Using electrostatic modelling to study cone discharges

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Abstract. Cone discharges, also known as bulking brush discharges, can arise when charged
insulating powder accumulates in a heap in silos. They can be an effective ignition source to
relatively ignition sensitive powders and therefore represent a possible electrostatic hazard. The
current international guidance on control of electrostatic hazards (IEC/TS 60079-32-1 [1]),
endorses the usage of electrostatic modelling to estimate the electric field above the powder
heap. “Such model calculations should be based on the charge to mass ratio, bulk density and
filling rate of the powder, the relative permittivity and resistivity of the bulked powder as well
as the silo geometry.” This study shows a practical demonstration of this modelling technique.
It also examines whether the shape of the heap affects the strength of the electric field above
the powder heap, and thus the likelihood of cone discharges from occurring.

1. Introduction
Cone discharges are one of five types of electrostatic discharges found in process industries. They
occur when highly charged powder lands on a heap of previously settled charged powder. The
compression of charges of the same polarity under gravity may lead to a high electric field across
the heap. If the breakdown voltage of air is exceeded then a discharge across the surface will occur.

The latest standard (IEC/TS 60079-32-1 [1]) endorses the use of electrostatic modelling to estimate
the electric field when assessing the hazards of cone discharges. Electrostatic modelling entails solving
the well-known Poisson differential equation \[ \nabla^2 \phi = 0 \] [2]. The electric field is then compared with the
breakdown voltage of air, taken to be 3 MVm\(^{-1}\), and thus predict the presence of cone discharges. This
study gives particular focus on how the shape of the heap affects the strength of the electric field.

2. Process overview, powder properties and shape of heap
The scenario considered is for an earthed metallic silo of 3 m in diameter and 8 m in height, filled up
to around the 6 m level at a rate of 5 kgs\(^{-1}\), of powder with which has charge to mass ratio of \(1 \times 10^6\)
Ckg\(^{-1}\), relative permittivity of 2, volume resistivity of \(5 \times 10^{12}\) Ωm and bulk density of 500 kgm\(^{-3}\).
The charge relaxation time of the powder can be approximated by using Equation (1) [1]:

\[ \tau = \varepsilon_0 \varepsilon_r \rho_v \] (1)

Where \(\tau\) is the charge relaxation time, \(\rho_v\) is the powder resistivity, \(\varepsilon_0\) is the Electric Constant and \(\varepsilon_r\)
is the relative permittivity. Substituting the values considered for this scenario into Equation (1) yields
a charge relaxation time of 88.5 s.
2.1. Heap Shapes

The heap shapes shown in figure 1 were considered for this study. The angles chosen for the inclined heap, conical heap and inverse conical heap allows a degree of comparability.

Figure 1a. Flat heap, Figure 1b. Inclined heap with a repose angle of 30°. Figure 1c. Conical Heap with a 60° cone angle. Figure 1d. Inverse conical heap with a 300° cone angle.

3. Boundary Conditions

There are two boundary conditions when modelling the electric field in the silo:

1. The silo walls (top, bottom and shell) are at zero potential.
2. The total charge quantity in the powder. There are two ways of approaching this. Either, not taking the charge relaxation into account and this is a conservative approach. Or, as carried out in this study, taking into account the charge relaxation of the powder and this is a more realistic approach.

To obtain the total charge in the powder taking into account the charge relaxation, the following method was used. For an ideal material the charge relaxation time is the period when the powder charge will have dropped to 1/e, or about 0.37 of its initial value. For a true exponential decay this would be known as the time constant for the decay. The mass of powder flowing into the silo during this period (i.e. 88.5 seconds) is the product of the mass flow rate and the time constant, i.e. 442.5 kg. For a charge to mass ratio of 1 μCkg⁻¹, the total charge in this 442.5 kg of powder is the product of the charge to mass ratio and the total mass of charged powder, i.e. 0.000443 C in this situation.

