

Computational Modeling of the Electrohydrodynamics Influencing Trace Mercury Adsorption Within Electric Utility Electrostatic Precipitators

H. Clack¹

¹University of Michigan, Ann Arbor, MI, USA

Abstract

INTRODUCTION: Anthropogenic mercury (Hg) emissions into the atmosphere increase the risk of neurological and neonatal health effects in humans through fish consumption. The U.S. Environmental Protection Agency (EPA) recently (2012) promulgated the first regulations for mercury emissions from coal-fired power plants [1] and 140 countries recently signed the United Nations Environment Programme's Minamata Convention, a legally binding treaty to reduce mercury in the environment [2].

Anticipating the EPA rule, more than a decade of R&D by U.S. government agencies and industry (see reviews by Pavlish et al. [3] and Srivastava et al. [4]) has produced several technological approaches to controlling mercury emissions from coal combustion, the most mature of which is the injection of a powdered mercury sorbent, typically activated carbon, into the flue gas upstream of the particulate control device (PCD). As most such PCDs are electrostatic precipitators (ESPs), both in the U.S. (70%) and world-wide (>90% in India and China), the effectiveness of the process is dependent on the complex interplay of physico-chemical phenomena within ESPs. The present study reveals previously unknown details of this interplay that far exceed previous quasi-1-D analyses [5-8].

USE OF COMSOL MULTIPHYSICS®: Traditional ESPs consist of dozens of high-voltage discharge electrode wires, at whose surfaces oxygen molecules are ionized. Electrically grounded collection electrode plates interspersed between rows of discharge electrodes induce an electric field that accelerates the ionized molecules, which in turn transfer their momentum as they collide with neutral molecules and suspended particles. Thus, accurate representation of mercury captured within ESPs requires the computation of the coupled electric and space charge fields, velocity field, and particle volume fraction distribution and trajectories, with mercury removal occurring by adsorption from the interface between the suspended particles and the gas. The COMSOL Multiphysics® Electrostatics interface (.es) was used to solve for the electric potential (voltage) distribution within the inter-electrode region of a representative 2-D ESP section containing three -50 kV wire discharge electrodes. Through separate iterations, Poisson's equation and current continuity were simultaneously satisfied. The Turbulent Single-Phase Fluid interface (.spf2) was used to calculate the fluid velocity field under the influence of the

volumetric body force stemming from the charge density and electric fields. The computed fluid velocity field served as the initial condition for the Mixture Model interface (.mm), which determined the spatial distribution and trajectories of suspended sorbent particles. Finally, the computed mixture model solution was used as a mercury flux boundary condition to calculate the decay in mercury concentration in the fluid using the Transport of Dilute Species interface (.chds).

RESULTS: Figure 1 illustrates the complex, electro-hydrodynamically-influenced flow field in the inter-electrode region. Figures 2 and 3 present gas-phase mercury concentrations associated with (separately) wall-bound (Figure 2) and suspended (Figure 3) mercury sorbent particles. The overall removal efficiency would be the cumulative effect of both figures.

CONCLUSIONS: These simulations reveal the first detailed interrogation of the electro-hydrodynamic phenomena occurring within ESPs acting as both PCDs and trace gas adsorbers. Such simulations will enable unprecedented optimization of these concurrent processes.

Figures used in the abstract

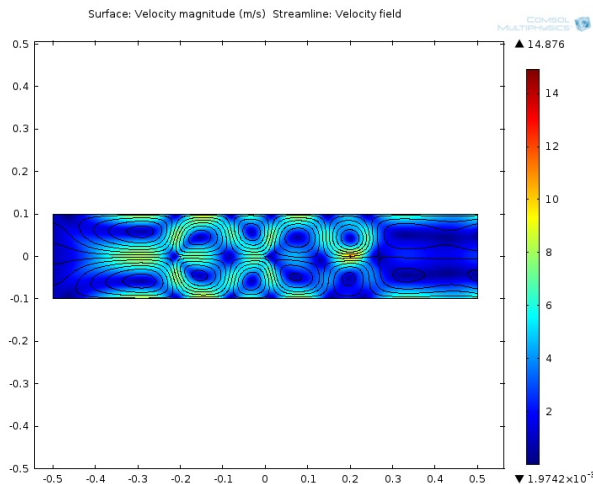


Figure 1

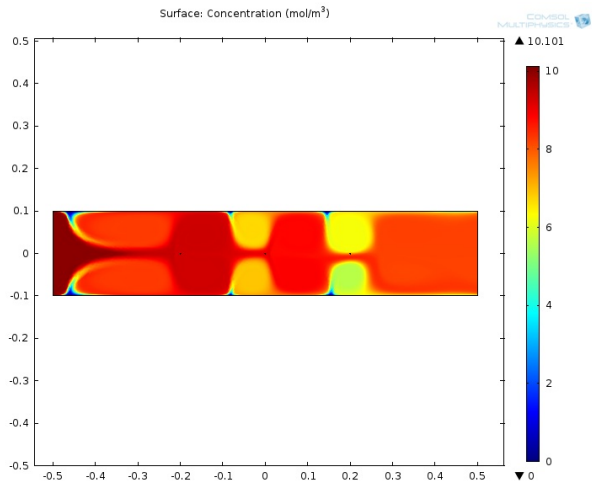


Figure 2

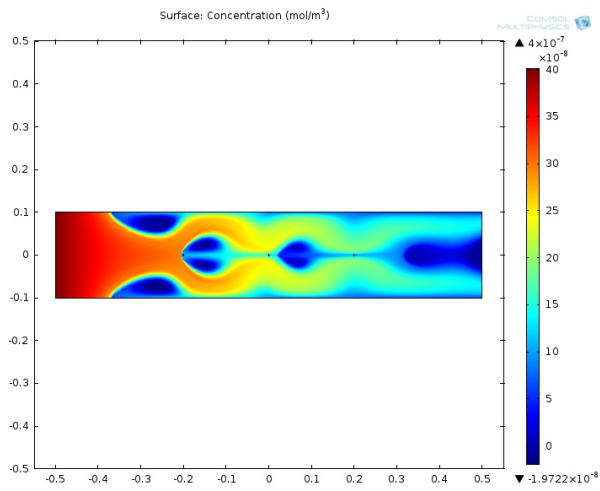


Figure 3