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Investigation of environmental variations on the performance of a cascade impactor

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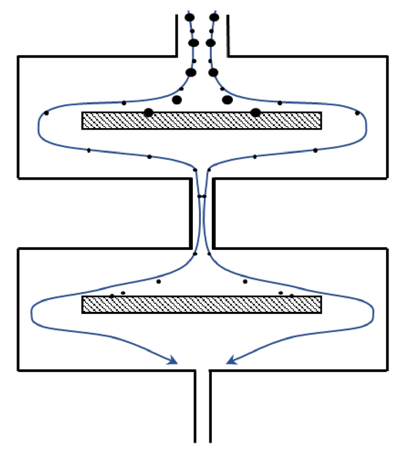
The goal of this study was to simulate the collection efficiency curves of a DEKATI-ELPI® cascade impactor. Seven of the twelve stages of the device in the lower range of deposition, D_{50} of 10 nm to 600nm, were simulated. "High Mach number flow; laminar & turbulent (hmnf)" and "particle tracing for fluid flow (fpt)" modules were used. Particle-agglomeration was investigated on the impaction platforms of the device using three parameters; density, pressure, and temperature. Simulation results were compared experimental results obtained by variation of the three mentioned parameters. The results for the simulated deposition-spots and the obtained collection efficiency curves are in good agreement with the values reported in the literature and obtained from the tests.

1- cascade impactor basics

- The DEKATI ELPI™, electric low pressure cascade impactor, used in this study, is a cascade impactor with 12 stages
- Each stage consists of a chamber at a certain pressure with several entrances and exits optimized for that stage
- Particles that enter each stage could impact a platform at the center of the stage
- At each stage, a certain range of particle diameters impact the platform and are collected
- The impaction depends on "μ" fluid viscosity, "D" diameter of the jet out of the nozzle, "ρ_p" the density of the particle, "Q" the flow rate, and "stk_{50}=0.24" the stokes number for 50% collection efficiency for a circular jet
- The particle diameter with 50% collection efficiency for each of the platforms can be found using the formula for "D_{50}" [1]:

