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Journal of Electrostatics 63 (2005) 923–927
Journal of ELECTROSTATICS
www.elsevier.com/locate/elstat

Behavior of polydisperse dust in electrostatic precipitators

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Available online 25 March 2005

Abstract

Continuous upgrading of electrostatic precipitators (ESPs) is forced by more and more strict dust emission requirements limiting emission level below 30 mg/m$_3$N and regulations for PM 10 and PM 2.5. In order to fulfil the required improvement of ESPs both the numerical model computations and laboratory and in situ measurements have to be carried out. Therefore, our existing numerical model (worked out on the basis of the co-operation of experts of high-voltage engineering and experts of fluid mechanics) had to be upgraded from a monodisperse, steady state model into a polydisperse one.

The paper represents the new development of our ESP model, the theoretical background and its structure. Results of calculation are also presented to compare differences between monodisperse and polydisperse cases.
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Keywords: Modeling; Electrostatic precipitator; ESP; Polydisperse dust load

1. Introduction

Polydispersity of the dust phase plays significant role in the operation and especially in the efficiency of electrostatic precipitators (ESP), its effect cannot

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0304-3886/$ - see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.elstat.2005.03.062

be neglected in most cases. Some of the latest development in the new theory and practice (e.g. the so called agglomerator unit at the inlet of the ESP published recently [1]) especially underline the analysis of the behavior of polydisperse dust particles and force the researchers to turn to polydisperse ESP models [3].

For that purpose, our previous model published in [2] was upgraded. The first goal of the development was to handle polydisperse dust load, the second was to improve modeling capability for the examination of the time dependencies of the precipitation process. Therefore, in the new model particle movement calculations are made for different time steps instead of finding the steady state. Regarding that our new model can follow the time dependence of the processes, it is possible to compare the effect of impulse energisation with DC supply mode, too.

2. Brief description of the ESP model

The new version of our ESP model contains different modules. The first module computes the velocity distribution of the gas stream using a simple approach of a 2D turbulent boundary layer Eq. (1). The electrostatic forces acting on the gas phase and the gas–particle and particle–particle interactions are neglected in this form. The straight forward numerical scheme results of the gas velocity components, v_x and v_y in direction x and y, respectively. V is the velocity outside the boundary layer while v_t is the turbulent viscosity. (Each quantity should be substituted according to their SI units into each equation of the paper.)

$$v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} = V \frac{\mathrm{d}V}{\mathrm{d}x} + \frac{\partial}{\partial y}\left(v_t \frac{\partial v_x}{\partial y} \right). \tag{1}$$

For electric field calculation one half-channel of the precipitator is divided into n pieces of elementary volumes containing constant space charge $\rho_{v1} \ldots \rho_{vn}$, while collecting plates and corona wires are substituted by surfaces with k pieces of surface charge values $\rho_{v1} \ldots \rho_{vk}$. The module solves matrix Eq. (2) for one half-channel of the precipitator.

$$\underline{\underline{A}}\, \underline{\rho}_S + \underline{\underline{B}}\, \underline{\rho}_V = \underline{\varphi}\,. \tag{2}$$

In this equation $\underline{\varphi}$ represents the column vector containing the voltage values of the elementary part of electrodes ($\varphi_1 \ldots \varphi_m$), 0 for the elements of the collecting plate, U predefined voltage for the elements of corona wires. Column vectors $\underline{\rho}_S$ and $\underline{\rho}_V$ contains values of $\rho_{v1} \ldots \rho_{vn}$ and $\rho_{v1} \ldots \rho_{vk}$ respectively. Parameters in $\underline{\underline{A}}$ and $\underline{\underline{B}}$ are determined according to the geometry (distance between a certain charge amount and the place where the potential must be calculated).

In practice $\underline{\varphi}$, $\underline{\underline{A}}$ and $\underline{\underline{B}}$ are known, vectors $\underline{\rho}_S$ and $\underline{\rho}_V$ have to be determined. First, let us focus on $\underline{\rho}_V$. The total space charge contains two parts, an ionic and a dust one. Denoting the scalar–vector functions of these quantities by ρ_{ion} and ρ_{dust}, equation system (3) has to be solved. In the equation system $\boldsymbol{J}$ is the ionic current

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