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# Modelling of Electrostatic Ignition Hazards in Industry: too Complicated, not Meaningful or only of Academic Interest?

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With 3 examples (silo filling and assessment of occurrence of cone discharges, calculation of capacitances of screws and flanges for assessment of earthing and bonding requirements and assessment of requirements for plastic hoses with a metal spiral for pneumatic transfer of powders) the usefulness and benefit of model calculations of electrostatic phenomena for the assessment of electrostatic ignition hazards is demonstrated.

## 1. Introduction

Modelling of electrostatic phenomena has often been used in the last century to assess ignition hazards due to static electricity in industry. Typical examples are the filling of tank trucks, reservoirs and containers with hydrocarbon fuels Walmsley (1991) or washing cargo tanks of super tankers with high pressure sea water in the late sixties of last century Chubb (1975). Such modelling is nowadays only very rarely – if at all - applied in industry, nor is it used to analyse explosions and fires attributed to the ignition source static electricity. What is the reason for that? In the age of computer sciences such modelling can nowadays very easily be done on a personal computer or laptop. Is it still too complicated?, not meaningful? or is it only of academic interest?

The argument “too complicated” is more a fear of contact. It may have to do with the prejudice many technicians and engineers have when they remember - or rather not remember - Gauss’s law and Poisson Equation from their physics lectures. The power of modern computer algorithms and programs allows however forgetting solving complicated differential equations. In 2 dimensions the problems can even be solved with EXCEL sheets using the finite element algorithm. One thing can however not be relieved from the engineers, that is a serious and deep understanding of the relationships between charges, potentials and electrical fields. Such an understanding can however best be gained and improved by doing modelling of electrostatic phenomena.

The argument “not meaningful” has to be taken serious. It is a well-known fact, that electrostatic phenomena show frequently a very poor reproducibility in practice. Thus, the doubt, how meaningful the result of modelling will be, is really understandable. However, only by doing a so called sensitivity analysis by variation of many different parameters in the model calculations will give the right answer to questions about the reproducibility of given phenomena such as the strength of the electrical field, the potential of an isolated conductor or the occurrence of incendive discharges.

The argument “only of academic interest” is best excluded by giving examples, where such model calculations can improve safety and in addition may save money. Such examples are given in the paper. They include answers to the following questions and situations:

- Do cone discharges occur when filling silos with product of medium to moderately high resistivity?
- What is the capacitance of metal screws in a plastic flange? Must they be grounded?
- What are the requirements for plastic hoses with a grounded metal spiral to avoid propagating brush discharges during pneumatic transfer of flammable powder?

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## 2. Modelling of electrostatic phenomena and ignition hazard assessment

Modelling of electrostatic phenomena can be used in different ways to assess the electrostatic ignition hazard associated with the build-up of charges in practical situations. The most general approach is to model the distribution of the electrical field in space and time. High electrical field strength does however not yet cause ignition. On the other hand ignition may also be provoked in electrical fields of medium strength, if the field becomes locally distorted.

Ignition may occur if a break down or a so called discharge occurs, which forms the hot plasma (hot spot) required for ignition. Under ambient condition break down in air occurs if the electrical field strength reaches about 3 MV/m. If the electrical field becomes distorted e.g. by introducing an electrode (working tool, fingertip, etc.), a strength of 3 MV/m may locally be reached based on an original homogeneous electrical field of a few hundred kV/m. This is the typical situation for occurrence of so called brush or corona discharges.

Other critical threshold values also mentioned in the relevant guidelines CLC TR 50404 (2003), TRBS 2153 (2009) and IEC 60079-32-1 (2012) are

- **Breakdown voltage** of 4 kV across a dielectric sheet or layer, below which no propagating brush discharges have to be expected.
- **Surface charge density** of $2.7 \cdot 10^{-4}$ C/m$^2$ on top of an insulating coating in contact with a metal surface, below which no propagating brush discharges have to be expected.
- **Capacitance** of 3 or 10 pF for small conductive plant items (e.g. single screws or bolts), below which no incendive spark discharges have to be expected and which therefore must not be grounded, if high electrostatic charging processes are avoided during normal operation including maintenance and cleaning.
- **Resistances** for many different kinds of arrangements (resistivity, surface resistance, surface resistivity, overall resistance to ground, etc.)