$$D_{50} = \frac{9\pi\mu D^3\,(stk_{50})}{4\rho_p\,Q} - 0.078$$

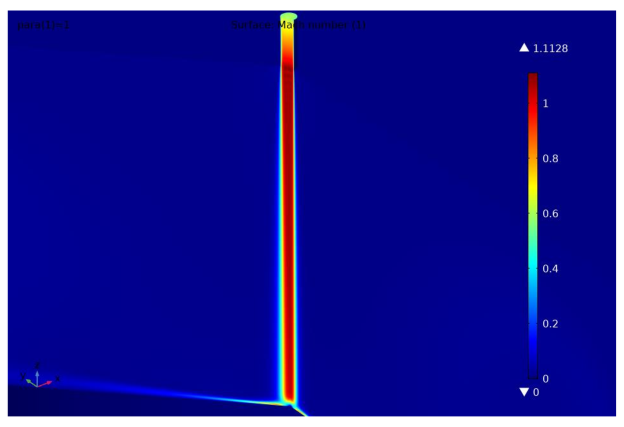
DECATI ELPI™



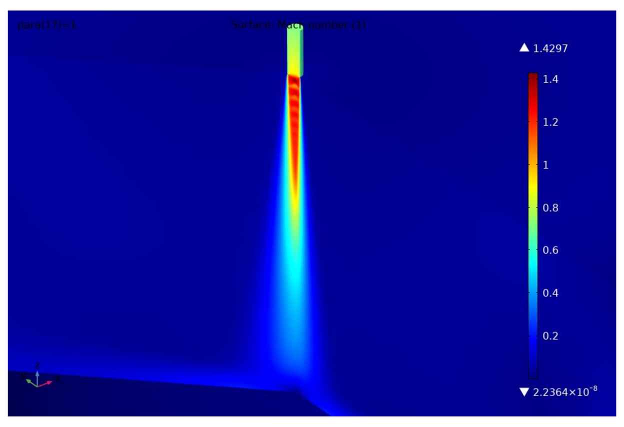
Impaction separation method

2- COMSOL Implementation considerations

- The flow in the device is compressible and in the sonic region: high Mach number flow (hmnf) is used for simulations
- Particle tracing for fluid flow (fpt) was used for the simulation of the solid particles in the flow
  - The effect of particles on the flow is negligible and omitted
- The pressure in the device varies from 1 [atm] at the entrance of the highest stage (12th stage) to 100mbar at the lowest stage (1st stage).
  - The input and output pressures of each stage are boundary conditions of the simulations.
- Each Stage of the ELPI has several entrance and exits, however the simulated models were simplified to one nozzle for each stage



Mach No. on Stage 3-laminar flow

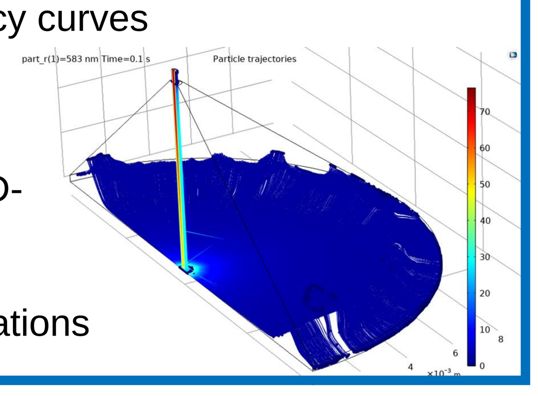


Mach No. on Stage 3-turbulent flow

Stage No.	Re
N1	1283.7
N2	619.33
N3	1779.1
N4	1893.8
N5	1389.4
N6	594.72
N7	636.16

Nozzle Reynolds No.

- The flow is either in the subsonic (>0.3 Ma) or transonic region for all the tested stages
- The Reynolds number calculated at the nozzle show the flow to be in the laminar region
- Turbulence effects: Arffman et al [2] have simulated the flow and particle trapping of the ELPI system Using "the CFD package of Fluent 6" using the "SST-k-ω-model" for turbulence
  - Arffman et al [2] emphasize that "turbulence is the dominant mechanism reducing the resolution when the local Re is over 1800"
  - However, in our simulations, turbulent flow (k-ε flow) resulted in very divergent flows which in return, caused completely wrong collection efficiency curves
  - Simulations presented here are thus based on laminar flow
- Laminar 3D simulations of one single nozzle were compared 2D-axisymmetric simulations and the results were quasi identical
  - Simulation time could be greatly reduced by using 2D simulations



references

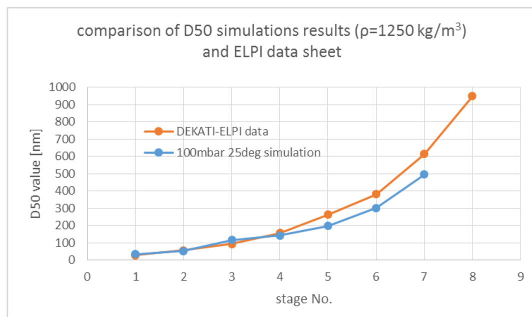
[1] "Wiley: Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, 2nd Edition - William C. Hinds."

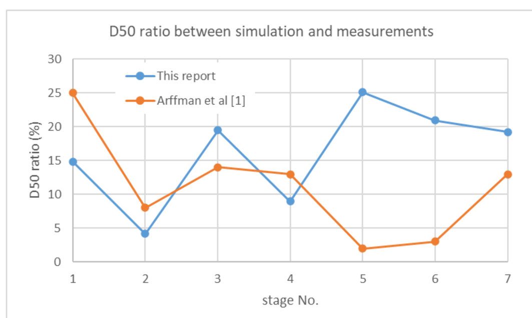
[2] A. Arffman, M. Marjamäki, , and J. Keskinen, "Simulation of low pressure impactor collection efficiency curves," J. Aerosol Sci., vol. 42, no. 5, pp. 329–340, May 2011.

