Tribocharging: How particles gain charge in turbulent flows

How particles charge in turbulent flows through pipelines

***C. Wilms, H. Grosshans**, Institut für Apparate- und Umwelttechnik, Otto-von-Guericke-Universität Magdeburg*

In Short

- Triboelectric charging of particles can lead to dust explosions
- Effect of pipeline installations on particle electrification is unknown
- LES of particle-laden turbulent flows through pipeline systems
- Parameter study of different elbow configurations and a T-junction
- Machine learning algorithm to extrapolate limited sensor data to full cross-sections

In the United Kingdom and Germany, every 10th day, a dust explosion caused by static electricity is recorded, in Japanese industry 153 electrostatic accidents have been documented over the last 50 years, and in the United States, 1000 people died or were severely injured for the same reason over 25 years [1–3]. Often, the reason seems to be that the powders acquired charge by triboelectrification. When powders, e.g., pulverized food, pharmaceuticals, or chemicals, are transported by an air stream, commonly termed pneumatic conveying, the particles collide with walls or each other. Electrons can be exchanged in these collisions, resulting in a charge build-up. A similar everyday experience is, for example, the doffing of a wool pullover: hair rubs against the pullover, acquires charge, and stands up due to the repelling forces. Sometimes, discharges can even be recognized by a crackling sound. High energetic discharges can trigger explosions when handling combustible particles in the industry.
Up to now, particle charging in turbulent flows has been mainly simulated for straight pipe, channel, or ducts [4,5]. In this project, we will investigate particle charging in industrial-relevant pipeline configurations. Therefore, we developed an open-source solver, called *triboFoam* [6], based on the *OpenFOAM* framework, which gives due to the finite volume method the flexibility to simulate flows in complex geometries. In particular, the investigations will cover a single 90° elbow, a double elbow where the second elbow is out of the plane, a double elbow in S-shape, and a T-junction, see figure 1. For all elbow configurations, we will change the bend radius. For the double elbows, we will also change the distance between the two elbows. In addition to the geometrical variations, we will vary fluid flow and particle parameters, namely the Reynolds number, particle diameter, particle number density, and different precharge levels. With *triboFoam*, we will perform Large Eddy Simulations (LES) as the big eddies strongly influence the particle motion, e.g., by clustering. These simulations provide detailed information regarding the correlation of the carrier flow's turbulence and particle charging. As an example for a simulation, Figure 2 depicts a particle-laden flow through a T-junction.

The data acquired from the parameter study serves to answer several research questions, in particular:

- How does the bend radius of a single elbow influence the charging of particles?
- In a double elbow, does the disturbed inflow influence the charging in the second elbow?
- How much stronger is the particle charging in T-junctions due to the higher collision forces?
- Can reducing the Reynolds number reduce the charging rate?

In addition to the physical interpretation, we plan to use the data to train a machine learning (ML) algorithm. We have developed a patented measurement principle that can spatially resolve the charge distribution. The measurement is based on tracking particles within a laser sheet, with and without applying an external electric field. In the case of duct or pipe

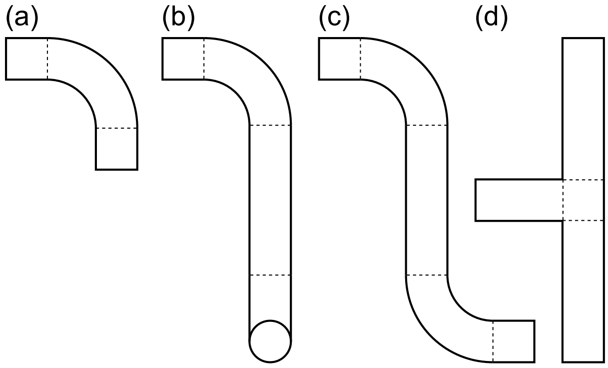

***Figure 1:** Sketch of the four pipeline configurations: (a) single 90° elbow, (b) double elbow where the second elbow is out of the plane, (c) double elbow in S-shape, and (d) a T-junction.*

