Extended Abstract

Nanoparticle Trajectories In An Electrostatic Precipitator: Numerical Simulation And Experimental Validation

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Motivation

Electrostatic precipitators (ESP) can be used for the collection of airborne particles. These particles, first neutralized and selected with a DMA, are precipitated on an electrode where a high voltage is applied. In the frame of the EMRP Project ENV02, an electrostatic particle precipitator was built to sample aerosol particles for analysis with Transmission Electron Microscope (TEM) or Atomic Force Microscope (AFM).

In this study, we simulated the trajectories of the particles in the precipitator and studied the influence of an AFM sample holder on the precipitation efficiency.

Method

We first validated the simulation against experimental data without a sample holder. The simulation with sample holder can then be used to optimize the parameters (i.e. sample flow, voltage, …) for particle collection.

In the simulation, a 2D simplified geometry of the ESP is drawn and finely meshed. The stationary electric field and nitrogen laminar flow are computed with the software COMSOL Multiphysics. Uniformly distributed spherical particles are released at the entry of the cavity in a nitrogen flow (0.3lpm). All particles are released at time 0 with the same velocity as the gas, which exhibits a fully developed laminar profile. Particles are assumed to have a 40 nm diameter and a positive +1 charge (ISO 15900). As the Cunningham slip correction factor is not taken into account in COMSOL, the voltage on the collecting electrode was multiplied by the corresponding factor (6 for a particle diameter of 40nm) (Hinds, 1982).

For the experimental validation, the new ESP is used. A high voltage (about 1kV) is applied on the electrode, which is electrically isolated with Teflon from the rest of the grounded cavity (fig. 2). Salt (NaCl) particles are generated from an Aerosol Atomizing Generator (AAG). Positively charged particles with 40 nm diameter are selected with a DMA and led into the ESP. The concentration of particles is measured with two condensation particle counters (UCPC 3776 from TSI and CPC 5.400 from Grimm) in front of and behind the ESP (fig. 1). The collection efficiency is given by:

$$Coll.eff. = \frac{conc._{CPC1} - conc._{CPC2}}{conc._{CPC1}}$$

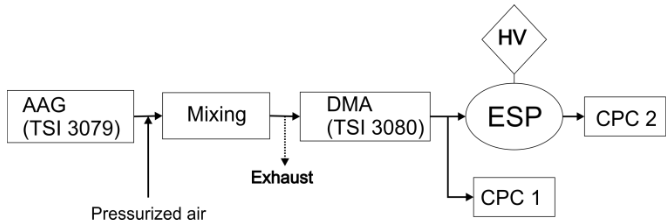

Figure 1. Schematic setup for the experimental validation.

Electrostatic charging is important with unipolar charged particles; the use of conductive tubing after the DMA is recommended for reliable results.

Results

Figure 2 displays the particles trajectories and vertical velocities of 40nm particles in a 0.3lpm nitrogen flow at -800V without sample holder.

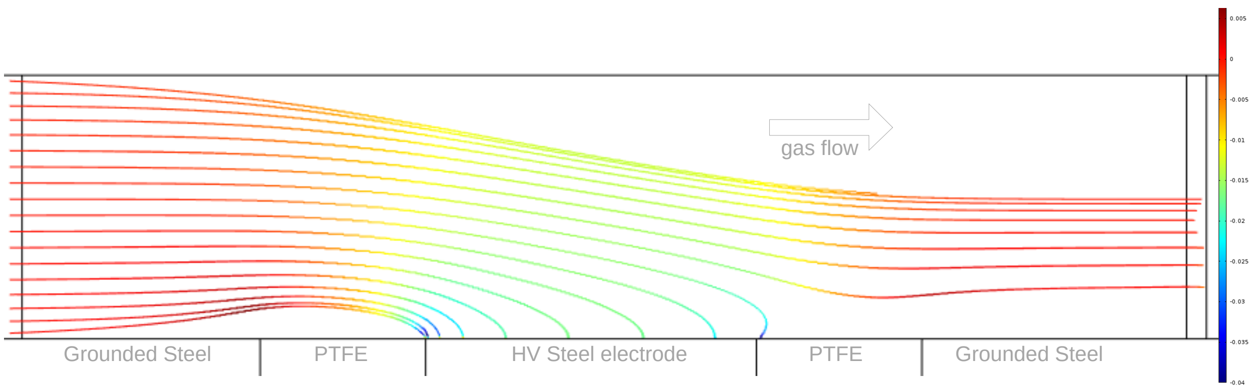

Figure 2. Particles trajectories in a 0.3lpm flow under a -800V voltage. The color bar indicates the vertical velocities.

