Aerosol modelling and pressure drop simulation in a sieving electrostatic precipitator

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Abstract

This paper first describes so-called sieving electrostatic precipitator suitable for efficient and cost-effective cleaning of polluted gases of both large and ultra-fine particulates in a very broad temperature range. In SEP the particulate-laden gas is passed through a set of closely packed and charged fine-wire screens. In the last three years, a large number of fly ash collection-efficiency experiments have been conducted—first, on a bench-size unit both at room and elevated temperatures and, in a laboratory pilot-scale setting. Most recently, a consortium led by American Electric Power (AEP), Ohio University, Ohio Coal Development Office and PECO have built and started tests on a pilot slip-stream unit in AEP's plant in Conesville, Ohio.

However, deeper understanding of SEP calls for numerical treatment of particulates charging, their agglomeration, and various particulate-capturing mechanisms (field and diffusion charging, interception by screen wires etc.) simultaneously taking place in laminar flow conditions. The paper describes our attempt to model this process.
Keywords: sieving electrostatic precipitator, modelling, particle charging, coagulation, particulate capture.

1 Introduction

Sieving electrostatic precipitator (SEP), developed at Ohio University, is the next generation of electrostatic precipitators. It could offer better particle collection efficiency than conventional precipitators. Also, the step forward is its small size, lower operational and overall cost, and enhanced ability to collect submicron-sized particles. The main difference between SEP and conventional electrostatic precipitators is in the collecting units: conventional precipitators

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have plates parallel to the air flow, while SEP utilizes screens that are set perpendicular to the gas flow and therefore fly ash is being sieved—hence the term “sieving”. This difference results in new particle-capturing mechanisms which differ from those in conventional precipitators.

In SEPs screens are under high DC voltage of about 40-60 kV. The SEP typically operates at gas velocities about 1 m/s, particulate concentration 3-10 g/m^3, DC current of 40-60 kV. Screen openings are 500 microns or less and the screen spacing is about 5 mm. For more details see Pasic et al. [1].

This paper attempts to recognize the complexity of the particle behaviour in the collecting equipment—in particular the SEP. Furthermore, it suggests necessary steps to resolve some of these problems utilizing numerical methods and existing software packages or combining those specialized packages into a single one capable of handling this multidisciplinary modelling.

2 Modelling/results

The SEP is a new technology. It is not completely tested and therefore fully optimized. Many parameters have yet to be tested and validated. This could be done by elaborate and expensive laboratory parametric testing. Hopefully, some or eventually a large number of these research steps could be replaced or at least supplemented with numerical treatments. This could greatly reduce research time and the overall cost. Computational fluid dynamic software FLUENT is one such example, offering opportunity to make SEP research more rapid. In addition, with various software plug-ins it could possibly depict most of the processes which particles undergo in the SEP.

In SEP, particles are captured with almost all possible mechanisms. The dominant ones are due to field and diffusion charging, coagulation (of small into larger particles that are easier to capture), and capture-by-obstacles, such as by impaction and interception. Nowadays, most of these mechanisms are quite well described in the literature and are (or could be) easily software-implemented.

There exist numerous numerical approaches and the corresponding software for numerical simulations of some of those specific aspects, such as particle interaction with other particles or interacting with obstacles to which they could possibly attach. However, most of these simulations are restricted to applications in a limited space domain or to small particle numbers, etc.—issues primarily related to a limited computer capacity. Indeed, as computer technology advances, new opportunities emerge for better implementation of those already developed numerical methods.

In what follows, we will illustrate just some aspects of that modelling through simulations of the gas pressure drop and screen clogging. For other modelling results, such as collision frequencies of charged particles and their agglomeration, and more detailed simulation see Telenta [2].

2.1 Pressure drop

Pressure drop is one of the most important design parameters related to efficacy and efficiency of any particle collection device. In SEP, particulate-laden gas is forced through tens of screens. Determining the pressure drop requires the gas flow simulation as the first step. Many CFD software packages are available and could be used to accomplish this step. One such package—FLUENT was used in this work (for more details see Telenta [2]). Also, in Telenta [2] the user defined functions (UDFs) have been used, as well, since FLUENT, as it is, is limited in certain aspects of pressure drop simulation. UDFs are additional features that are easily implemented in FLUENT. In the case of SEP, UDF is utilized in conjunction with so-called porous media to properly represent the pressure drop created by sets of screens, since velocity and, therefore, pressure profiles in front of the screens are not uniformed (Figs 1 and 2, Telenta [2]).

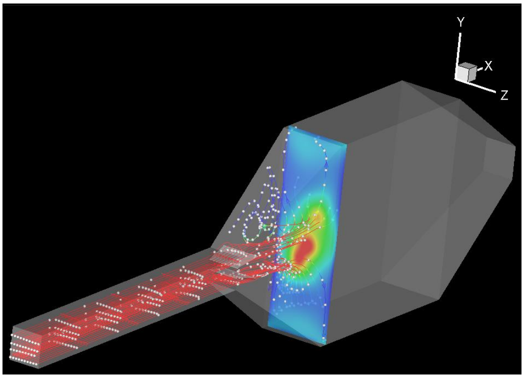

Figure 1: Velocity profile with streamlines in front of the first screen [2].