## 3. Computer Modelling of electrostatic phenomena – case studies

In the cases listed below the most important input data for the modelling are either space- or surface charge distributions or charging current densities. The relevant differential equation for the calculation of the related potential distribution is the well-known Poisson equation, which is an elliptical partial differential equation. From the potential distribution $\phi(x,y,z)$, which is a scalar field the electrical field $E(x,y,z)$ is then calculated as the gradient of $\phi(x,y,z)$, which is a vector field: $\mathbf{E}(x,y,z) = \mathbf{grad}\phi(x,y,z)$. In the examples below these equations can no longer be solved analytically. They are solved by iterative algorithms such as e.g. the finite difference element method. All model calculations described in the following have been performed on a 64 bit HP EliteBook 8460p Laptop with the software COMSOL Multiphysics® Version v4.3.

### 3.1 Silo filling with insulating bulk material – occurrence of cone discharges

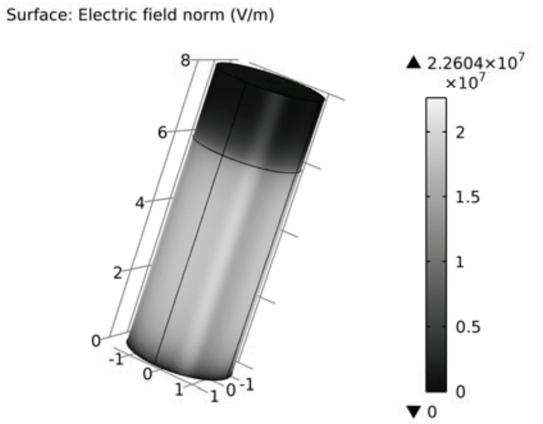
in the relevant guidelines CLC TR 50404 (2003), TRBS 2153 (2009) and IEC 60079-32-1 (2012) a measurement of the electric field strength above the powder heap within the silo is recommended to assess the probability of the occurrence of so called cone discharges. It became however evident, that such measurement are rather sophisticated and are not frequently done in industrial practice.

As an alternative to the measurement of the strength of the electrical field above the powder heap, this field strength may be calculated by computer modelling based on the charged product and the resulting space charge density within the silo. If the charge relaxation time of the product is similar or shorter than the filling time of the silo, it is worth while taking into account charge relaxation in the model calculations. In this case the space charge density within the silo stays no longer homogeneous and the Poisson equation can no longer be solved analytically. For the model calculations the following data are needed:

- Charge to mass ratio of the incoming product
- Bulk density of the product
- Filling rate of the product
- Relative permittivity of the bulked product
- Resistivity of the bulked powder
- Silo geometry.

If the radially directed electrical field exceeds 3 MV/m, cone discharges can no longer be excluded.

In the following the results of model calculations for a metal silo of diameter 3 m and height 8 m, filled up to a level of 6 m with product of bulk relative permittivity 2, charge to mass ratio $10^{-6}$ C/kg, bulk resistivity $\rho$ $5 \cdot 10^{12}$ $\Omega \cdot$m or $5 \cdot 10^{10}$ $\Omega \cdot$m and bulk density $0.5 \cdot 10^{3}$ kg/m$^3$ at a rate of 5 kg/s (18 t/h) are shown in Figures 1 to 6.



