

# Dynamical Behaviors of Charged Particles in Horizontal Switching Electrophoretic Cell

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## ABSTRACT

*We propose a modeling for calculating the dynamical behaviors of a charged particle depending on the patterned electrode in horizontal switching electrophoretic cell. Many important properties of colloidal dispersions in a fluid are directly or indirectly determined by the electric charge of the colloidal particles. We calculate the interaction between electrical field and particle. As a result, we can calculate particle mobility in horizontal switching electrophoretic cell.*

## 1. Introduction

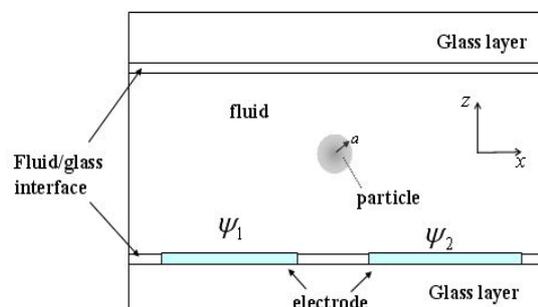
Recently, There some techniques proposed in order to realize electrophoretic displays (EPDs) [1,2]. Electrophoretic displays are non-emissive devices base on the electrophoresis phenomenon of charged pigment particles suspended in the medium. Electrophoresis was focused as an important technique for the manipulation of micro- and nano-sized particles, in terms of their charge.

Electrophoretic display has some advantages. It is bistable and very thin, light weight. Thus, EPD has been long developed for their high contrast and low power consumptions. There have been presented that a driving property study of the AC and DC electrokinetic properties of latex particles as suspending medium conductivity and viscosity is presented [3]. In most particle-based displays, charged particles are used and driven by DC field. To advance quality of the EPD, it need to numerical approach the electrohydrodynamic characteristics of the charged particles in a viscous fluid. In the previous paper, Bert et al. presented complete model for the transport of particles in electrophoretic display using analytical formulae [4,5]. Tanaka and Araki proposed a new simulation method for solving multi phase problem. Using their method, the simulation process has been simplified. The key assumption in the Tanaka's method is that the solid regard a kind of medium surrounding the solid. And also, the solid area has much higher viscosity than the bulk area. So, solid area should be hardly deformable [6]. Kodama presented a simulation result of the dynamics of charged colloidal suspensions. It is formulated that is based on the Tanaka's method so as to incorporate the electrohydrodynamic interactions be-

tween the three relevant elements of charged colloidal suspensions, i.e., colloidal particles, ion clouds and liquid [7]. However, he concerned that the charged colloid consists of the non-electrostatic body force and the attached ions. To investigate the behavior of the charged particles for display application, however, we apply the electrostatic body force for calculate the electrophoretic mobility of charged particle [8]. The purpose of this paper is to present our numerical attempt to investigate the electrokinetic property between the electrophoretic and hydrodynamic characteristics when external electric field is applied at the horizontal switching electrophoretic cell.

## 2. Potential calculation of the EPD cell

We discuss numerical methods for calculating the potential distribution in 2-D cell, considering the electrophoretic cell we employ the artificial boundary condition for the fluid/glass interface.



**Figure 1. Geometry of the EPD cell structure for simulation.**

An EPD cell consists of two flat and large glass plates whose surfaces are coated with conductive electrode that generate nonuniform fields: see figure 1.

Note that eq. (1) is Poisson's equation. Alternatively, in glass layer which is no charge density and homogeneous, isotropic, we calculate electric potential by solving Laplace's equation using a successive over-relaxation (SOR) method. Equation (1) also can be solved directly and we can obtain the potential distribution of the fluid layer and glass layer.

$$\rho_e = \text{div}(\epsilon\epsilon_0 \text{grad } \psi) \quad (1)$$

$$\psi_{i,j} = \hat{\psi}_{i,j} + \omega(\psi_{i,j} - \hat{\psi}_{i,j}) \quad (2)$$

where  $\epsilon_0$  is the permittivity of space and  $\epsilon$  is the dielectric constant of the medium,  $\psi$  indicate the electric potential,  $\omega$  is an over-relaxation factor which depended on number of grid. We take the optimum value of  $\omega$  was about 1.4. Here the hat  $\hat{\psi}_{i,j}$  variables indicate the ones obtained in the previous time step. For calculating the fluid/glass interface layer, we employed artificial boundary condition for electric potential. The z component of D in the fluid and the glass are as follow.