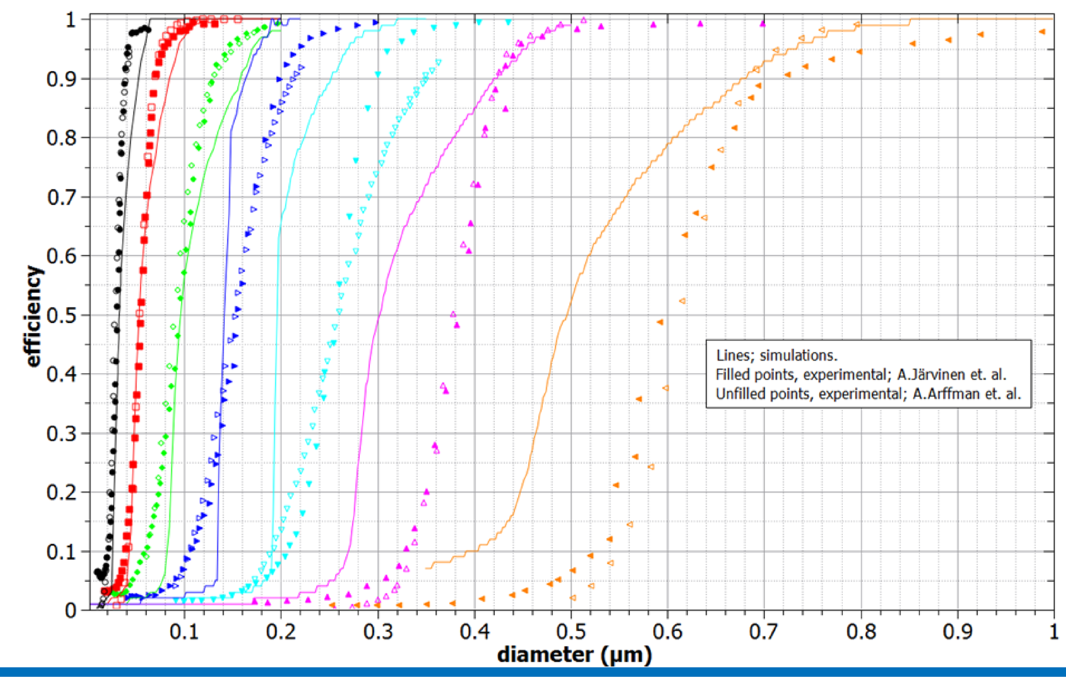
[3] A. Järvinen, M. Aitomaa, A. Rostedt, J. Keskinen,, and J. Yli-Ojanperä, "Calibration of the new electrical low pressure impactor (ELPI+)," J. Aerosol Sci., vol. 69, pp. 150–159, Mar. 2014.

3- obtained efficiency curves

- Efficiency curves were extracted from the simulations and were compared with the empirical efficiency curves of the ELPI system, extracted from literature [2-3]
- The D_{50} values from simulations diverge from the values provided by the ELPI datasheet at higher stages
  - This difference could be due to the iteration-based procedure used in the hmnf module. It leaves a small difference between the set and obtained pressure values (Δp ≈ 10-50 Pa).
- The D_{50} ratios between the experimental and simulation results show that the values are comparable with values reported in the literature [2]