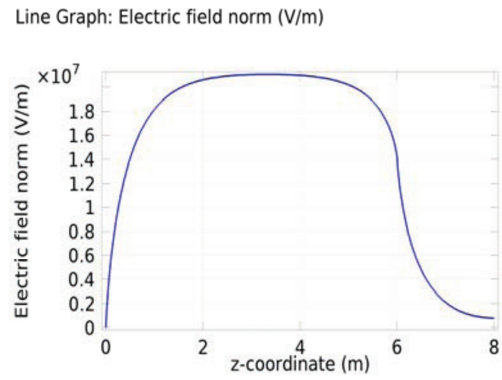
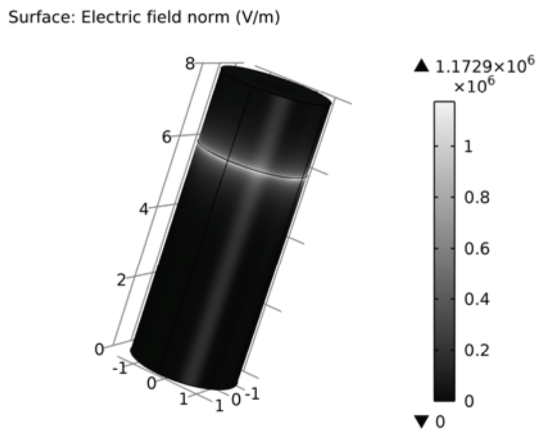




*Figure 1: Field strength at the inner silo wall without allowing for charge relaxation.*

*Figure 2: Field strength at the inner silo wall along the z-axis (silo height) without allowing for charge relaxation.*



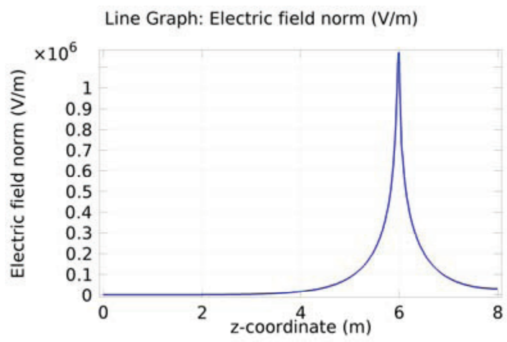
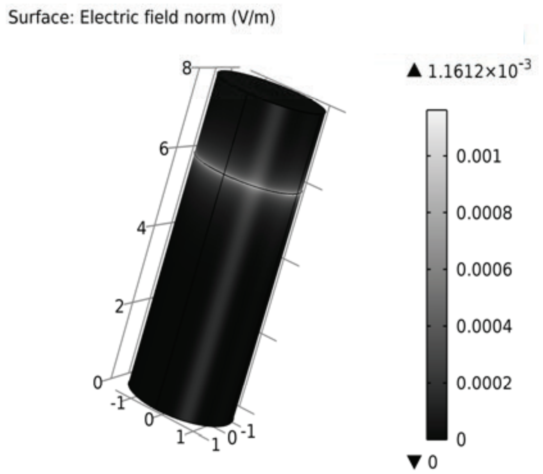




*Figure 3: Field strength at the inner silo wall with allowing for charge relaxation* $\rho = 5{\cdot}10^{12}\ \Omega{\cdot}m$.

*Figure 4: Field strength at the inner silo wall along the z-axis (silo height) with allowing for charge relaxation* $\rho = 5{\cdot}10^{12}\ \Omega{\cdot}m$.



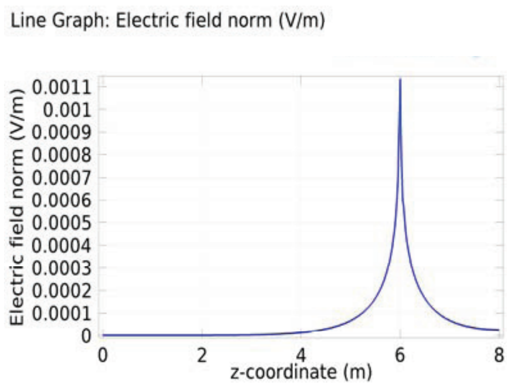




*Figure 5: Field strength at the inner silo wall with allowing for charge relaxation* $\rho = 5{\cdot}10^{10}\ \Omega{\cdot}m$.

*Figure 6: Field strength at the inner silo wall along the z-axis (silo height) with allowing for charge relaxation* $\rho = 5{\cdot}10^{10}\ \Omega{\cdot}m$.