Counting the particles on the electrode at the end of the simulation reveals 50% collection efficiency at -800V and 80% at -1500V. For the validation of the simulation, the numerical data are compared with experimental results. Figure 3 shows the results obtained with two sets of data. The CPCs were interchanged in order to consider the influence of the counting efficiencies of the two different devices. There is a good agreement between both experimental and numerical results.

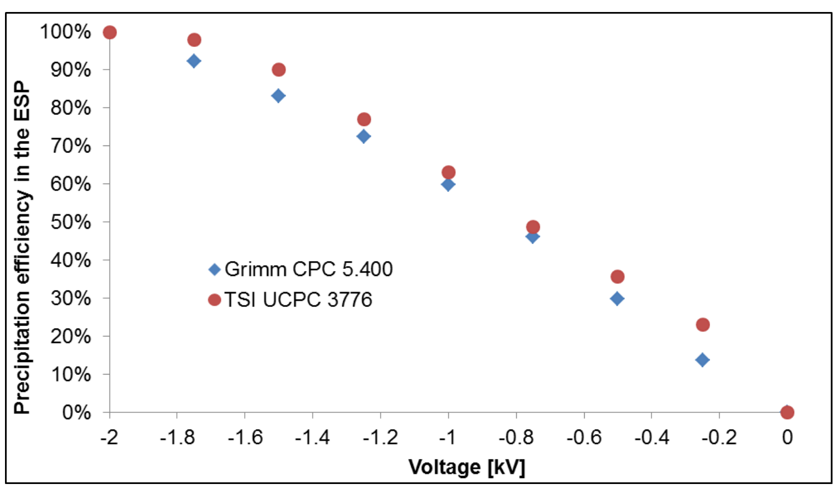

Figure 3. Experimental data of the precipitation in the ESP for different voltages. The device in caption is CPC2 behind the ESP in the experimental setup in figure 1.

For the simulation of the particles trajectories with AFM sample holder, mica and silicon layers were used. Two thicknesses were assumed (400 and 800 µm).

The AFM sample holder modifies the electric field strength and the gas flow. The electric field is more intense in the cavity with the sample holder, especially in the vicinity of the holder. Figure 4 shows the change in the vertical component of the electrical field caused by the presence of the sample holder. The flow profile is also dependent on the sample holder (fig. 5).

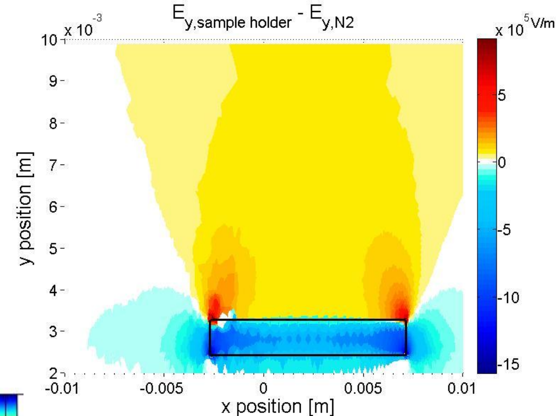

Figure 4. Change of the electric field in the vertical direction due to the sample holder (800µm Si).

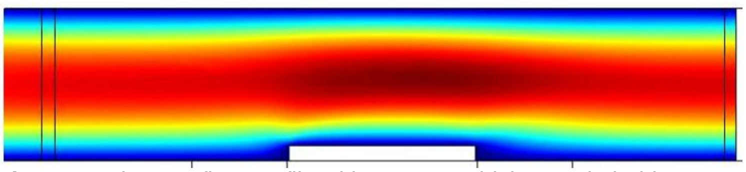

Figure 5. Nitrogen flow profile with a 800µm thick sample holder.