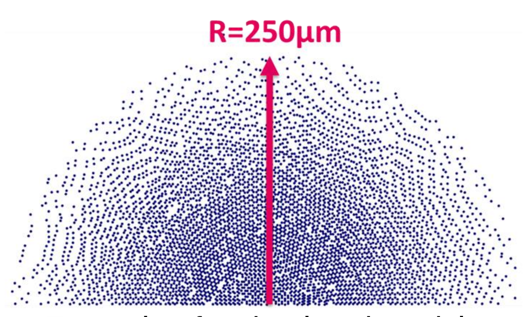




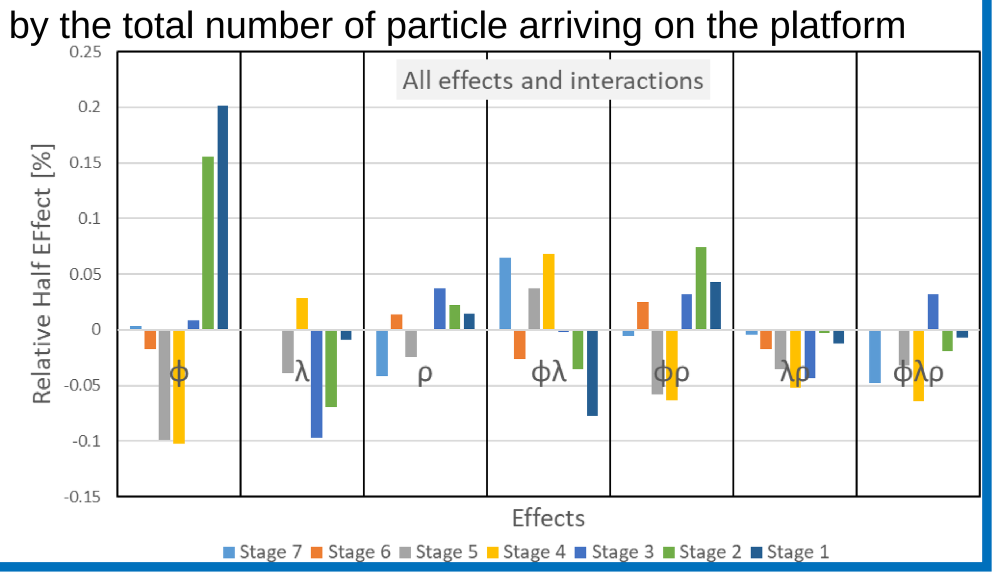


4- DoE analysis of agglomeration

- For the DoE analysis, radius of deposition-area under the nozzle was chosen as the response
- particle density (ρ), pressure (Φ), and temperature (λ) were varied between 1-20 g/cm³, 100-300 mbar in the lowest ELPI platform, and 25-60 °C, respectively:
  - The greatest overall amplitude of variation in these effects lies in the flow pressure
  - Temperature has most of the time an effect on the deposition area
  - There is interaction between the flow pressure and temperature
  - Flow pressure and particle density interactions are also inducing variations
- However, these variations are small and do not have a significant effect on the agglomeration
  - Agglomeration is mostly affected by the total number of particle arriving on the platform

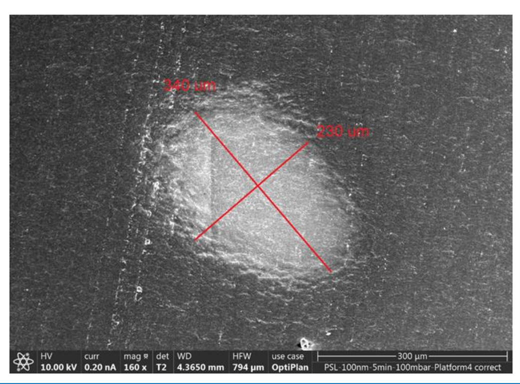


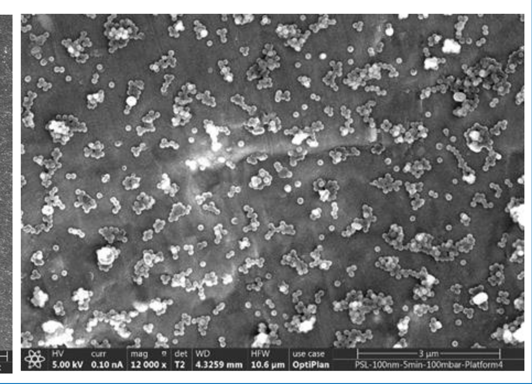
Example of a simulated particle deposition on a platform under the nozzle



5- Experimental results

- Experimental results show that the deposition diameter has the same order of magnitude as the simulations. However, they have an ellipsoidal shape. This can be due to the effect of the adjacent nozzles (omitted in our simulations) that alter the flow shape.





6- Conclusion

- According to the analyzed data from the performed experiments and the simulations, we can conclude that the results for the simulated deposition-spots and the obtained collection efficiency curves are in good agreement with the values reported in the literature and obtained from the tests