Figures 1 to 6 show the huge influence of charge relaxation on the maximum electrical field during filling silos with highly charged product. Without allowing for charge relaxation the field strength exceeds with a theoretical value of 22.6 MV/m by far the critical value of 3 MV/m, above which cone discharges can no longer be excluded, whereas already in case of a still rather high resistivity of the bulked product of $5 \cdot 10^{12}\ \Omega \cdot m$ it stays with 1.17 MV/m below the critical value. The field strength is practically reduced to zero when the resistivity of the bulked product drops to $5 \cdot 10^{10}\ \Omega \cdot m$. Thus such model calculation may help to make a precise assessment of the ignition hazard and can save a lot of money, if it can be demonstrated that no additional measures are required.

**3.2 Capacitance of screws and bolts in plastic pipes**

In the relevant guidelines CLC TR 50404 (2003), TRBS 2153 (2009) and IEC 60079-32-1 (2012) limit values for the capacitances of isolated metallic objects like screws and bolts etc. are given, below which these objects must no longer be earthed. The question may now arise above which diameter and length such metal screws on plastic flanges must be grounded? Depending on the answer, this question may have huge economic consequences, since earthing and bonding of say 100 screws or flanges costs a lot of money.

It is a well-known fact that the capacitances of plant items not only depend on the geometry of the plant item itself but also a lot on its surroundings. Particularly earthed conductive objects close to such screws and flanges increase their capacitance substantially. It is exactly because of this fact that such large uncertainty exist in industrial practice. With the help of model calculations this uncertainty can be removed. In Figures 7 to 10 the capacitances of screws and flanges are calculated in free space (actually in the middle of a production room of dimensions 8 m x 6 m x 4 m) and in the presence of earthed conductive objects close to them).

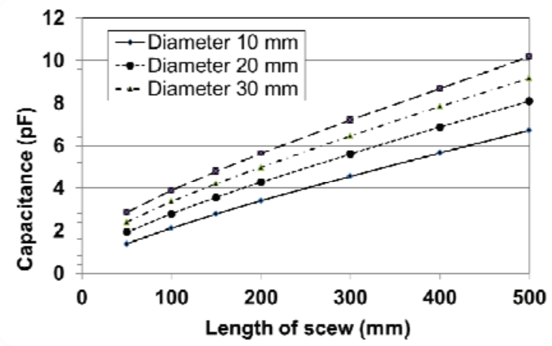



*Figure 7: Capacitance of screws in free space.*

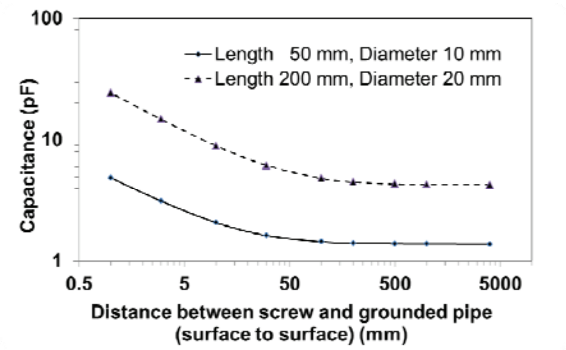



*Figure 8: Capacitance of screws close to a grounded metal pipe of diameter 200 mm, length 3.8 m mounted parallel to screw axis.*