With these two effects, the particle precipitation is slightly more efficient in the presence of the sample holder. With a 800µm silicon layer, a precipitation efficiency of 55 and 100% is reached for voltages of -800 and -1500V respectively (fig. 6). The influence of the material (mica or silicon) is negligible as similar collection efficiencies are obtained with the same computation parameters. While voltage has a strong influence on the precipitation efficiency, the influence of the thickness of the holder seems lower: when increasing the thickness from 400 to 800µm, the increase of the precipitation efficiency is less than 10%.

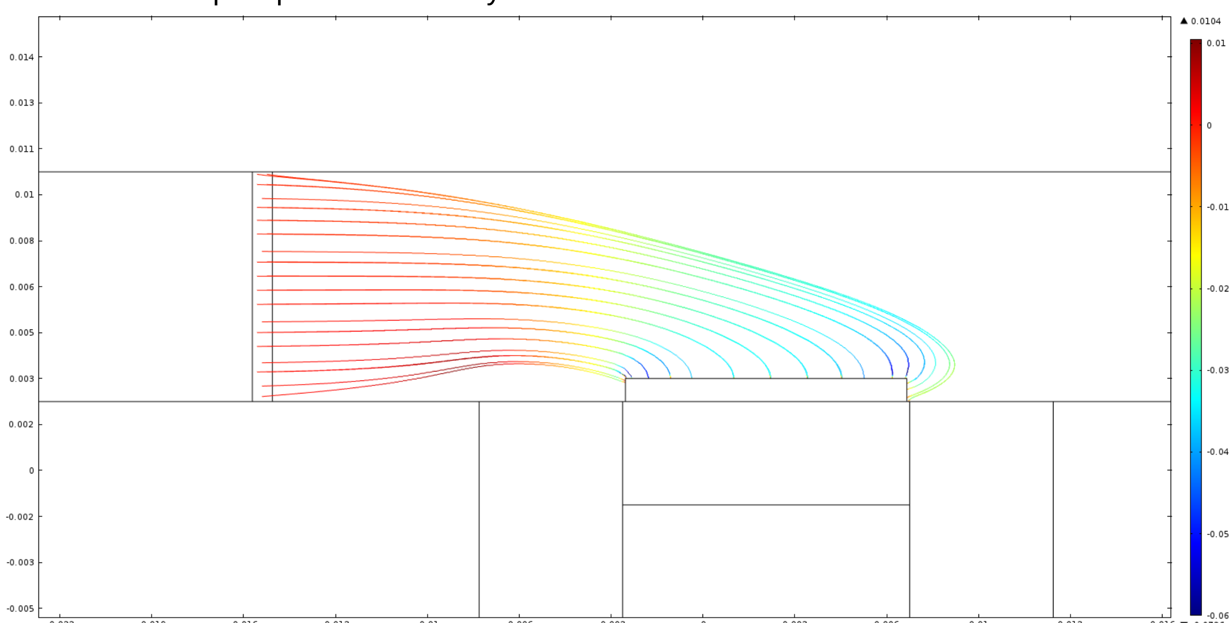

Figure 6. Particles trajectories and vertical velocities with a 800µm silicon layer at -1500V in a 0.3lpm nitrogen flow.

Conclusion

The computation of particles collection efficiency in an electrostatic particle precipitator without sample holder showed good agreement with experimental results. In the presence of the sample holder, the efficiency increased slightly: the electric field is more intense with the sample holder and the flow profile is modified. While the collection efficiency is highly influenced by the applied voltage on the electrode, the influence of the holder thickness seems much lower and that of the materials negligible.

References

ISO 15900:2009, Determination of particles size distribution – Differential electrical mobility analysis for aerosol particles.

Hinds W C, *Aerosol Technology: Properties, behavior, and measurement of airborne particles*, Johan Wiley and Sons, 1982, p. 407.

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Nanoparticle Trajectories In An Electrostatic Precipitator : Numerical Simulation And Experimental Validation

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Motivation and objective

Electrostatic precipitators (ESP) are used for the removal or collection of airborne particles. A voltage drop modifies the trajectories of charged particles, first neutralized and selected with a Differential Mobility Analyzer (DMA). In the frame of the EMRP Project ENV02, an electrostatic particle precipitator was built in order to sample aerosol for analysis with a Transmission Electron Microscope (TEM) or an Atomic Force Microscope (AFM).

In the present study, we investigated the trajectories of particles within the cavity of the precipitator and studied the influence of AFM sample holders on the collection efficiency.