$$D_z^{fluid} = -\epsilon_0(\epsilon_{fluid} \frac{\partial \psi}{\partial z}), D_z^{glass} = -\epsilon_0(\epsilon_{glass} \frac{\partial \psi}{\partial z}) \quad (3)$$

where  $\epsilon_{glass}$  is the dielectric constant of the glass,  $\epsilon_{fluid}$  is the dielectric constant of the fluid. If there is no surface charge, D at the interface fluid/glass are same [9]. In our simulation, we take above calculation method. We calculate the potential distribution of computational domain in order to calculate electrophoretic mobility equation. Figure 2 shows calculated results of the potential distribution of the fluid layer filled incompressible fluid. Then, we can calculate the moving time of charged particle associated with EPD.

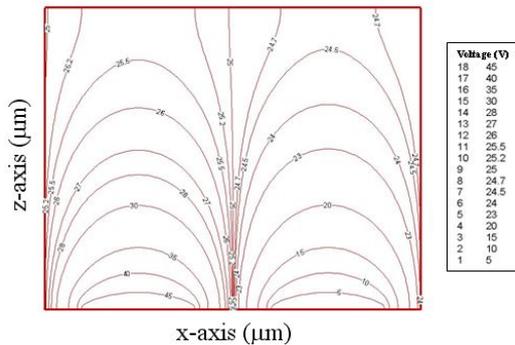


Figure 2. Calculated potential distribution in the EPD cell.

### 3. Governing equation.

Within the framework of a continuum assumption, the electrophoretic flows in micro-scale can be predicted employing Navier-Stokes equation for Newtonian fluids with an electric body force which is usually obtained from the Poisson equation governing the electric field

$$\begin{aligned} \nabla \cdot V &= 0 \\ \rho \left( \frac{\partial}{\partial t} + V \cdot \nabla \right) V &= -\nabla p + \nabla \cdot \mu [(\nabla V) + (\nabla V)^T] \\ &+ \rho_e E \end{aligned} \quad (4)$$

where V is the velocity vector containing u and v components along the x- and z-directions, respectively,

$\rho$  is the fluid density, p is the static pressure, and  $\mu$  on the fluid viscosity,  $\rho_e$  is the net charged density, E is the electric field. Here the third term stems from the body term.

We assumed two material phases is given from difference in the viscosity. For the phase separation, we use the value calculated from the following equation depending on the position of the particle center point.

$$\phi = 0.5 \left[ 1 + \tanh \frac{\alpha - \sqrt{(x_{i,j} - x_p)^2 + (y_{i,j} - y_p)^2}}{\xi} \right] \quad (5)$$

where  $(x_p, y_p)$  are the coordinates of the solid particle's center,  $\alpha$  is the radius of a particle and  $\xi$  denote the interface width. The phase function is close to 1 for the solid and far from the particle it is zero for the liquid. Then the value of  $\phi$  in a computational domain is given as the volume fraction of the dispersed phase. Then the spatial distribution of the viscosity is given by  $\mu = \mu_f + (\mu_p - \mu_f)\phi$ , in here  $\mu_p$  is the viscosity of the particle. And also, the continuous force field F acting on a charged particle can be calculated by follow equation

$$F = \sum (\rho_e E)_{i,j} \phi_{i,j} / \int \phi_{i,j} dr \quad (6)$$

Since the solid particle is of a circular shape we are allowed it use a very simple method to obtain the particle's position. The only thing we should do is to integrate the equation of motion given in terms of the coordinates of the particle's center position:

$$x_p = \hat{x}_p + \Delta t u_p, y_p = \hat{y}_p + \Delta t v_p \quad (7)$$

To obtain velocity of particle, we assumed the particle to be spherical and the frictional drag force to be given by the Stokes law [10]. The mobility of a particle can be related to charge, velocity and the electrokinetic force

acting upon it by relation  $\rho_e E = 6\pi\mu_f \alpha u_{ep}$ . Then the electrophoretic mobility of a charged particle,  $\mu_{ep}$ , is described by Debye-Huckel-Henry theory [11].

