Flow Of Air In A Plate DMA: How COMSOL Multiphysics® Revealed A Geometry-induced Effect

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Abstract

A plate Differential Mobility Analyser (DMA) is composed of two parallel plates between which aerosol-laden air flows. A specific device charges the aerosol particles electrically before they enter the DMA. Applying a voltage difference between the plates allows to deflect the particles depending on their weight and electric mobility and to separate them in different classes.

We designed and built one such device with the long-term objective of separating particles according to their shape (e.g. fibrous vs. non-fibrous). Separation is understandably better if the particles enter the DMA as a thin "beam". We therefore coupled the DMA with an electrostatic precipitator that could produce such a "beam" in a sheath of clean air. This part had to be vertical since we did not want gravity to interfere at this stage. On the other hand, the DMA must obviously be horizontal: the two devices (precipitator and DMA) had to be connected by an elbow pipe as illustrated on Figure 1. The outlet of the DMA was divided in two parts so as to collect the particles in the upper and lower half separately. Figure 1 also illustrates the supposed trajectory of the particles "beam".

Upon test, it was found that the transfer function (proportion of particles exiting in the upper or lower part, as a function of applied voltage) was much broader than expected, which is clearly detrimental to the resolution of the system. One of the possible explanation for this was the development of vortices in the elbow pipe, of the same nature as the Dean vortices in a curved duct. This possibility appeared unlikely at first since we estimated the Dean number to be too low (about 30) for vortices to appear; but on the other hand the elbow pipe has a fairly complicated geometry that makes the calculation of the Dean number difficult.

We therefore launched CFD calculations with the "laminar flow" interface of COMSOL Multiphysics®. These calculations showed a twisting movement of the flow lines in the elbow pipe as illustrated in Figure 2. This movement corresponds to two counter-rotating vortices indeed similar to Dean vortices and its extent is correlated with the flow rate in the system. Calculations of particle trajectories with the COMSOL Multiphysics® Particle Tracing Module actually confirmed that the edges of the particle "beam" tended to wrap as shown by Figure 3.

Based on these calculations, it was possible to devise modifications in the electrostatic precipitator to eliminate the troublesome edges of the particle "beam".

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Figures used in the abstract

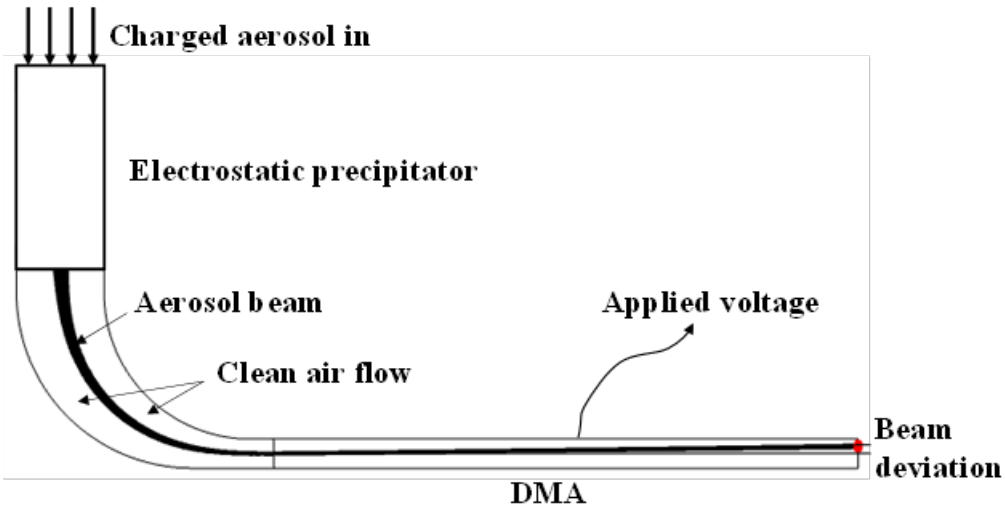

Figure 1 : A sketch of our device for particle separation.

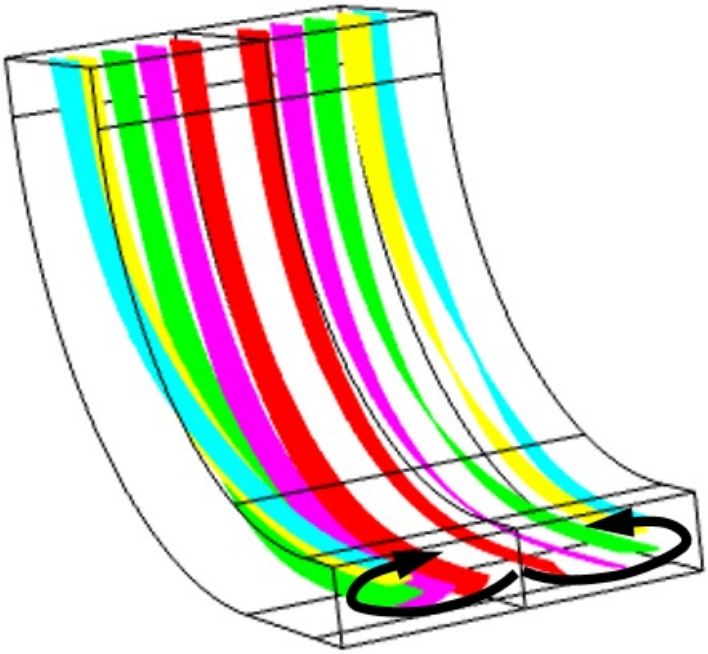

Figure 2 : Flow lines in the elbow pipe

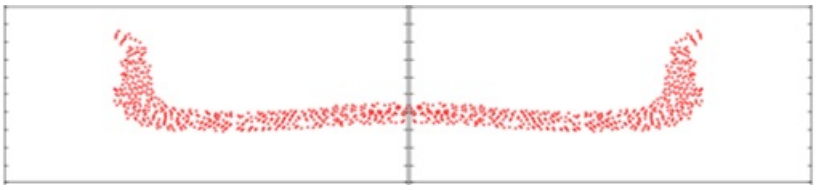

Figure 3 : Shape of the particle “beam” at the entrance of the DMA