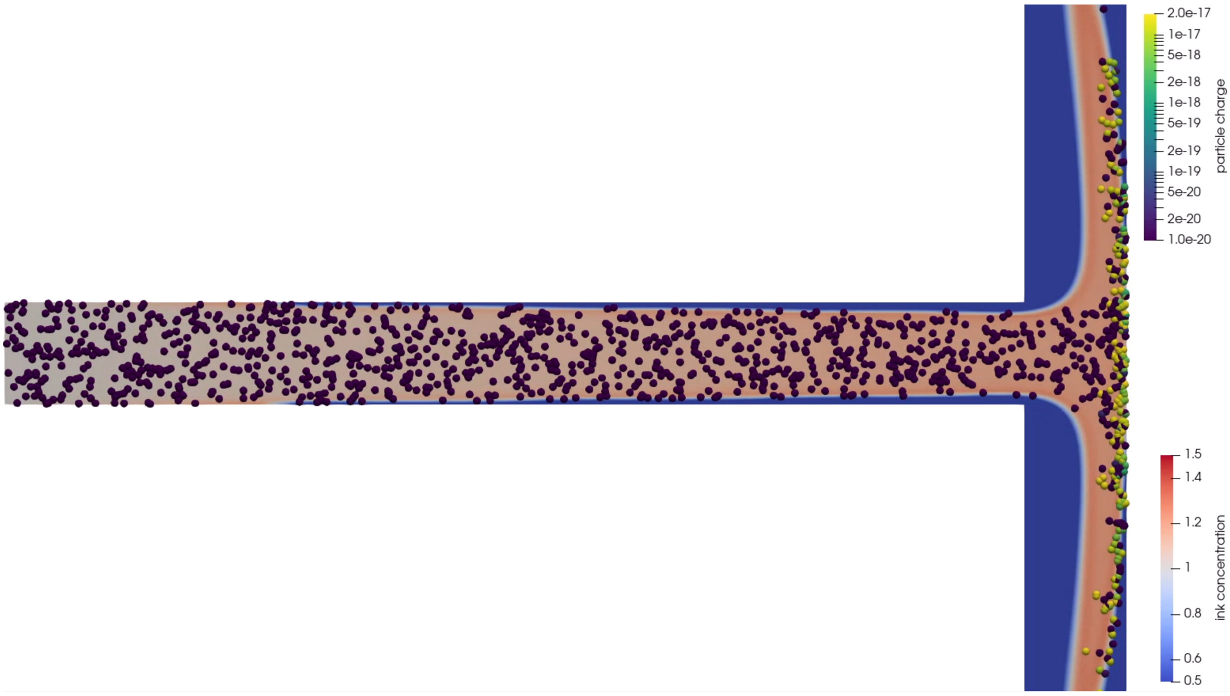

Figure 2: *Snapshot of a particle-laden turbulent flow through a T-junction. The turbulence is modeled using the Reynolds Averaged Navier-Stokes (RANS) approach. The high kinetic collision of the particles with the transverse wall accelerates the particle electrification.*

flow, the laser sheet has to be shifted to scan the entire cross-section by many measurements. However, this is not feasible in practical applications, especially when optical access is limited. To overcome this limitation, we enhanced the measurement principle with the ML algorithm, which can extrapolate a one-dimensional single-line measurement to the two-dimensional field of the entire cross-section of a duct or pipe [7]. The algorithm's performance, especially in the extrapolation of complex disturbances, heavily depends on the training data. The simulations of such a broad parameter space are ideal for the training of the ML algorithm.
The combination of both sub-projects, the deeper physical understanding and the more robust ML algorithm, will contribute to reducing the hazards during pneumatic conveying. A reduced number of fatal dust explosions can save many human lives and plant facilities.

WWW

https://www.ptb.de/cms/asep/

More Information

[1] M. Glor, *Powder Technology*, **135-136**, 223–233 (2003). doi:10.1016/j.powtec.2003.08.017

[2] A. Ohsawa, *Journal of Physics: Conference Series*, **301**, 012033 (2011). doi:10.1088/1742-6596/301/1/012033

[3] European Agency for Safety, Health at Work (2013). doi:10.2802/25457

[4] H. Grosshans, M. Papalexandris, *Journal of Fluid Mechanics*, **818**, 465–491 (2017). doi:10.1017/jfm.2017.157

[5] S. Jantač, H. Grosshans, *Physical Review Letters*, **132**, 054004 (2024). doi:10.1103/PhysRevLett.132.054004

[6] C. Wilms, H. Grosshans, *triboFoam*, https://gitlab1.ptb.de/asep/triboFoam

[7] C. Wilms, W. Xu, G. Ozler, S. Jantač, S. Schmelter, H. Grosshans, *Journal of Loss Prevention in the Process Industries*, **92**, 105474 (2024). doi:10.1016/j.jlp.2024.105474

Project Partners

Physikalisch-Technische Bundesanstalt, Analysis and Simulation in Explosion Protection

Funding

European Research Council (ERC), 947606

DFG Subject Area

404-03