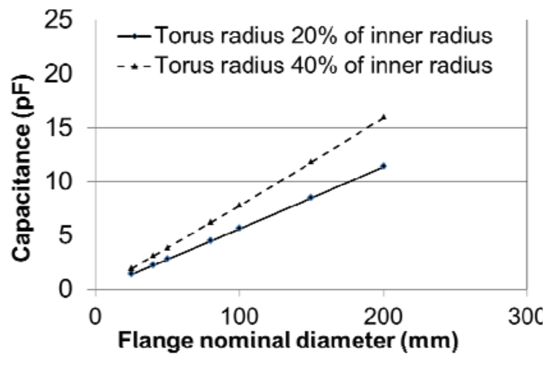



*Figure 9: Capacitance of flange (torus) in free space.*

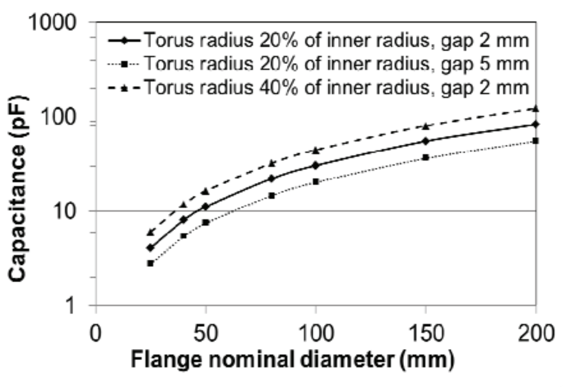



*Figure 10: Capacitance of flange (torus) mounted on a grounded metal pipe without making contact (gap width of 2 mm and 5 mm respectively).*

As it is well known from basic physics, the capacitance of an isolated object is very much determined by its surroundings as can be seen from Figures 7 to 10. For example a screw of diameter 10 mm and length 50 mm has a capacitance of about 1.4 pF in free space (Figure 7), whereas its capacitance increases to 3.1 pF or even 4.9 pF if a grounded metal pipe with diameter 200 m is mounted in parallel to the screw axis at a distance (surface to surface) of 3 mm or 1 mm respectively (Figure 8).

**3.3 Occurrence of propagating brush discharged in hoses with earthed metal spiral**

Propagating brush discharges have been observed in industry during the pneumatic transfer of powders through hoses made from insulating material with an earthed metal spiral embedded in the wall. Furthermore, Pavey (2009) demonstrated in experiments the formation of propagating brush discharges in such hoses and in similar geometrical arrangements. According to the German guidelines on the avoidance of ignition hazards due to static electricity TRBS (2009) it is therefore required to use dissipative material for the inner part of the hose in which the earthed metal spiral is embedded. Since - according to these guidelines - a dissipative property can be achieved by limits for the surface resistance as well as for the volume resistivity and the corresponding upper limits are $10^{11}$ Ohm (at 23°C and 30% rh) or $10^{9}$ Ω·m respectively, there existed qualified doubts, whether these limits are low enough to exclude propagating brush discharges under realistic conditions. In order to correctly specify the requirements to exclude the occurrence of these discharges from such tubes and hoses, it is important to know the charging current running to and through the inner surface of the hose during the powder transfer. If this charging current is known, the potential at the inner surface of the hose wall can be calculated by computer simulations. If the potential stays below 4 kV no propagating brush discharges will occur, as specified in the relevant guidelines CLC TR 50404 (2003), TRBS 2153 (2009) and IEC 60079-32-1 (2012). In experiments this charging current has been measured under different conditions Fath et al. (2012). Based on these measurements model calculations have been performed under the following assumptions:

- The hose is made from a dissipative material with a volume resistivity of $10^{9}$ Ω·m
- The wall thickness is 6 mm
- The external radius of the hose is 20 mm
- The spiral is made from metal and has a radius of 1 mm
- The spiral is located within the dissipative wall at a distance of 2 mm from the inner surface (distance between spiral surface and inner wall surface)
- The height of one turn of the spiral is 25 mm
- The length of the model hose is 200 mm
- The metal spiral is earthed
- The conductive layer on the outside is earthed (if present at all)
- The charging current is 1 mA/$m^2$ derived from experiments by Fath et al. (2012)

Figure 11 shows the geometry of the model hose and Figures 12 and 13 show examples for the surface potential distribution along the inner wall of the hose in axial direction.

