Flow and Electric Field in Electrostatic Precipitator Using Multiphase Continuum Flow and Charge Simulation Method

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***Abstract*—Although there are many works that deal individually with different phenomena in electrostatic precipitators (ESP), for instance, the distribution of electric field, corona current and flow of gas-solids, there are few models considering the interactions between these different phenomena. This paper presents a methodology based on multiphase continuum flow (Eulerian) to determine the velocity and distribuition of gas and solids in a Wire-Duct ESP. The forces due to the electric fields and charged particles is determined from the charge simulation method (CSM) coupled to multiphase continuum fluid dynamic model. The results show good agreement with discrete simulations and experimental results.**

***Index Terms*—Electrostatic precipitator; Wire-duct system; Charge Simulation Method.**

I. Introduction

Electrostatic precipitators equipment are very old, dating from the early twentieth century and even today are used successfully in the process of collecting particles in power plants and industries that use fossil materials for generating energy [1].

In this context, the techniques and methods used in models to predict the behavior of gases, particulates and the electric fields are evolving.

An approach based on physical modeling using computational fluid dynamics multiphase (CFD Computational Fluid Dynamics) has increased in recent decades and gaining wide acceptance as a design tool for devices where exist the presence of gas and solids in the medium.

There are at least five possible methods used to describe the gas-solids flow, Direct Simulation (DNS), Lattice-Boltzmann (LBM), discrete element (DEM), direct simulation Monte Carlo (DSMC) and multiphase particles in cells (MPPIC) each of these methods has its particularities with respect to effort spent on modeling and processing time [2].

This methodology proposed here, disregards up paths of individual particles (Eulerian) in order to reduce the computational time cost [3]. The information regarding the charging process, electric field and potential are obtained from the CSM.

II. Multiphase Continuum Formulation

Two approaches are commonly used to arrive at equation continuous multiphase flows, averaging methods and mixture theory, both approaches come in a set of balance equations for mass, momentum and energy. The equation for the moment the solid phase is given by (1)

$$\left[\frac{\partial}{\partial t}(\varepsilon_m \rho_m U_{mi}) + \frac{\partial}{\partial x_j}(\varepsilon_m \rho_m U_{mj} U_{mi})\right] = -\varepsilon_m \frac{\partial P_g}{\partial x_i} + \frac{\partial \tau_{mij}}{\partial x_j} - \sum_{m=1}^{M} I_{mli} + \varepsilon_m \rho_m g_i \tag{1}$$

Where the subscripts g and m stand for gas and solids phase respectively; ε stands for volume fraction; U stands for velocities; ρ stands for density; τ_{mij} is the gas-phase stress tensor, I_{mli} is the momentum transfer between phases and $\varepsilon_m \rho_m g_i$ is the body force due to gravity.

It is possible to predict the magnitude velocities of charged particles flowing in the ESP from the equation of moment (1) and CSM .

III. Charge Simulation Method

The charge simulation method was initially created in order to be an efficient method for accurate calculation of divergent fields, has been used in some studies to compute the electric field and particles charging in ESPs as in the case presented in [4].

The basic working principle of the method is quite simple, once defined the types of charges and their locations, it is possible to relate the potential ϕ_i with charge Q_j, quantitatively anywhere.

In the conventional method, the number of contour points is equal to the number of charges. Then charges can be determined through (2) [5].

$$[P]_{n,n}[Q]_n = [\phi]_n \tag{2}$$

Where:

$[P]_{n,n}$ the coefficient matrix of potential;

$[Q]_n$ is a column vector with the values of the unknown charges;

$[\phi]_n$ is a column vector with the values of potential.

For example for a cartesian coordinate system, the field $\overrightarrow{E_i}$ at a point within the domain is given by (3).

$$\vec{E_i} = \left[\sum_{j=1}^{n} \frac{\partial P_{ij}}{\partial x} Q_j\right]\vec{a_x} + \left[\sum_{j=1}^{n} \frac{\partial P_{ij}}{\partial y} Q_j\right]\vec{a_y}$$
$$= \left[\sum_{j=1}^{n} (f_{ij})_x Q_j\right]\vec{a_x} + \left[\sum_{j=1}^{n} (f_{ij})_y Q_j\right]\vec{a_y} \quad (3)$$

Where $(f_{ij})_x$, $(f_{ij})_y$ are the field strength or field coefficients in the direction of the unit vectors $\vec{a_x}$ and $\vec{a_y}$.

