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Coagulation of bipolarly charged ultrafine aerosol particles

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Abstract

Particle charging during coagulational growth is widely used in material synthesis processes as well as with industrial particle removal equipment. Coagulation behavior of charged particles is significantly different from that of neutral particles. To calculate the change in size/charge distribution of particles undergoing bipolar coagulation, a two-dimensional sectional model has been usually used. This method, however, needs considerable computation time although it gives very accurate prediction. In this study, the moment model, to solve the bipolar coagulation problem in the free-molecule regime, was developed to provide a time-efficient tool. Simultaneous particle charging by bipolar ions was also considered in this study. The developed model is based on the assumption that particles cannot have more than one unit charge and the particle size distribution remains log normal. The developed model was compared to the two-dimensional sectional model, with good agreement being shown. Some characteristics of bipolar coagulation were investigated using the developed model. The bipolar coagulation with simultaneous bipolar diffusion charging was shown to significantly increase the coagulation rate compared to the neutral Brownian coagulation. It was also shown from the simulation results that if one needs a higher coagulation rate in the initial stage, bipolar coagulation without ions is recommended, while bipolar coagulation with simultaneous charging by bipolar ions should be used if one wants a high coagulation rate for a long time.

Keywords: Bipolar coagulation; Bipolar diffusion charging; Ultrafine particles; Moment method

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1. Introduction

Coagulation behavior of charged aerosol particles is significantly different from that of neutral particles. Eliasson, Egli, Ferguson, and Jodeit (1987) have presented calculations and measurements of the coagulation rate of bipolarly charged aerosol particles. They reported that the coagulation rate of bipolarly charged particles can be increased by a factor of 10^4 compared to neutral particles. Eliasson and Egli (1991) studied the effect of bipolar charging on the coagulation rates of aerosols using a sectional technique. They found that bipolar charging and coagulation more rapidly decreases the particle number concentration compared to neutral particle coagulation.

Particle charging during growth by coagulation is increasingly being used in gas-phase processes for the manufacture of particulate materials such as carbon black, silica, and titania to control the product particle size and chemical composition. In their theoretical study, Xiong, Pratsinis, and Mastrangelo (1992) showed that it is possible to considerably reduce the average particle size and narrow the particle size distribution by introducing unipolar charges during gas-phase particle formation. Vemury and Pratsinis (1996) investigated the effect of corona charging during flame synthesis of silica particles and showed that the primary particle size decreases with increasing field strength. Borra et al. (1999) presented a new process where the controlled coagulation of droplets produced by electrosprays is achieved through electrical forces. In that process, the coagulation of oppositely charged droplets enables controlled mixing on a micro-scale and subsequent chemical reactions inside the combined droplets resulting in uniform droplet size and composition.

The charging process is also used for devices measuring particle size distribution such as differential mobility analyzer. Alonso, Hashimoto, Kousaka, Higuchi, and Nomura (1998) theoretically and experimentally studied the transient charging process of a nanometer aerosol undergoing coagulation. They showed that due to coagulation there exists for each particle size an optimum residence time at which the output concentration of charged particles is a maximum.

One of the most important applications of bipolar coagulation is its use in electrostatic precipitators (ESP). In a conventional electrostatic precipitator the aerosol particles are unipolarly charged, then separated from the air flow by the electrical force. One of the most difficult problems to be resolved for ESP is the low separation efficiency of small particles. One possible solution that has been suggested is to change the size distribution of the aerosol particles in the gas flow, i.e. shift it to larger particles by coagulation (Eliasson & Egli, 1991). One way to increase the coagulation rate is to charge some of the particles with positive ions, and the remainder with negative ions, for introducing attractive electrical forces.

With bipolar coagulation, both the particle size and the particle charge change with time. Therefore, to solve the bipolar coagulation equation, a two-dimensional computation model has to be developed. Several researchers have developed those kinds of models (Oron & Seinfeld, 1989a,b; Vemury, Janzen, & Pratsinis, 1997), but they need considerable computation time.

The moment method is widely known to be highly time efficient in calculations for the time evolution of size distribution of polydisperse aerosol particles undergoing coagulation. In this study, we apply the moment method to bipolar coagulation to develop a time-efficient tool for calculating the particle size/charge distribution change due to the bipolar coagulation and simultaneous charging by bipolar ions. The developed model was compared to an existing model and validated. Some characteristics of bipolar coagulation were investigated using the developed model.