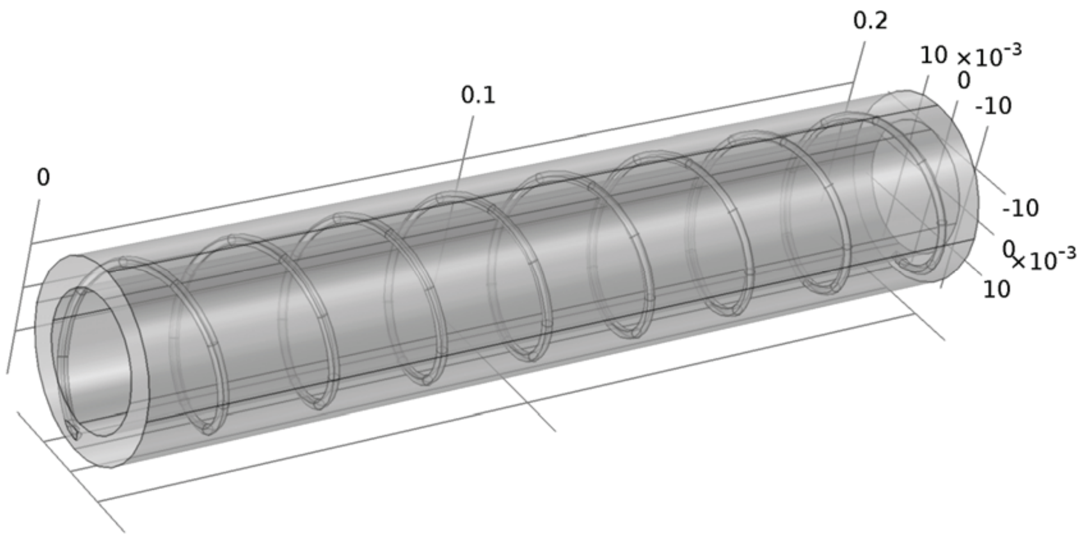



*Figure 11: Geometry of the hose used for the model calculations*

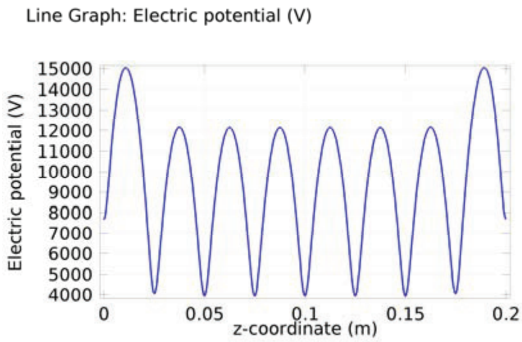



*Figure 12: Surface potential at the inner wall in axial direction. Without a conductive layer on the outside.*

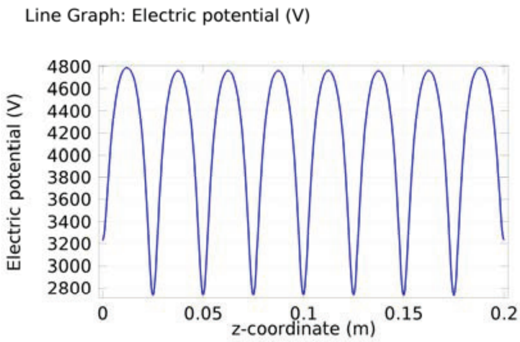



*Figure 13: Surface potential at the inner wall in axial direction. With an earthed conductive layer on the outside.*

Based on the model calculations the following characteristics can be derived:

- The surface potential along the inner wall is directly proportional to the resistivity of the dissipative layer
- The surface potential along the inner wall is directly proportional to the current density entering the surface of the inner wall.
- There is a large difference between the potential of the inner surface at places opposite to the spiral $U_S$ and the potential at places in between two spiral turns $U_I$ independent on whether there is an earthed conductive wall on the outside of the hose or not, as can be seen in Figures 12 and 13.
- The potential of the inner surface at places opposite to the spiral $U_S$ as well as the potential at places in between two spiral turns $U_I$ is strongly influenced by the presence of an earthed conductive layer on the outside of the hose, as can be seen by a comparison of Figure 12 with Figure 13.

In conclusion propagating brush discharges can be excluded in hoses with earthed metal wires if the wire is embedded in a material of sufficiently low volume resistivity. The requirements for the volume resistivity can be derived by computer model calculations for the given geometrical arrangement. For example a hose with a wall thickness of 6 mm, an external radius of 20 mm, a metal spiral with a wire radius of 1 mm and a height per turn of 25 mm placed 2 mm from the inner surface, the resistivity must not be higher than $3.3 \cdot 10^8$ Ω·m without an earthed conductive external layer and the resistivity must not be higher than $8.3 \cdot 10^8$ Ω·m with an earthed conductive external layer.

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