*M. Chen et al. (Eds.)*

*doi:10.3233/ATDE230506*

# Design of a Circular Micro-Particle Filtration Device

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**Abstract.** Particles in a non-uniform electric field solution are subjected to dielectrophoresis, and the trajectory of particle movement is altered. This study is based on the principle of dielectrophoresis to design a device for the filtration of micro-particles of two different sizes that are in an AC electric field solution. Firstly, the two-dimensional plane structure of the filtration device is designed, and the filtration device model with coupled multi-physics fields is established by using the finite element analysis method. The electrode voltage magnitude, inlet flow rate, particle size, and particle conductivity in the model were analyzed and discussed to summarize the influencing factors that affect the filtration effect of micro-particles. The higher the electrode voltage of the filtration device, the greater the change in the trajectory of particle movement occurs, and it is difficult to achieve particle filtration when the electrode voltage is less than 5v. When the inlet flow rate increases the electrode voltage needs to be increased to achieve filtration of microparticles. When the flow rate of the filtration reaches 3000μm/s, it is difficult to filtration even when the voltage increases to 10V, so the suitable maximum flow rate of this device is 2000μm/s. The factors affecting particle manipulation are adjusted to improve the filtration effect of micro-particles, and this filtration device can filtration out larger size particles and leave smaller size particles.

**Keywords.** Micro-particle filtration, dielectrophoresis, AC electric field, finite element analysis

## 1. Introduction

As the demand for applications of micro-sized particles increases, the need for sorting, filtration and purification of micro-particles in solution increases. The current techniques for manipulating micron particles are dielectrophoretic manipulation [1-3], acoustic manipulation [4], magnetophoretic manipulation [5], and inertial flow manipulation [6]. The dielectrophoretic particle manipulation technique does not require marking of the manipulated particles [7], and there is no contact or damage to the manipulated particles, simple manipulation equipment, and strong manipulability of the particles [8]. In this study, based on the dielectrophoretic manipulable micron-size particle technique [9], a circular microparticle filtration device that can filtration out larger size particles and leave smaller size particles under the action of AC electric field was designed. The finite element analysis method is used to study the trajectory of particles and the number of particles at the outlet to analyze and obtain the factors

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affecting the filtration of microparticles. The factors affecting micro-particle filtration were changed to optimize the electrode voltage magnitude and inlet flow rate of the device designed in this study to improve the micro-particle filtration efficiency. Design a circular shaped micro-particle filter that can filter out large size particles. The micro-particle filtration device designed in this study has the advantages of small size structure, easy handling, non-destructive to particles, short filtration time, a wide range of applicable micro-particle sizes, and high filtration effect.

## 2. Mathematical Models

The micro-particle filtration device designed in this study consists of a solution particle inlet channel and a solution particle outlet channel, which are connected by a circular structure in the middle. Electrodes are distributed on the channel walls of the circular structure of the filtration device, and the two-dimensional structure of the circular microparticle filtration device is shown in figure 1. A is the inlet channel of particles and solutions to be filtrationed, E is the outlet channel of the filtration device, F is the circular filtration area, and C, B, D and G are the electrode sheets. By designing an annular filtration channel, the overall structure of the filtration device is reduced in size without reducing the time for particles to be subjected to dielectrophoresis, and the filtration effect of the filtration device can be improved. The particle filtration enables particles of a larger radius to flow out of the outlet channel E and particles of a smaller radius to remain in the annular filtration zone. The electrodes C, B, D and G in the ring structure are applied with AC, after which a non-uniform electric field is formed with the ring structure, so that the particles to be filtration flows through the ring structure are subjected to dielectrophoresis. The width of the A inlet channel and E outlet channel is 70 μm. The width of the annular filtration zone F is 80 μm.

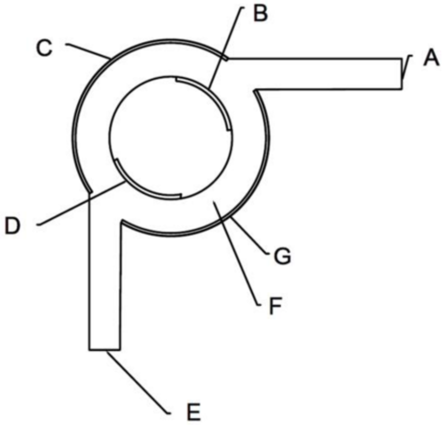


**Figure 1.** Schematic diagram of the two-dimensional structure of the circular filter.

The dielectrophoretic force on particles in the annular filtration zone is

$$F_{dep} = 2\pi r_p^3 \varepsilon_0 \mathrm{real}(\varepsilon_r^*)\mathrm{real}(\frac{\varepsilon_{r,p}^* - \varepsilon_r^*}{\varepsilon_{r,p}^* + 2\varepsilon_r^*}) \nabla |E_{rms}|^2 \quad (1)$$