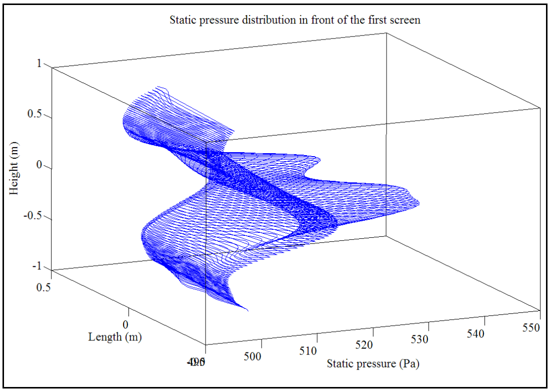

Figure 2: Static pressure profile [2].

This gas flow analysis takes care of the fluid flow part and gives a solid basis for the future upgrades concerning the particle collection. However, FLUENT offers only limited options regarding the particle simulation, Triesch et al. [6], and needs to be supplemented with additional UDFs in order to be applied to SEP simulations. Without UDFs, it cannot be used for modelling particulates charging, coagulation, and obstacle collection.

2.2 Particle charging

Particle charging is an important issue in SEP. Particles are charged in a DC high-voltage electric field which creates a strong corona field near tips of discharge electrodes. Thus, after acquiring the charges, particles stick to each other, due to agglomeration, or to screen wires. These phenomena, such as Coulomb equations for interactive forces between particles, for example, are well known and documented in the literature and adequate UDFs can be developed and implemented in FLUENT. One such example is DEM Solutions' [3] software jointly developed with NASA.

2.3 Coagulation

Coagulation process could be implemented in and modelled by FLUENT. Namely, once particles' position are tracked by FLUENT, and when two or more particles get close enough, their coagulation can be modelled by a UDF which is based on well established theory; for more details and results see Telenta [2].

2.4 Collection by obstacles and screens clogging

These processes can be dealt with in a manner similar to that used in coagulation studies. Particle position, which is calculated by FLUENT, can be compared using UDF in reference with the screen wire position, and if the obstacle is in the particle way, the particle is captured. After a certain amount of particles are captured and piled, clogging of the screen can occur.

Some work has already been done in software different than FLUENT, Figs. 3-5, Tafreshi at al. [4]. This is done on a micro-level analyzing a small number of particles and obstacles.

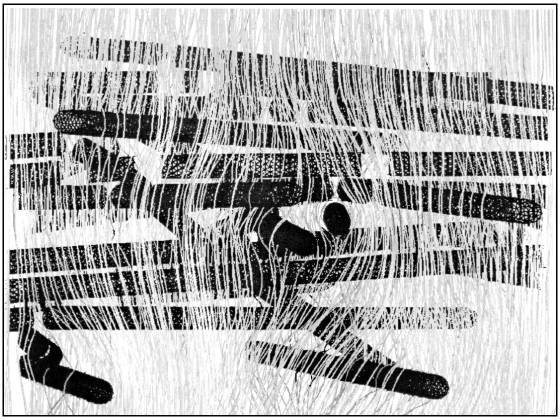

Figure 3: Flow path lines between fibers [4].

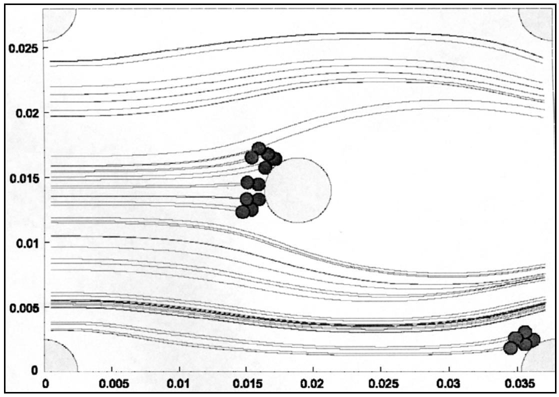

Figure 4: Particle deposition on a cylindrical obstacle/fiber [4].

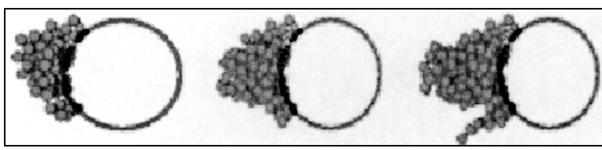

Figure 5: Progression of particle deposition on a cylindrical obstacle/fiber [4].

Also, FLUENT can be combined with EDEM software to do this kind of simulation, Fig. 6 [3].

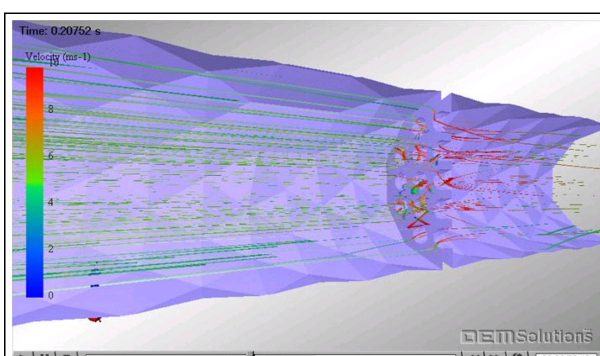

Figure 6: Filter screen designed to catch large particles; stream view [3].

3 Conclusions

This paper attempts to recognize the complexity of the particulate behaviour and its capture in sieving electrostatic precipitator. A deeper understanding of this process calls for numerical treatment of particulates charging, agglomeration, and various particulate-capturing mechanisms, such as field and diffusion charging, interception by screen wires, etc., all simultaneously taking place in laminar flow conditions. The paper describes our attempt to model this process.

Furthermore, we have made an attempt to resolve some of these issues by utilizing numerical methods and existing software packages or combining those specialized packages into a single one capable of handling this multidisciplinary modelling, Telenta [2].

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