We first simulated the particle velocities and trajectories without sample holder and validated the computation with experimental data. Then we simulated how the sample holder influences the electric field and the particles trajectories, in order to optimize the experimental parameters (i.e. sample flow, voltage, …) for particles collection.

Numerical simulation

- A 2D simplified geometry of the precipitator is drawn and finely meshed. Stationary electric field and nitrogen laminar flow are computed with the software COMSOL Multiphysics.
- Uniformly distributed spherical particles are released at time 0 at the entry of the cavity at the same speed as gas flow (0.3lpm). Particles are assumed to have a 40 nm diameter and a positive +1 charge.
- All particles in the precipitator are charged as they have passed through the DMA before. At such a size, less than 3% of particles have a multiple charge. (ISO 15900)
- As the Cunningham slip correction factor is not taken into account in COMSOL, the voltage was multiplied by the corresponding factor (6 for a particle diameter of 40nm). (Hinds, 1982)
- The influence of the charged particles (10^4/cm^3) on the electric field in the ESP is about 10^5 times smaller than the voltage drop.

Experimental Setup

- For the validation of the simulation, the new ESP is used. A high voltage is applied on the electrode (1cm x 1cm), which is isolated with PTFE from the grounded rest of the cavity (fig. 2).
- Salt (NaCl) particles are generated from an Aerosol Atomizing Generator (AAG). Positively charged particles with 40nm diameter are selected with a DMA and led into the ESP.
- The concentration of particles is measured with two condensation particle counters (UCPC 3776 from TSI and CPC 5.400 from Grimm) in front of and behind the ESP (fig. 1). Collection efficiency is given by:

$$Coll.eff. = \frac{conc._{CPC1} - conc._{CPC2}}{conc._{CPC1}}$$

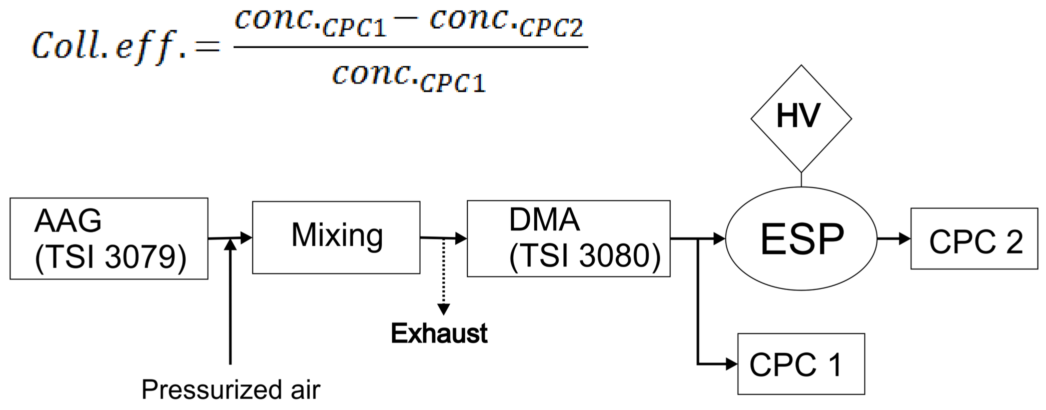


Figure 1. Schematic setup for the experimental validation.

- Electrostatic charging with unipolar charged particles is important. The use of conductive tubing after the DMA is important for reliable results.

References

Hinds W C, Aerosol Technology: Properties, behavior, and measurement of airborne particles, Johan Wiley and Sons, 1982, p. 407.
ISO 15900:2009, Determination of particles size distribution – Differential electrical mobility analysis for aerosol particles.

Comparison between simulation and experience

Figure 2 displays the particles trajectories and vertical velocities within the ESP cavity in a 0.3lpm nitrogen flow at -800V.