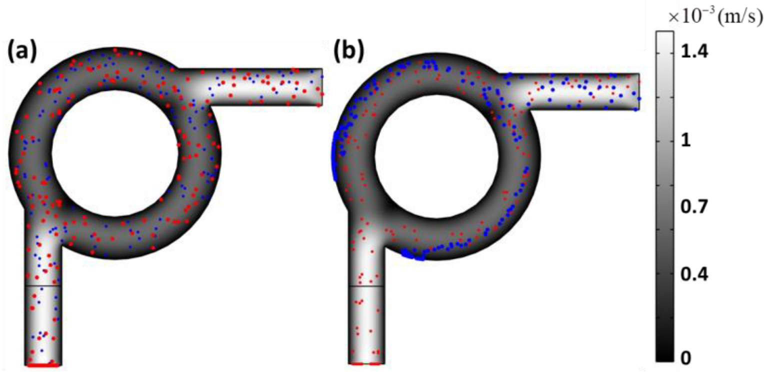
$r_p$ is the size radius of the particles to be filtration. $\varepsilon_0$ is the dielectric vacuum permittivity and takes the form of $8\times10^{-12}\mathrm{F/m}$. $\varepsilon_r^*$ is the dimensionless complex permittivity of a solution mixed with particles. $\varepsilon_{r,p}^*$ is the dimensionless complex permittivity of the particle to be filtration. $\mathbf{E}_{rms}(\mathrm{V/m})$ is the effective electric field. The complex permittivity in this model is $\varepsilon^* = \varepsilon - \frac{i\sigma}{\omega}$. $\varepsilon$ (F/m) is the dielectric constant. $\sigma$ $(S/m)$ is the electrical conductivity. $\omega$ (Hz) is the electric field frequency. The electric field frequency chosen for this model is 100 kHz.

The particle conductivity and dielectrophoresis in the present study were investigated by Equation 1. The solution conductivity is defined as 50(mS/m) and the dielectric constant is defined as $80\varepsilon_0$. The density and viscosity of the solution are classified as $\rho = 1000(\mathrm{kg/m^3})$, $\eta = 0.001\mathrm{Pa\cdot s}$. The length and width of the device in this study were much greater than the height, and the particles were subjected to the same electrophoretic action when they were at different heights in the same position [10]. In order to reduce the simulation cost, a planar model was used for modeling and analysis in this study. The model designed in this study couples the electric field equation, the flow field equation and the multi-particle tracking module to investigate and analyze this design device. Can simulate the filtration effect of the filtration device to the maximum extent.

## 3. Results and Analysis

### 3.1. Filtration Results

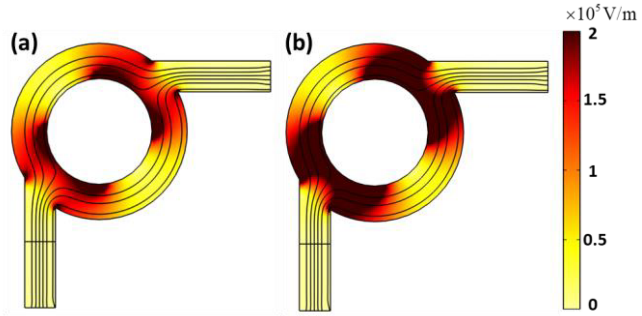
The solution mixed with two microparticles enters the filtration device from the inlet of channel A at the flow rate $1000(\mu\mathrm{m/s})$. The diameter size of the blue particle is $1.8[\mu\mathrm{m}]$, its conductivity is $10^{-4}[S/\mathrm{m}]$, and its dielectric constant is $3\varepsilon_0$.The diameter size of the red particle is $5[\mu\mathrm{m}]$, its conductivity is $10^{-5}[S/\mathrm{m}]$, and its dielectric constant is $60\varepsilon_0$. As shown in figure 2(a), no voltage is applied to the electrode sheet in the filtration device. The solution with both particles enters the filtration device from the entrance A. When the solution passes through the circular filtration zone F, the particles in the solution are not subjected to dielectrophoresis because no voltage is applied to the electrodes, and the trajectory of the particles does not change and finally flows out from the outlet channel E. Therefore, the filtration effect cannot be achieved without applying voltage to the electrodes of the filtering device. Figure 2(b) shows that a voltage of 7V is applied to electrode C and G and -7V is applied to electrodes B and D in the filtration device. The solution enters from the channel inlet A and passes through the circular filtration area F. The particles in the solution are subjected to dielectrophoresis and the trajectory of the particles changes, with blue particles leaning toward the outside of the circular shape to stay in the filtration device and red particles flowing out from the exit channel E to realize the filtration of particles. Therefore, it shows that particle filtration can be achieved when voltage is applied to the electrodes of the filtering device. The black and white color in figures 2(a) and (b) represent the flow rate of the solution in the filtration device, the darker the color the lower the flow rate, and the lighter the color the higher the flow rate. As can be seen in figure 2, the flow velocity is highest at the inlet channel A and outlet channel E of the filter device, and lowest at the circular filtration zone F. The slow flow of particles in the circular filtration zone increases the time that the particles are subjected to dielectrophoresis, thus improving the filtration effect at same voltage. The design of the circular filtration zone in the filtration device increases the cross-sectional area of the filtration device channel and reduces the density of the particles to be filtered in the filtration device channel, thus improving the filtration effect.



