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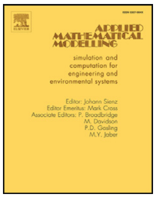

# Predictions of the gas–liquid flow in wet electrostatic precipitators

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ABSTRACT

Based on Computational Fluid Dynamics (CFD), the present paper aims to simulate several important phenomena in a wet type ESP from the liquid spray generation to gas-droplet flow in electric field. A single passage between the adjacent plates is considered for the simulation domain. Firstly, the electric field intensity and ion charge density are solved locally around a corona emitter of a barbed wire electrode, which are applied to the entire ESP using periodic conditions. Next, the Euler–Lagrange method is used to simulate the gas-droplet flow. Water droplets are tracked statistically along their trajectories, together with evaporation and particle charging. Finally, the deposition density on the plate is taken as the input for the liquid film model. The liquid film is simulated separately using the homogenous Eulerian approach in ANSYS-CFX. In the current case, since the free surface of the thin water film is difficult to resolve, a special method is devised to determine the film thickness.

As parametric study, the variables considered include the nozzle pressure, initial spray spreading patterns (solid versus hollow spray) and plate wettability. The droplet emission rate and film thickness distribution are the results of interest. Main findings: electric field has strong effect on the droplet trajectories. Hollow spray is preferred to solid spray for its lower droplet emission. The liquid film uniformity is sensitive to the plate wettability.

## 1. Introduction

Electrostatic Precipitator (ESP) can effectively remove fine particulate matters from many industry emission sources, such as exhaust gases from coal fired power plants [1]. ESPs operate in a three-step process – particle charging, collecting and finally cleaning the dust layer off the collection surface. When using the traditional dry ESP, the main challenges come from the difficulty of collecting ultra-fine particles of high electric resistivity. As an alternative, the wet ESP technology applies water spray, or running water on the collecting plate [2–4], so that the dust collected can be washed into the hopper without the use of mechanical rapping. The liquid film should be controlled such that minimum liquid is consumed without causing dust accumulation. Moreover, re-entrainment can be eliminated so that the Wet ESP allows a much higher gas velocity, which would make the design more compact compared with the traditional dry ESP. In addition, droplets and dust particles may interact via some mechanisms such as impact, space charge, which enhance the collection efficiency of dust particles

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**Nomenclature**

| | |
|---|---|
| $b$ | electric mobility of ion charge ($\mathrm{m^2\,s^{-1}\,V^{-1}}$) |
| $C_P$ | specific capacity ($\mathrm{J\,kg^{-1}\,K^{-1}}$) |
| $D$ | diffusivity coefficient ($\mathrm{m^2\,s^{-1}}$) |
| $d_p$ | particle diameter (m) |
| $\boldsymbol{E}$,$E$ | electric field ($\mathrm{V\,m^{-1}}$) |
| $\boldsymbol{F}$ | force (N or $\mathrm{N\,m^{-3}}$) |
| $H_{\mathrm{ev}}$ | heat of evaporation ($\mathrm{J\,kg^{-1}}$) |
| $k$ | turbulence kinetic energy ($\mathrm{m^2\,s^{-2}}$) |
| $k_{\mathrm{B}}$ | Boltzmann constant ($\mathrm{J\,K^{-1}}$) |
| $m$ | mass (kg) |
| Nu | Nusselt number |
| $n_e$ | number of charge on a particle |
| $n_p$ | particle number density ($\mathrm{m^{-3}}$) |
| $p$ | pressure (Pa) |
| $q$ | charge (C) |
| $q_e$ | unit charge (C) |
| $S_\phi$ | source of generic variable |
| Sh | Sherwood number |
| $T$ | temperature (K) |
| $t$ | time (s) |
| $\boldsymbol{u}$ | velocity vectors ($\mathrm{m\,s^{-1}}$) |
| $V$ | electrical potential (V) |
| $W$ | molecular weight ($\mathrm{kg\,mol^{-1}}$) |
| $X$ | mole fraction |
| $\kappa$ | dielectric constant |
| $\varepsilon_0$ | electrical permittivity of free space ($\mathrm{F\,m^{-1}}$) |
| $\rho$ | density ($\mathrm{kg\,m^{-3}}$) |
| $\rho_{ion}$ | space charge density ($\mathrm{C\,m^{-3}}$) |
| $\lambda$ | thermal conductivity ($\mathrm{J\,m^{-1}\,K^{-1}}$) |
| $\mu$ | dynamic viscosity (Pa s) |
| $\mu_t$ | turbulent eddy viscosity (Pa s) |
| $\phi$ | generic variable (temperature, mass fraction) |
| $\Gamma_\phi$ | diffusivity of generic variable (Pa s) |
| $\Gamma_{\mathrm{min}}$ | minimum wetting rate ($\mathrm{kg\,m^{-1}\,s^{-1}}$) |
| $\delta$ | falling liquid film thickness (m) |
| $\sigma$ | surface tension coefficient ($\mathrm{N\,s^{-1}}$) |
| $\sigma_\phi$ | turbulent Prandtl number of generic variable |

*Subscript*

| | |
|---|---|
| $g$ | gas phase |
| $l$ | liquid phase |
| $p$ | particle phase |
| $dis$ | dispersion |

[5,6]. Introduction of liquid spray also changes the gas flow conditions (e.g., temperature, humidity) which affect favourably the electric field and particle charging, although the fundamental mechanism is yet to be fully understood.

Particularly, spray can generate mists and increase the moisture in the gas, which favors ultra-fine dust particle charging. For example, experimental results of Chen et al. [7] showed that without fine water mist, nanoparticle collection efficiency was 67.9–92.9%, which was greatly enhanced to 99.2–99.7%, via a mechanism “condensational growth”, when the Wet ESP was operated with fine water mist.

Complicated transport phenomena are involved in such an ESP process, e.g., multi-scale, multiphase flows (gas, liquid and solid particle), multi-field (electric field, flow field and force field in dust cake formation) [8]. Particle collection efficiency depends strongly on the gas flow, the behaviours of spray droplets, and the distribution of liquid film. In this context, mathematical/numerical simulations in terms of flows, heat and mass transports can provide more detailed process information related to wet type ESP. The present paper reports the recent progress on the development of a comprehensive ESP model, with a particular objective to investigate the liquid phase flow.

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