$$\mu_{ep} = \rho_e / 6\pi\mu_f \alpha \quad (8)$$

where  $\alpha$  is the Stokes' radius of the particle. The Stokes radius can also be equated to the mass of the particle by the following equation

$$Mass = (4/3)\pi r^3 \quad (9)$$

### 3. Results and discussion

#### 3.1 Setup of the system

Using the phase function, the solid particle has a high viscosity than the fluid. And also, the interfacial force is automatically calculated. Therefore, we do not calculate the boundary problem at the particle surface. The case of electrophoretic flow in micro-scale, the Reynolds number is very small. Thus, we ignore the convective acceleration in Eq. (4). We assumed no Brownian motions and use a staggered grid system in our simulation. The density of particle and fluid are same. So, the density is constant in computational domain. And we choose a finite volume method (FVM) based on the SIMPLE algorithm, which is known to be very robust. A particle was put on the electrode to investigate the moving time when applying voltage was imposed two pattern of bottom electrode. In order to calculate Eq. (4), We calculate time evolution by using an explicit Euler integration. We employ the no-slip boundary condition of fluid/glass layer. And periodic boundary imposed side surface of fluid layer.

The simulation parameters are as bellows.

particle radius(a)	6 $\mu\text{m}$
charge density of particle ( $\rho_q$ )	-10 $\mu\text{C/g}$
viscosity of dispersant fluid(oil)( $\mu_f$ )	10 $\text{cS}$
Dielectric constant of the fluid(oil) ( $\epsilon_f$ )	2.6
Permittivity of vacuum ( $\epsilon_0$ )	$8.8542 \times 10^{-12} \text{ F/m}$
Reynolds number (Re)	1
Interface width ( $\xi$ )	0.1
Cell gab	48 $\mu\text{m}$
Width of the electrode line	18 $\mu\text{m}$
Distance between bottom two electrode	12 $\mu\text{m}$

Table 1. Simulation parameter for the EPD cell.

#### 3.2 Simulation Result

We simulate the electrophoretic flow of charged particle in the EPD cell. Figure. 3 shows the simulation result when applied voltage on right electrode. According to change of voltage, the moving time of charged particle was decrease. More specifically, the strength of applied voltage can be a key factor to control the particle velocity. Figure. 4. shows the simulation result that flow property of micro-scale in 2-dimentional space. The charged particle was move to the opposite electric polarity electrode.

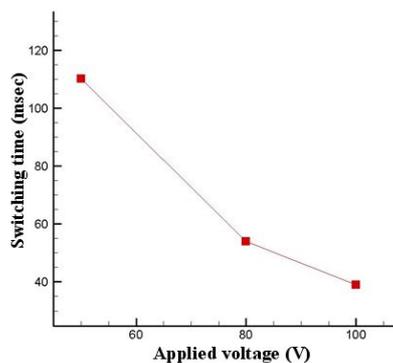


Figure. 3. Simulation result of moving time according to change of applied voltage.

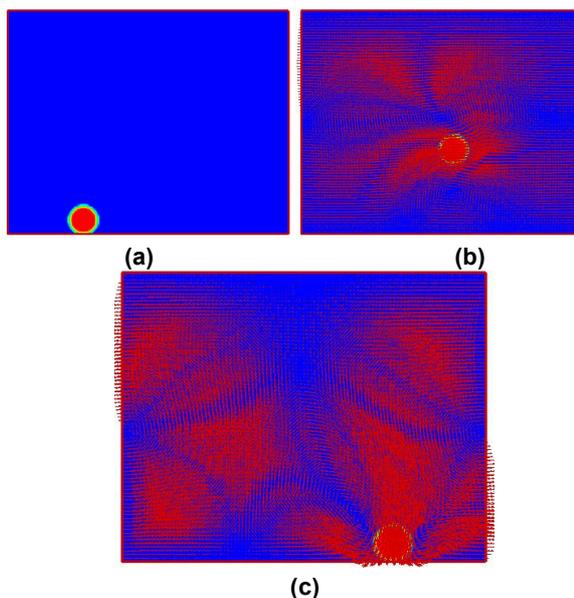


Figure. 4. Snapshots of the electrophoretic flow process. The arrows denote the velocity field in the fluid layer. The density plot represents the phase separation between the solid and fluid. (a) 0ms, (b) 56.8ms, (c) 110.16ms.

#### 4. Conclusion

In this paper, we calculate electrophoretic mobility depending on intensity of applied voltage. The charged particle move with their charge related the local field strength. We present our numerical results with a focus on the dependence of applied voltage. We confirmed that according to the intensity of applied voltage, the moving time was reduced. As a result, this method can be investigated to dynamic behavior of charged particle in the EPD.

#### 5. Acknowledgement

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