(a) Not energized; (b) Energized.

**Figure 2.** Schematic diagram of the trajectory of particles moving through the filtration device.

In figure 3(a), an AC voltage of 7 V is applied to the filtration device and the inlet flow rate is $1000\mu m/s$. It can be seen from the figure that the electric field strength is maximum at the edges of both sides of electrodes B and D. As the applied voltage increases to 10 V, the area of electric field strength increases as shown in figure 3(b). The places with the highest electric field intensity are at the connection of the circular filtration area with the inlet channel and the outlet channel, respectively. The electric field strength at the inlet channel and the connection of the circular filtration area is large so that the particles entering the filtration area are subjected to dielectrophoresis, and the trajectory of particles of different sizes changes. The electric field strength at the connection of outlet channel and circular filtration area is large, which can improve particle filtration effect and prevent poor particle filtration effect. Combined with Equation 1, it is clear that the larger the electric field strength the greater the dielectrophoretic effect on the particles. Comparing the flow velocity line diagram of figure 3 (a) and (b), it is found that increasing the flow velocity of the solution into the inlet channel A does not change the flow field direction. It indicates that increasing the flow rate can only increase the velocity of particle movement and reduce the time that particles stay in the filtration.



(a) The applied AC voltage is 7V and the inlet flow rate is 1000μm/s; (b) The applied AC voltage is 10V and the inlet flow rate is 1500μm/s.

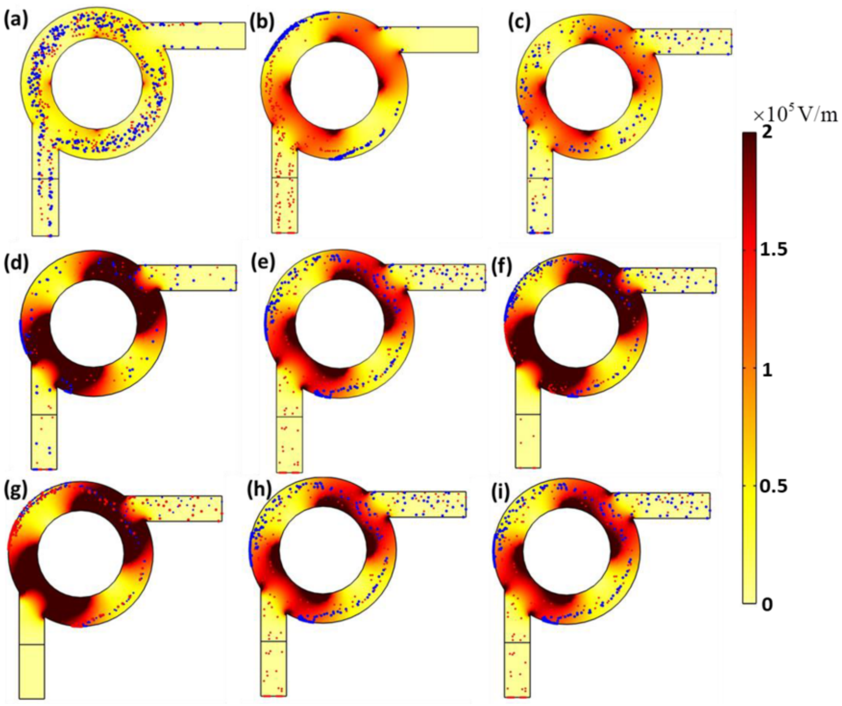
**Figure 3.** Electric field strength and flow velocity line diagram for particle filtration device.