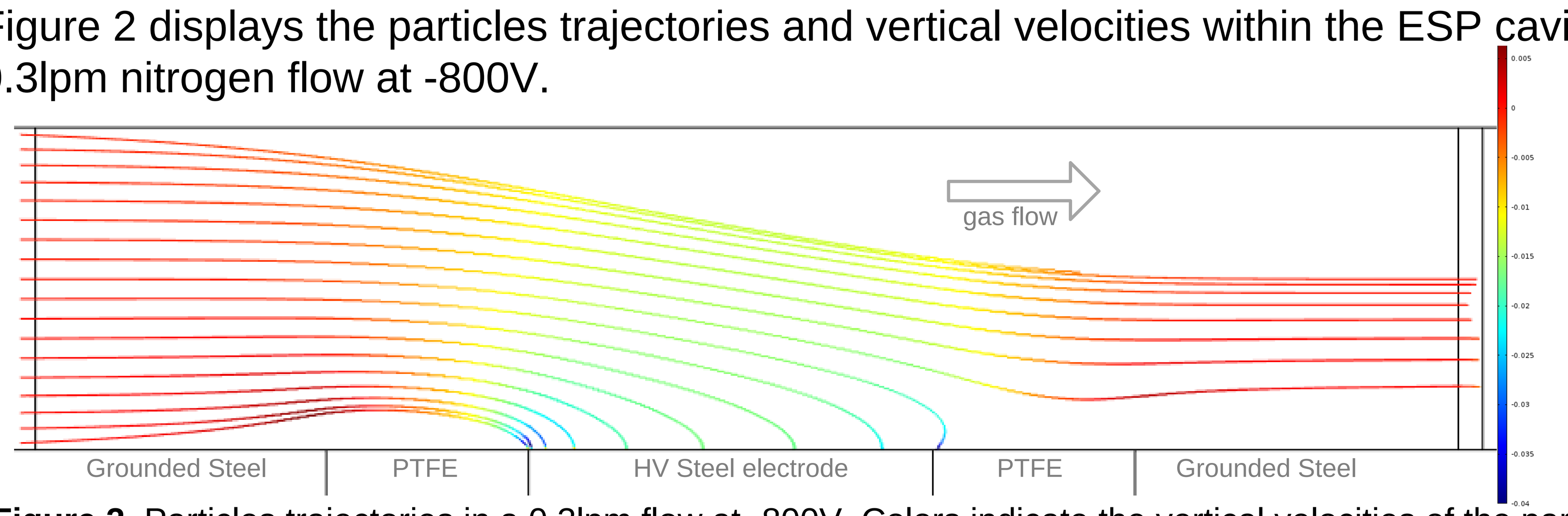


Figure 2. Particles trajectories in a 0.3lpm flow at -800V. Colors indicate the vertical velocities of the particles.

Counting the particles on the electrode reveals a 50% collection efficiency for 40nm particles at -800V and 80% at -1500V.

In order to validate the simulation, the numerical results are compared with experimental data. Two sets of data are shown with CPCs interchanged in order to consider the influence of counting efficiencies of the two different devices. For the two voltages computed (green circles on fig. 3), the experimental results are in good agreement with the numerical data, i.e. about 50 and 80% precipitation efficiency.

