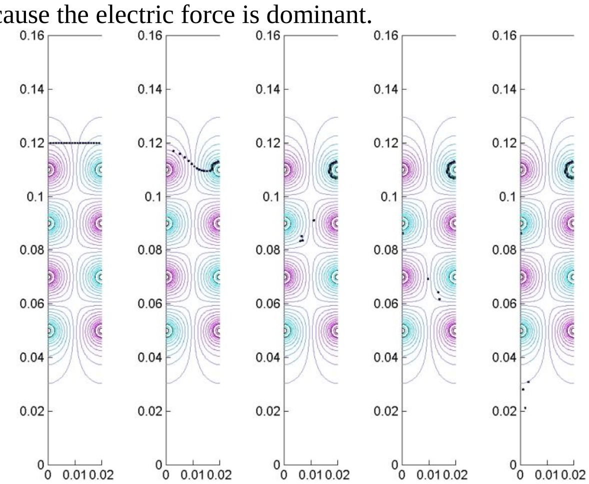


Fig. 2. Analysis results of micro particle motions

IV. Experiment Using Micro Particle Collector

A. Experimental Setup

Experiment using micro particle collector is carried out, and experimental diagram is shown in Fig. 3. The fan filter unit (FFU) is used to remove existing micro contaminants in the booth and to control the flow velocity, and the high voltage supply ranges from 0 to 100kV. The four micro particle collectors, which are used in numerical analysis, are installed in the middle of booth, and parallel with the ground. The particle counter is set inside booth to check the number of particles at the bottom.

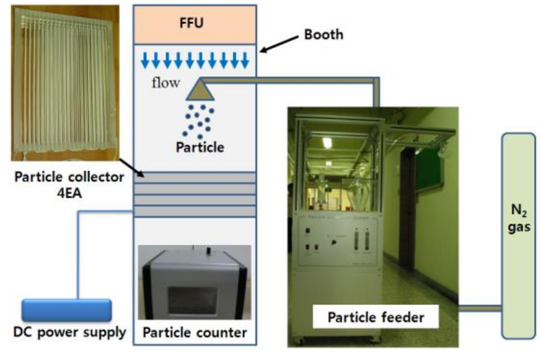
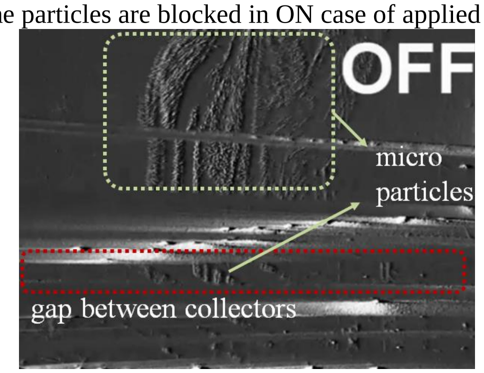


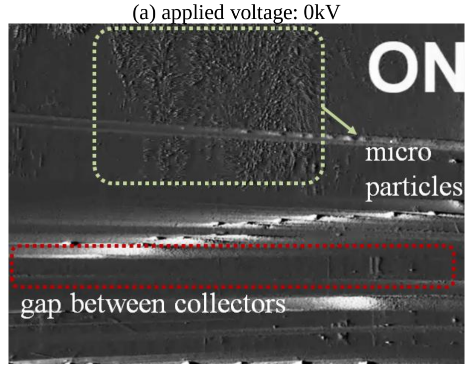
Fig. 3. Diagram of experimental setup

B. Experimental Results

The micro carbon particles are used in the experiment, and their diameter is uniformly 3μm. The pictures of particles taken by a laser visualization device are compared in Fig. 4, where the particles are blocked in ON case of applied voltage.



(a) applied voltage: 0kV



(b) applied voltage: 30kV

Fig. 4. Comparison of particle distributions in ON and OFF of applied voltage

In the full paper, the collecting rate of micro particles, which is calculated through the experiment results, is compared with the collecting rate of analysis. The analysis and experiment results according to flow velocity and applied voltage will be shown.

References

[1] K. R. Parker, Applied Electrostatic Precipitation, 1st ed., Chapman & Hall, 1997, pp. 11-54.

[2] Thomas B. Jones, "Basic Theory of Dielectrophoresis and Electrorotation", *IEEE Engineering in Medicine and Biology Magazine*, pp. 0739-5715, 2003.

[3] Thomas B. Jones, *Electromechanics of Particles*, 1st ed., Cambridge University Press, 1995, pp. 5-18.