Assuming a true exponential decay, more than 99% of the starting charge would be lost after 5 time constants, i.e. once a layer of powder has settled in the silo and been there for 5 time constants there is just less than 1% of the charge left which could thereafter be considered at earth potential. Utilising this fact, this study divided the charged powder at the surface into five distinct layers corresponding to the 5 time constants. Here, it is very important to correctly define the depth of each charged layer. The depth of the charged layer itself is dependent of the surface area of the heap. The assessment of how thick the depth will be for various heap shapes is omitted in this paper for the sake of brevity. However the results of the assessment are shown in table 1:

| Layer No. or Time Constant | Exponential decay in percentage (to 1 d.p.) | Flat Heap Powder Depth (m) | Inclined Heap Powder Depth (m) | Conical Top and Inverse Conical Top Powder Depth (m) | Charge (×10⁻³ C) |
|----------------------------|--------------------------------------------|---------------------------|-------------------------------|--------------------------------------------------|-----------------|
| 1                          | 36.8 %                                     | 0.125                     | 0.0939                        | 0.125                                            | 0.443           |
| 2                          | 13.5 %                                     | 0.250                     | 0.187                         | 0.250                                            | 0.163           |
| 3                          | 5.0 %                                      | 0.375                     | 0.282                         | 0.376                                            | 0.060           |
| 4                          | 1.8 %                                      | 0.500                     | 0.376                         | 0.501                                            | 0.008           |
| 5                          | 0.1 %                                      | 0.625                     | 0.470                         | 0.626                                            | 0.004           |
4. Simulation Results
The electric field was determined numerically by using a finite element software package [3].

**Figure 5a.** Electric field magnitude at the surface of the flat heap. The maximum electric field is 5.19 MV m\(^{-1}\).

**Figure 5b.** Electric field magnitude at the upper part of the silo. Half of the space above the powder surface has been cut away to show regions of interest.

**Figure 6a.** Electric field magnitude at the surface of an inclined heap. The maximum electric field is 6.84 MV m\(^{-1}\).

**Figure 6b.** Electric field magnitude at the upper end of the silo. Half of the space above the powder surface has been cut away to show regions of interest.

**Figure 7a.** Electric field magnitude at the surface of a conical heap. The maximum electric field is 5.41 MV m\(^{-1}\).

**Figure 7b.** Electric field magnitude at the upper end of the silo. Half of the space above the powder surface has been cut away to show regions of interest.
5. Discussion and Conclusions
The majority of the silo is at zero electric field. This is because the powder charge relaxation has been taken into account, thus the electric field is concentrated around the top part of the silo where charged powder is concentrated. Out of the four shapes that were considered, the maximum electric field is experienced by an inclined heap, followed by a conical heap, followed by a flat heap and the last is the inverse conical heap. Just to show the significance of this difference; the maximum electric field at the powder surface for the inclined heap is more than twice than the maximum electric field at the powder surface for the inverse conical heap. The simulation has shown that the breakdown strength of air is exceeded in all scenarios except for the inverse conical heap.

The regions of the highest electric field would be where electrostatic discharges should be expected and are therefore important enough to consider in more detail. The precise regions of the highest electric fields vary for the four heap shapes considered. The highest electric field for the flat heap is just below the surface, although the maximum electric field at the surface is not too dissimilar to that just below the surface. The highest electric field for the inclined heap is just below the lower side of the incline. The highest electric fields for the conical heap are at the edge of the heap surface, just below the edge, and just above the cone apex. The highest electric field for the inverse conical heap is below the edge of the powder surface.

Where the highest electric fields occur at the surface or above the surface, then hazardous discharges should be expected. However, if the highest electric fields are just below the surface, then it is very likely that that region will be fuel rich and thus represent a much lower likelihood of causing an explosion.

Given this, it can then be concluded that the safest way to fill a silo is to fill it equally around the circumference such that an inverse conical heap is obtained, and the least safest option would be filling the silo at one side such than an inclined heap is generated. The relationship between the heap shape and the electrical field is worthy of further investigation. The results from this study may be exploited to design silos so as to avoid the problem of cone discharges.

6. References
[1] IEC/TS 60079-32-1:2013 Explosive Atmospheres – Part 32-1: Electrostatic hazards, Guidance
[2] Britton L 1999 Avoiding Static Ignition Hazards in Chemical Operations (New York: Wiley-AIChe)
[3] Mecway Ltd 2013 Mecway version 1.1 (New Zealand)