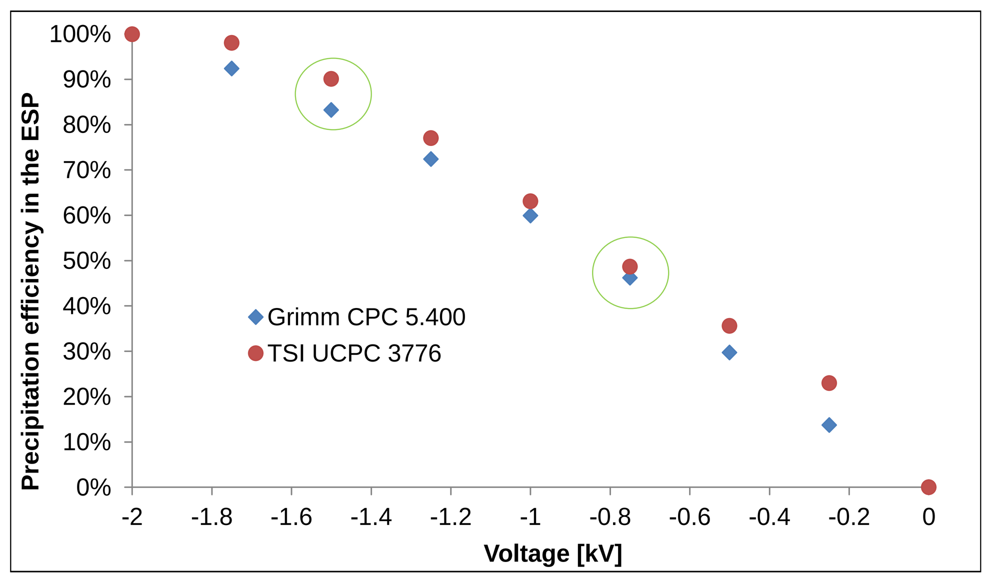


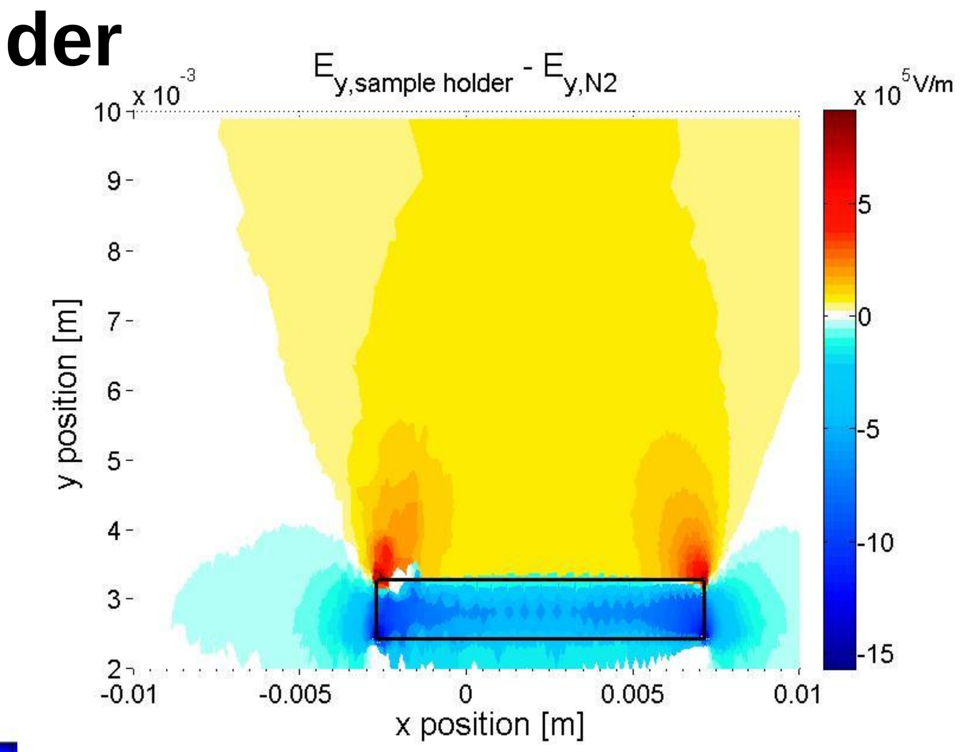
Figure 3. Precipitation efficiency in the ESP. The device in the caption is CPC2 behind the ESP. The values at -800V and -1500V (circles) are in good agreement with the simulation.

Influence of the sample holder

400µm and 800µm layers of mica and silicon have been considered for the simulation of the sample holder.

The electric field is more intense in the cavity with the sample holder. Figure 4 shows the change in the vertical compenent of the electric field.

The flow profile in the ESP is also dependent on the sample holder (fig. 5).



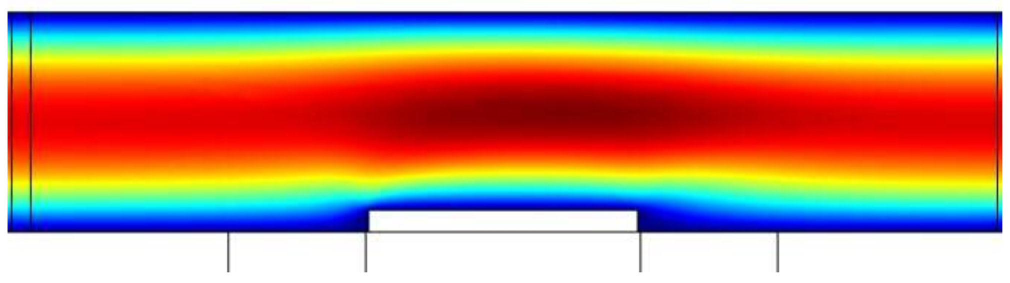


Figure 4 (above). Intensity difference of the electric field in the vertical direction with sample holder (800µm silicon) and without.

