Comparison of current signatures for brush discharges using different resistance values in the discharge probes

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Abstract. Incendiary brush discharges can occur when a large or grounded conductor approaches a charged insulator in the presence of flammable atmosphere. The probability of ignition of these discharges is essential to risk assessment in process industry. It is known that even if the total energy released in the discharge exceeds the minimum ignition energy (MIE), there may not be an ignition [1]. In a companion paper in this conference, we have reported simultaneous measurements of ignition and discharge current waveforms for brush discharges in an ethylene-air mixture in ignition tests based on an IEC standard test method [2]. In this paper we show that the resistance of the electrostatic discharge measurement system can have an effect on the peak discharge current signatures and charge transferred in the brush discharge from an insulating surface. The resistance of the discharge probe seems to affect the peak current value, but also to lesser extent the amount of charge transferred in the discharge.

1. Introduction
A brush discharge occurring in the presence of flammable atmosphere may or may not be incendiary, even if the total energy release in the discharge exceeds the minimum ignition energy (MIE) there might not be an ignition [1]. A risk assessment that reflects the actual risk of ignition is therefore of interest for the whole community. An electrostatic discharge (ESD) is initiated when the local electric field exceeds the electrical breakdown strength of the surrounding atmosphere. This is affected by various factors like amount and polarity of charge on the charged object, electrical properties and geometry of the discharging object, and air gap length of the discharge channel [3]. In this paper we will present some results from ignition tests done with a modified ignition probe, where the current signature has been recorded for two different resistance values. In addition we have made some discharge measurements in a controlled environment using a stripped down discharge probe with similar properties as the modified ignition probe, but without the flowing gas apparatus. The recorded discharges are taken from an insulating surface charged by triboelectrification.

2. Experimental setup
The experiments were performed at SP (address 1) at three different occasions. The first two of the experiments were done using the modified ignition probe in a heated outdoor facility designed for tests including flammable atmospheres. The relative humidity was around 60%, the temperature 20° C and
a resistance of 7 Ω in the ignition probe was used for the first experiment. During the second experiment the relative humidity (RH) was around 30% and the resistance of the ignition probe was 1 Ω. At the last experiment the discharges were made in 12 % RH and 23°C at a SP indoor facility with an altered ignition probe.

The discharge probe used was made according to the details presented reference [2]. Essentially it consists of a spherical ball electrode made of stainless steel connected to ground through a wire. The gas mixture is fed through a plastic container filled with glass beads, which are prevented from falling out by a metallic mesh. After the gas mixture has passed the metallic mesh it is confined within a plastic cone with an opening at its top where the gas passes the ball electrode and out in the air. This implies that the gas mixture is well defined is a small volume around the ball electrode under the assumption that no other objects are present. A schematic picture of the experimental set up is indicated in figure 1. For details about design and test procedure see reference [2].

![Figure 1](image1.png)

**Figure 1.** An overview of the experimental setup including the ignition probe and the charged object (plastic tray). The gas flow through the probe is indicated.

![Figure 2](image2.png)

**Figure 2.** Overview of the original probe (Original) and the modified probe (Modified). The oscilloscope is connected to the probe with a coaxial cable.

The plastic tray used in these experiments had the following measures 40 cm width, 60 cm length and 12 cm depth and was made of polypropylene. The back of the tray was charged using a homemade woolen mitten. The potential of the charge surface was estimated with a field meter to be around 25 kV. The distance between the ball electrode and the charges surface was in between 2 cm and 7 cm. It was the plastic tray that was moved not the ignition probe, since it was easier to handle the tray than the probe.

In figure 2 we show how the ignition probe was modified. The ground connector had a series resistance connected in between the ball electrode and ground. The oscilloscope was connected to the ignition probe via a 50 Ω coaxial cable and the 50 Ω input of the oscilloscope was used. The series resistance is obtained by connecting 8 resistors in parallel to distribute the current evenly to the coaxial cables ground shell. The charge transfer was calculated by integration of the digitized waveform over the elapsed discharge time.