It is also possible to calculate the electric fields in the presence of space charges, it is necessary only to calculate the charges on the electrodes since the charges in space are known (4).

$$[P]_{n,n}[Q]_n + [P_s].[Q_s] = [\phi] \quad (4)$$

As $[P_s]$ and $[Q_s]$ are known (4) the right side of the equation becomes a vector calculation of the electrodes charge is done the same way as in the case without the presence of charges in the space.

IV. Multiphase Continuum Flow and Charge Simulation Method

It is possible to determine the forces acting on the particles with the information of charges and fields provided by the CSM through the equation of conservation of momentum for the solid phase equation (1) including the term $\vec{F_e}$ effect of electric force on the particles resulting in equation (5).

$$\left[\frac{\partial}{\partial t}(\varepsilon_m \rho_m U_{mi}) + \frac{\partial}{\partial x_j}(\varepsilon_m \rho_m U_{mj} U_{mi})\right] =$$
$$-\varepsilon_m \frac{\partial P_g}{\partial x_i} + \frac{\partial \tau_{mij}}{\partial x_j} - \sum_{m=1}^{M} I_{mli} + \varepsilon_m \rho_m g_i + \vec{F_e} \quad (5)$$

Where the electric force $\vec{F_e}$ is give by (6)

$$\vec{F_e} = \rho_s \vec{E} \quad (6)$$

Based on equation (5), (6) and CSM is possible to predict the magnitude velocities of charged particles flowing in the ESP.

V. Results

Simulations were based on the model described in [6] the grid and the results are shown in Fig. 1, Fig. 2 and Fig. 3, the results shown by the model developed by the author compared [6] were close. Importantly, the processing time for the simulations were greatly reduced due to the fact of considering the continuum model compared with the discrete model.

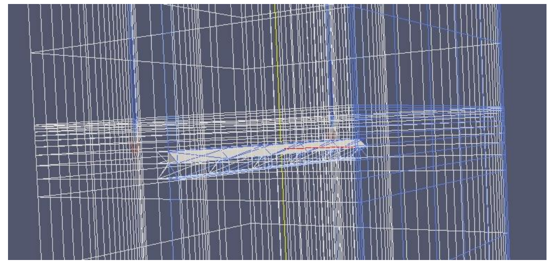

Figure 1: Computacional grid in the region of discharge electrode

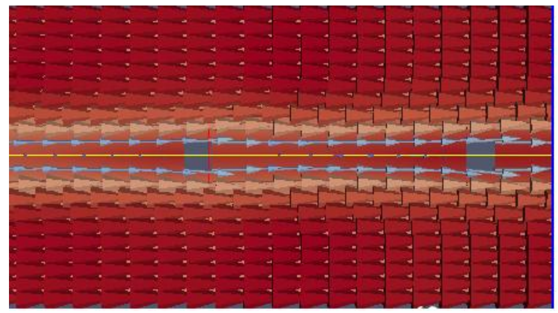

Figure 2: Flow field distribution in the ESP

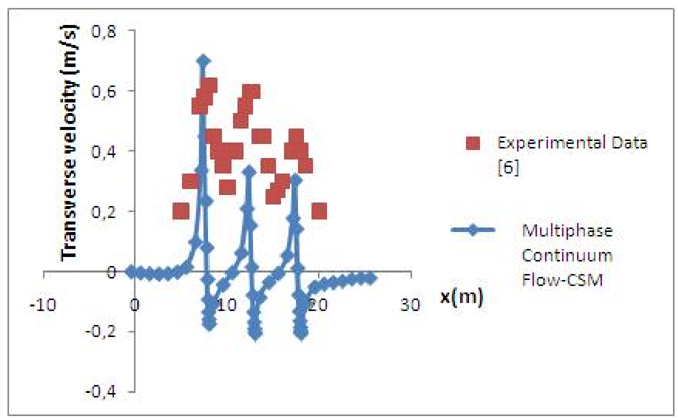

Figure 3: Transverse particle velocities along the x axis at y equal 5 mm from collecting plate

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