Figure 5 (left). Nitrogen flow profile with a 800µm thick AFM sample holder.

Thus the sample holder leads to a higher collection efficiency of the electrode: about 55% at -800V and 100% at -1500V with a 800µm Si layer (fig. 6).

The influence of the thickness of the holder is weaker (<10% more efficient when increasing from 400 to 800µm.)

The influence of the material (mica or silicon) is negligible. Similar efficiencies are obtained at the same conditions.

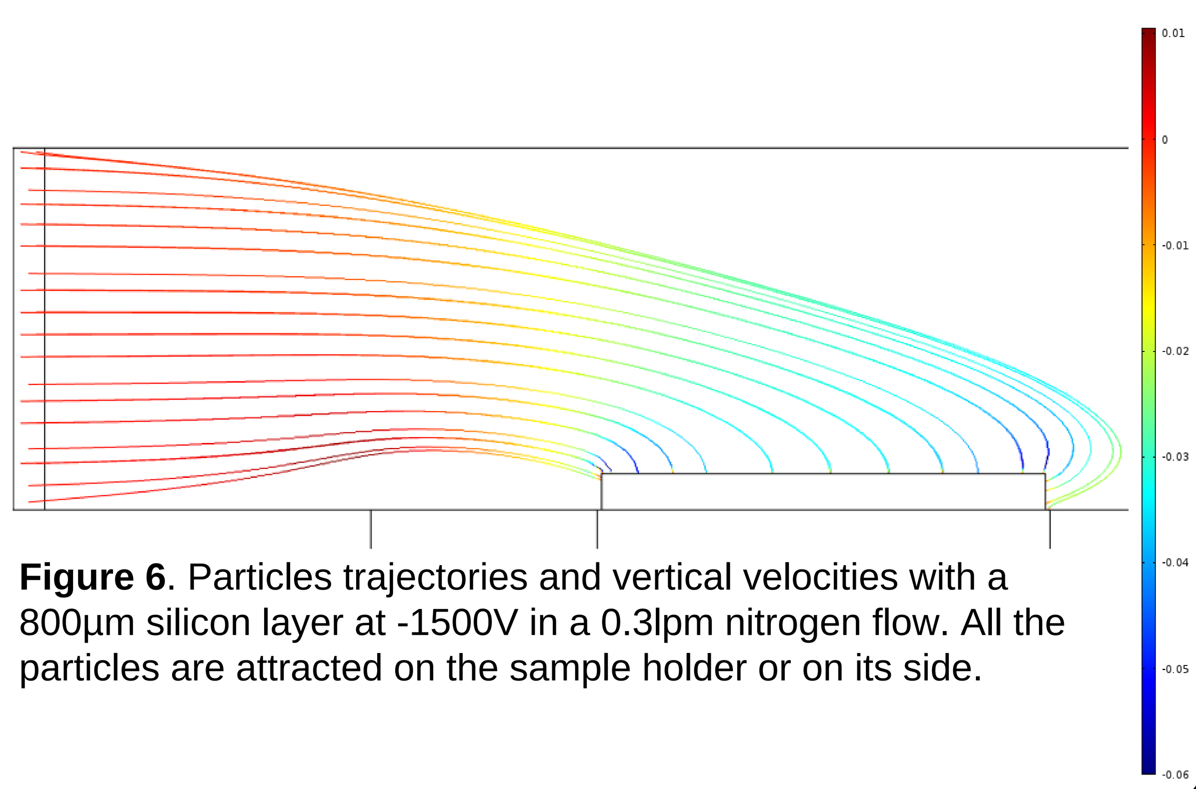


Figure 6. Particles trajectories and vertical velocities with a 800µm silicon layer at -1500V in a 0.3lpm nitrogen flow. All the particles are attracted on the sample holder or on its side.

Conclusions

- Without sample holder, numerical and experimental results are in good agreement about the precipitation efficiency.
- Particles collection in the ESP with sample holder is slightly more efficient, mostly because of the increased electric strength above the holder. The influence of thickness seems weaker and that of material negligible.
- Most of the particles trapped in the cavity are precipitated on the holder, while only a few are found on the sides or beyond the holder.