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ELECTROHYDRODYNAMIC FILTRATION AND SEPARATION OF NANOPARTICLES USING DIELECTROPHORESIS

Part I: Theoretical considerations review

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Abstract
This paper is a review regarding the theoretical works of nanoparticle's manipulation in electrical field. The nano-sized particles are massively generated in combustion or material synthesis processes are highly toxic to human health. Therefore, their filtration represents an important technological challenge, which makes the object of a very active research. A considerable interest is also shown to the separation of nano-particles in accordance with their physical or chemical characteristics. In this part, the dielectrophoretic, electrohydrodynamic and other forces are presented.

Keywords: nanometric particles, filtration, separation, electrohydrodynamic, dielectrophoresis.

1. Introduction

Nanosized particles have received considerable interest in the past two decades. Their toxicity for human health is relatively high because they can readily enter the human body through inhalation and have a large specific surface area. Their filtration is an important technological challenge, as they are produced in large numbers from material synthesis and combustion emission [1]. In many scientific and technical areas, a considerable interest is also shown to the separation of nano-particles in accordance with their physical or chemical characteristics, several new methods of particle manipulation being explored. Mechanical devices of controlling particle movement are less effective at this scale. Optical techniques sometimes used in trapping nano-particles have the major disadvantage that they produce significant heating of the fluid in which the targeted bodies are suspended. The methods utilizing electric fields are emerging as the most promising techniques for nano-particle manipulation. Indeed, the electrical forces can act both on particles and on the suspending

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fluid. As a consequence of electrohydrodynamic (EHD) effects, the high intensity electric fields give rise to fluid displacement and may cause particle movement through the viscous drag force [2], [3].

2. Theoretical Background

Motion of particles suspended in a fluid is due to electrophoresis and dielectrophoresis phenomena. Electrophoresis occurs due to the action of the electric field on charged particles, while dielectrophoresis involves polarized bodies only (Figure 1).

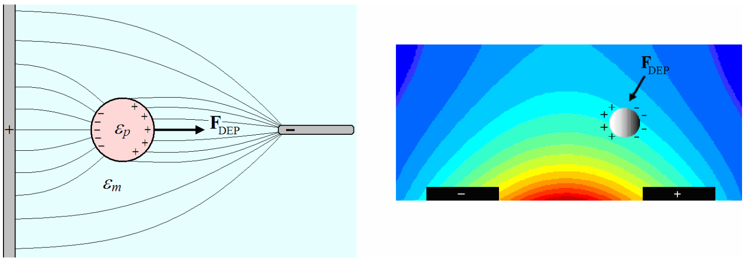

Figure 1: Electrically neutral particle in the presence of a spatially non-uniform electric-field. The dipole moment induced within the particle results in a translational force and the dielectric spherical particle undergoes a DEP motion.

The utilization of the difference between dielectrophoretic forces exerted on different particles in nonuniform electric fields is known as DEP separation. Particles experiencing repulsive and weak attractive DEP forces are eluted by fluid flow, whereas particles experiencing strong attractive DEP forces are trapped at electrode edges against flow drag [5], [6]. The total force on a polarisable particle in a nonuniform AC field can be written as the sum of a number of independently acting forces [2], [4], [5], and [6]:

$$\mathbf{F} = \mathbf{F}_{DEP} + \mathbf{F}_{\text{drag}} + \mathbf{F}_{\text{buyoancy}} + \mathbf{F}_{\text{thermal}} + \mathbf{F}_{\text{brownian}} \tag{1}$$

$\mathbf{F}_{DEP}$ is the dielectrophoretic force, $\mathbf{F}_{\text{drag}}$ is the hydrodynamic drag force, $\mathbf{F}_{\text{thermal}}$ the thermal force and $\mathbf{F}_{\text{brownian}}$ is the force due to the brownian motion of the particles. The dielectrophoretic force can be written as: $\mathbf{F}_{DEP} = \text{Re}\{(\mathbf{m}(\omega)\cdot\nabla)\mathbf{E}\}$ (2)
where $\mathbf{E}$ is the electric field, $\mathbf{m}(\omega)$ is the induced dipole moment of the particle and $\text{Re}\{\}$ indicates the real part of. The time averaged DEP force is found by substituting equation (4) into (3) and is given by:

$$\langle \mathbf{F}_{DEP} \rangle = 2\pi a^3 \varepsilon_m \operatorname{Re}\{k(\omega)\} \nabla |\mathbf{E}_{rms}|^2 \qquad (3)$$

where $\nabla |\mathbf{E}_{rms}|^2$ is the gradient of the square of the rms (root mean square) electric field.

The Clausius-Mossotti factor [6], [7] is a measure of relative permittivity between the particle and the surrounding medium. It can be seen that this factor determines the direction of the dielectrophoretic force. When the sign of *Re[k]* is positive, the particle is more polarisable than its surrounding medium and it undergoes what is known as positive dielectrophoresis (pDEP). The opposite occurs when *Re[k]* is negative, referred to as negative dielectrophoresis (nDEP). The Clausius–Mossotti factor depends on the dielectric properties of the particle and medium, but also on the frequency of the applied field. As a consequence dielectrophoresis can be used as an effective means of separating particles, solely according to their dielectric properties and size.

3. Other forces exerted on nanoscale particles

Particles actuated by dielectrophoresis move in a fluidic medium, therefore other force have to be taken into consideration when describing their motion (figure 2).

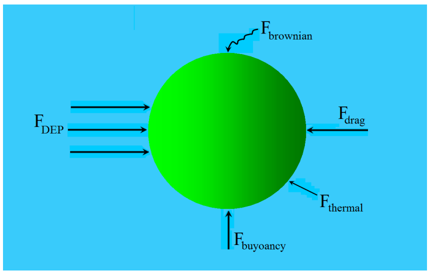

Fig. 2: Forces exerted on a particle moving in fluid, under the influence of dielectrophoresis

The most considerable of which are the hydrodynamic forces. The velocity of the particles will be significantly slowed by the resistance of drag forces while buoyancy forces may cause them to naturally float. Under certain conditions, electro-thermal effects and random Brownian forces can be included.

<u>a) Hydrodynamic forces</u> Nanometer scale particles have very small Reynolds numbers; they experience laminar Stokes flows in which inertia is negligible. The drag force for a spherical particle in a fluid the viscous drag term in equation (1) is: given by Stoke's law [4]:

$$\mathbf{F}_{drag} = 6\pi\eta_m a(\mathbf{v}_m - \mathbf{v}_p) \qquad (4)$$

where $\mathbf{v}_p$ is the velocity of the particle and $\mathbf{v}_m$ the velocity of medium.

The other hydrodynamic force exerted on particles manipulated by dielectrophoresis is buoyancy [7]: $\mathbf{F}_{buoy} = V_p(\rho_p - \rho_m)\mathbf{g}$ (5)

ρ_p and V_p represent the density and volume of the particle.

b) Electro-thermal forces The high intensity electric fields often needed to manipulate particles have been observed to produce joule heating inside the fluidic medium [6], [7], especially when dielectrophoresis is occurring at AC frequencies in the MHz range. This ohmic heating causes a temperature gradient that in turn results in spatial conductivity and permittivity gradients within the suspending medium. The variation of electrical properties within the medium results in coulombic and dielectric body forces that will induce extra fluid flow.

c) Random Brownian forces Brownian motion is the random movement of particles suspended in a fluid [4]. Since water molecules move at random, a suspended particle receives a random number of impacts of random strength and direction in any short period of time. Water molecules are about 1 nm in size; therefore particles such as viruses are small enough to feel the effects of these impacts.

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