### *3.2. Factors Affecting the Effectiveness of Filtration Devices*

To study the influence of the electrode voltage size on the filtration effect, the electrode voltage of 2V, 5V, 7V and 10V were chosen to study the filtration effect of the filtration device in this study. It was found that the filtration of particles could not be achieved by applying 2 V to the electrode of the filtration device and simultaneously reducing the inlet solution flow rate to 300μm/s , as shown in figure 4(a). The filtration device electrode is applied with 5V voltage and the inlet solution flow rate is 300μm/s. The particles can be filtration as shown in figure 4(b). It shows that the filtration device designed in this study is difficult to filtration after the applied voltage of the electrode is lower than 5V. When the applied electrode voltage is 5V, the inlet solution flow rate increases to 1500μm/s, and the filtration device cannot achieve the filtration of particles, as shown in figure 4(c). When the applied electrode voltage is 10V and the inlet solution flow rate is 3000μm/s, the particle filtration device cannot achieve particle filtration as shown in figure 4(d). It means that the higher the flow rate the higher the voltage to be applied to the electrodes of the filtration device. According to Equation 1, the greater the electric field strength, the greater the dielectrophoretic force on the particle. In order to increase the filtration efficiency of the filtration device, the voltage across the electrodes of the filtration device is increased at the same time as the flow rate of the solution into the filtration device is increased. To investigate the effect of electrode position on the filtration device, a voltage of 7 V was applied to electrodes C and G in the filtration device, and a voltage of -7 V was applied to electrodes B and D. It was found that there was no effect on particle filtration as shown in Figure 4(e).

To study the effect of particle diameter size difference on the filtration effect, this study increases the diameter of blue particles as 3.6[μm] compared with the original blue particle radius size data without changing the size of red particle diameter. It was found that when the electrode voltage of the filtration device was 10 V, the inlet solution flow rate was 1500μm/s, and the blue particle diameters were 1.8[μm] and 3.6[μm], it could filtration as shown in figure 4(f). In order to study the effect of particle conductivity on the filtration effect, the red particle conductivity is not changed.

The blue particle conductivity is changed to $10^{-3}[S/\mathrm{m}]$ as shown in figure 4(h). The blue particle conductivity is changed to $10^{-5}[S/\mathrm{m}]$ as shown in figure 4(i). By comparing figure 4(h) and figure 4(i), it was found that changing the conductivity of the blue particles had no significant change on the particle motion trajectory.



(a) Particle filtration electrode applied voltage of 2V, the inlet flow rate of 300μm/s;(b) Particle filtration electrode applied voltage of 5V, the inlet flow rate of 300μm/s; (c) Particle filtration electrode applied voltage of 5V, the inlet flow rate of 1500μm/s; (d) Particle filtration electrode applied voltage of 10V, the inlet flow rate of 3000μm/s; (e) A voltage of 7V is applied to the electrode pieces C and G of the particle filtration device, and a voltage of -7V is applied to the electrodes B and D; (f) The blue particles have a diameter of 3.6 [μm]; (g) The blue particles have a diameter of 5.4 [μm]; (h) The conductivity of the blue particles is $10^{-3}$ [S/m]; (i) The conductivity of the blue particles is $10^{-5}$ [S/m].

**Figure 4.** Plot of particle trajectory and electric field intensity distribution for filtration particles at 3s.

## 4. Summary

According to the need of filtration micro-particles of different sizes, this study uses dielectrophoresis to change the trajectory of particles and designs a device that can filtration particles of different sizes. The device can filter out larger particles and leave smaller ones, and the filtration is not affected by the electrical conductivity between particles, which is suitable for different types of particle filtration.By analyzing the filtration effect of this research design device through finite element modeling, the conclusion is as follows: the particle filtration effect is affected by the size of micro-particles, and the greater the size difference between two filtration particles, the better the filtration effect. The higher the electrode voltage of the filtration device, the greater the change in the trajectory of particle movement occurs, and it is difficult to achieve particle filtration when the electrode voltage is less than 5v. When the inlet flow rate increases the electrode voltage needs to be increased to achieve filtration of microparticles. When the flow rate of the filtration reaches 3000μm/s, it is difficult to filtration even when the voltage increases to 10V, so the suitable maximum flow rate of this device is 2000μm/s. It was found that changing the difference in conductivity of the two particles did not affect the filtration effect of the microparticles. The particle filtration device designed in this study has a simple structure, high filtration efficiency, and can achieve enrichment of another kind of particles while realizing the filtration effect. The effect of filtration between particles of different sizes can be controlled by adjusting the relationship between the flow rate of the solution at the inlet channel of the filtration and the electrode voltage of the filtration.

## Acknowledgement

The author(s) disclosed receipt of the following financial support for the research, authorship, and publication of this article: This work was supported in part by the Dongguan Science and Technology of Social Development Program (No.20211800905482) and in part by the Innovation Research Team of Mechanical Engineering in Guangdong University of Science and Technology grant number (GKY-2020CQTD-1) and Guangdong Priority Construction Discipline Research Capacity Enhancement Project(2021ZDJS114) and Natural Science Project of Guangdong University of Science and Technology (GKY-2022KYQNK-1).

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