Additional experiments were made in a controlled atmosphere with a stripped probe without the gas mixture apparatus present. This was done by removing everything except the ball electrode and the resistance from the ignition probe. The measurements with the stripped probe were done in the same way as the ones with the modified ignition probe, however the plastic tray was charged with a polyester cloth instead of a woolen mitten. This may affect the state of charging of the ESD source. One should take care in interpreting the amounts of charge transferred to the probe, in these two sets of experiments.
3. Results

The peak discharge currents and the amount of charge transferred in the brush discharges related to the probe resistance are presented here in table 1 and figure 3 and 4.

Table 1. Average Peak Current and Transferred Charge (including Standard Deviation)

| Experiment | Temperature / RH | Resistance | Average Peak Current | Average Transferred Charge |
|------------|------------------|------------|----------------------|----------------------------|
| 1          | 20 °C / 60 %     | 7 Ω        | -(0.37±0.18) A       | -(19.0±8.7) nC             |
| 2          | 20 °C / 30%      | 1 Ω        | -(0.84±0.24) A       | -(63±22) nC                |
| 3          | 23 °C / 12%      | 9 Ω        | -(0.51±0.09) A       | -(39±9) nC                 |
| 4          | 23 °C / 12%      | 1 Ω        | -(1.9±0.3) A         | -(24±5) nC                 |

In figure 3 and 4 we present, both current (full line) and charge (dashed line) as function of time, for two different resistances values 1 Ω (figure 3) and 9 Ω (figure 4) at 12 % RH. The charge as function of time is monotonic in the case of the 9 Ω resistance value, but not in the case of the 1 Ω resistance. For this reason we defined a new parameter, the peak transferred charge, as is exemplified in figure 3. The peak transferred charge was -(33±6) nC in the fourth experiment where the average transferred charge was -(24±5) nC.

Figure 3. The discharge current (dark) and the transferred charge (light) as function of time for 1 Ω resistance and 12 % RH

Figure 4. The discharge current (dark) and the transferred charge (light) as function of time for 9 Ω resistance and 12 % RH

In figure 5 and 6 we present the peak current as function of the transferred charge. In figure 5 we have discharges obtained with the modified ignition probe; triangles (1 Ω 30% RH) and dashes (7 Ω 60% RH). In figure 6 we have discharges taken with the stripped probe; diamonds (peak transferred charge) and crosses (transferred charge) (1 Ω and 12% RH) and circles (9 Ω and 12% RH). In figure 5 and 6 we also present the 1σ standard deviation from the average value of both the peak current and the peak transferred charge as ellipsoids, however any correlation between the variables is neglected.

In figure 5 we can clearly see that the charging level is different for the two data sets where the charging mechanism was the same (wool), but the humidity and probe resistance different (30%RH and 1 Ω triangles; 60% RH and 9 Ω dashes). It is possible that this difference depends on humidity [4] so we performed the last two sets of discharge experiments under constant humidity and temperature conditions, see figure 6. This implies that the peak current is strongly affected when the probe resistance goes from around 1 Ω to around 8 Ω.
If graphs presenting the discharge currents as function of time for many waveforms are viewed, it is very difficult to distinguish other characteristics than those already mentioned [5]. The discharge duration time is around 100 ns and the rise time around 10 ns.

Figure 4. Peak current as function of transferred charge. The ellipsoids indicate the 1σ standard deviation from the mean value.

Figure 5. Peak current as function of transferred charge. The ellipsoids indicate the 1σ standard deviation from the mean value.

4. Summary
Peak current was reduced when a higher resistance probe was used. The charging level of the ESD source may have been affected by humidity and the material of the rubbing cloth used. We believe this may have affected the transferred charge and transferred peak charge. Where the peak current was determined at constant humidity with two different resistance values (1 Ω and 9 Ω) their ratio was around 3.7. However the amount of charge transferred in the discharge doesn’t seem to differ that much when comparing the different resistance values of the discharge probe, when environmental and charging conditions are similar. Further investigations are needed to establish the relation between the peak current and the transferred charge for while fixing all known influential parameters.

These experiments demonstrate that the ESD source and measurement systems interact and it is not possible to separate them from the ignition process. In ESD ignition testing we must consider the whole system, not just the ESD and gas mixture. ESD ignition is a product of the gas mixture, ESD source, the test probe and the experimental situation.

References
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